Le Corum Conference Centre - Montpellier, France

February 3-5, 2020

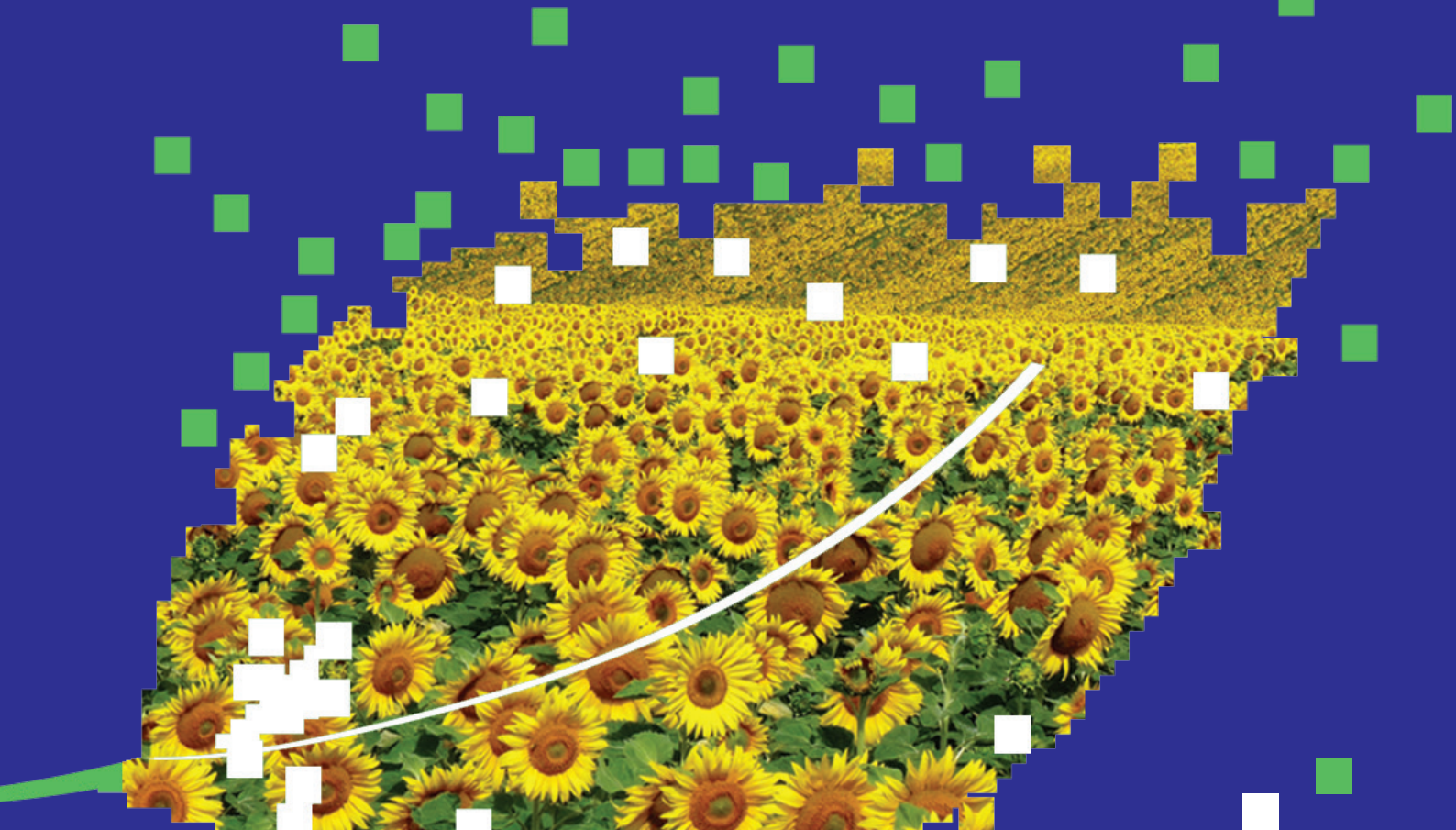
iCROPM 2020

Crop Modelling for the Future

Book of Abstracts

Second International

Crop Modelling Symposium



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WELCOME ADDRESS

Welcome to iCROPM 2020

Crop Modelling for the Future

On behalf of the Scientific and Organizing Committees, it gives us great pleasure to welcome you to **the International Crop Modelling symposium** (iCROPM 2020) dedicated to ***'Crop modelling for Agriculture and Food Security under Global Change'***.

Four years after the first International Crop Modelling symposium in Berlin (iCROPM 2016), crop modelers from around the world are meeting in Montpellier (France) from 3 to 5 February 2020 at the Corum conference center in Montpellier.

The city of Montpellier is home to one of the oldest European and French Universities and hosts research units from such institutes as **CIRAD**, **INRAE** and **INRIA**, which are proud to host the iCROPM 2020 symposium. The recently formed 'Montpellier University of Excellence' (**MUSE I-Site**) brings together 19 institutions to create a thematic research-intensive institution that is internationally engaged and recognised in the fields of agriculture, ecology, environment and health.

Global agriculture faces multiple crucial challenges. Achieving food security in the face of growing global population and increasing resource scarcity remains a central priority. Additional pressures from heating of the climate and other global drivers and the demand that agriculture contributes to net climate mitigation require innovative approaches to growing crops. In strong complementarity with experimentation in agronomy, crop models are increasingly called upon to understand and disentangle the environmental factors driving crop production and to support the design of improved genotypes and new cropping systems. While the development of connected sensors and the 'Internet of Things' offer opportunities it also necessitates novel crop modelling approaches.

Researchers and students participating in the iCROPM 2020 symposium are meeting to exchange on recent scientific advances related to model improvement, development and the use of experimental data for modelling, as well as on advancements in model applications considering new methods of model intercomparison, uncertainty propagation and scaling. While the main focus is on arable and grassland crops and crop-soil interactions, progress in related topics, like intercropping, agroforestry, agroecology, and integrated assessment modelling is also addressed. Digital farming and efforts to integrate crop and plant modelling with high-throughput phenotyping, remote sensing, and genetic improvement are also considered, as well as new modelling approaches and links to big data methods facilitated by innovative software technologies.

This iCROPM 2020 symposium gathers about 400 participants from 48 countries, representing 5 continents. We are sure that iCROPM 2020 will be a comprehensive and inspiring conference that will stimulate innovations to address both local and global challenges faces by agriculture. All types of crops and cropping systems and world regions will be considered, including high and low input systems, with relevance for large agricultural firms as well as for smallholder farmers.

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In addition, **side-events** are organized on 6 and 7 February 2020 (at Agropolis International and at CIRAD), allowing participants to continue to interact for a further two days in workshops. Activities of AgMIP -the Agricultural Model Inter-comparison and Improvement Project- and of other crop modelling research groups, such as the STICS model biannual workshop, will complete this Montpellier crop modelling week.

We wish you all a fascinating, successful, inspiring and enjoyable iCROPM 2020 symposium and we look forward to strengthening both the scientific community and the community of practice in crop modelling!

We warmly thank the Alpha Visa Congrès team for their professional and efficient support for organizing the logistics. We also greatly thank all sponsors that generously support us to make iCROPM 2020 a success!

Enjoy your scientific stay in Montpellier and also take the time to discover a modern but 1,000 year-old beautiful city!

Eric Justes and Christophe Pradal (CIRAD, France)
Pierre Martre and Marie Launay (INRAE, France)
Senthod Asseng (Univ. Florida, USA)
Frank Ewert (ZALF, Germany)
On behalf of the Organising and Scientific Committees

Crop modelling for Agriculture and Food Security under Global Change

iCROPM 2020

Crop Modelling for the Future

COMMITTEES

International Organising Committee

- Eric Justes, *CIRAD, France*
- Senthold Asseng, *University of Florida, USA*
- Frank Ewert, *ZALF, Germany*
- Marie Launay, *INRAE, France*
- Pierre Martre, *INRAE, France*
- Christophe Pradal, *CIRAD & Inria, France*

Scientific Committee

- **Karine Chenu (Chair)**, *UQ, Australia*
- **Roberto Confalonieri (Chair)**, *UNIMI, Italy*
- **Marc Corbeels (Chair)**, *CIMMYT & CIRAD, Kenya*
- **Elisabeth Pattey (Chair)**, *AAFC, Canada*
- **Reimund Rötter (Chair)**, *UG, Germany*
- **Heidi Webber (Chair)**, *ZALF, Germany*
- Ioannis Athanasiadis, *WUR, The Netherlands*
- Kenneth Boote, *UFL, USA*
- Jochem Evers, *WUR, The Netherlands*
- Gerrit Hoogenboom, *UFL, USA*
- Françoise Lescourret, *INRAE, France*
- Guillaume Lobet, *UCL, Belgium*
- Delphine Luquet, *CIRAD, France*
- Dilys MacCarthy, *UG, Ghana*
- Charlie Messina, *Corteva Agriscience, USA*
- Christoph Müller, *PIK, Germany*
- Claas Nendel, *ZALF, Germany*
- Jørgen Olesen, *UA, Denmark*
- Cheryl Porter, *UFL, USA*
- Vittorio Rossi, *UCSC, IT*
- Alex Ruane, *NASA, USA*
- Claudio Stöckle, *WSU, USA*
- Peter Thorburn, *CSIRO, Australia*
- Vincent Vadez, *IRD, France*
- Xiaogang Yin, *CAU, China*
- Xinyou Yin, *WUR, The Netherlands*
- Yan Zhu, *NAU, China*



ORGANISERS

- **CIRAD**
  Centre de coopération internationale en recherche agronomique pour le développement
  https://www.cirad.fr/en/

- **INRAE**
  Institut national de recherche pour l'agriculture, l'alimentation et l'environnement
  https://www.inrae.fr/

- **INRIA**
  Institut national de recherche en sciences et technologies du numérique
  Inria Sophia Antipolis - Méditerranée
  https://www.inria.fr/en/

PARTNERS

Duration	Time	Monday 3 February		
00:10	09:00	**Welcome by the Symposium Chairs** Eric Justes & Frank Ewert		
00:35	09:10	**Welcome by the Organizing Institutions** Michel Eddi - CIRAD Philippe Hinsinger - INRAE Patrick Caron - Montpellier University of Excellence Senthold Asseng - AgMIP		
		Plenary Keynotes Chair: John R. Porter		
00:30	09:45	**Bruno Basso -** Integrating crop models, AI, and sensing for scaling sustainable agricultural systems		
00:30	10:15	**Amy Marshall-Colon** - Integrative modeling and visualization for the development of in silico crops		
00:45	10:45	**Break**		
		Session V Chair: Heidi Webber	**Session I** Chair: Reimund Rötter	**Session VI** Chair: Roberto Confalonieri
00:15	11:30	**Keynote Session V** **Frank Dentener** - Risks and opportunities for the European agricultural sector under 2050 climate change conditions	**Simone Bregaglio** - Methodological advances to incorporate damage mechanisms from diseases in crop models	**Keynote Session VI** **Pierre Martre** - Crop2ML: A Crop Modelling MetaLanguage shared between different crop simulation platforms
00:15	11:45		**Sotirios Archontoulis** - Modeling shallow water table and impacts on soil, root, and plant processes using APSIM	
00:15	12:00	**Andy Challinor** - Crop modelling for sustainable nutrition security: lessons from UK Climate Change Risk Assessment and Africa projects	**Jan Graefe** - A new efficient method for upscaling soil water flow to randomly dispersed or clustered roots	**Kyungdahm Yun** - Design of Declarative Crop Modeling Framework
00:15	12:15	**Alex Ruane** - Historical climate uncertainty in the AgMIP GGCMI ensemble of agricultural models	**Montse Salmeron Cortasa** - Soybean multi-model sensitivity analysis for prediction of seed nitrogen, biological N fixation, and N cycling	**Meagan Lang** - yggdrasil: A Python package for connecting models across programming languages in support of model reuse and modularity
00:15	12:30	**Taru Palosuo** - Combining stakeholder views and simulations to boost sustainable intensification of cereal production in North Savo	**Sibylle Dueri** - Evaluation of a new nitrification/denitrification/N_2O emission model in three different crop models	**Cheryl Porter** - New sources of data for crop model evaluation and improvement: recycling existing agronomic data using AgMIP protocols
00:15	12:45	**Stewart Jennings** - AFRICAP diets, impacts, mitigation modelling for climate smart food security in sub-Saharan Africa	**Tobias Weber** -Soil hydraulic properties matter: A physically comprehensive model for improving crop model simulations	**Hélène Raynal** - AgGlob: Workflow for simulation of agronomic models at a global scale
01:30	13:00	**Lunch**		
		Plenary Model & Software Presentations Chair: Christophe Pradal		
00:10	14:30	**Gerrit Hoogenboom** - Overview of the Decision Support System for Agrotechnology Transfer (DSSAT)		
00:10	14:40	**Greg McLean** - Overview of the Agricultural Production Systems sIMulator (APSIM) platform for modelling and simulation of agricultural systems		
00:10	14:50	**Samuel Buis & Marie Launay** - Overview of STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard), a generic crop growth model		
00:10	15:00	**Claudio Stöckle** - Overview of CropSyst, a user-friendly multi-year and multi-crop growth model		
		Session V Chair: Jørgen Olesen	**Session III** Chair: Karine Chenu	**Session VI** Chair: Cheryl Porter
00:15	15:20	**Marco Carozzi** - Potential GHG mitigation and carbon sequestration from European cropland by modelling crop residues management	**Keynote Session III** **Jana Kholova** - Utilization of crop modelling tools as a guiding principles in crop improvement programs; current status at CG-system	**Hendrik Boogaard** - Application of the crop simulation model WOFOST at parcel scale through distributed cloud computing
00:15	15:35	**Francisco Meza** - Vulnerability Map for Chilean Agriculture: Using crop and niche models to assess future impacts and adaptation options		**Bahareh Kamali** - Future of permanent grasslands in Germany: implications for grassland management
00:15	15:50	**Jose Guarin** - Impacts of tropospheric ozone and climate change on Mexico wheat production	**Sandra Truong** - Adaptive landscapes to explore genetics and environment	**Hussein Kanso** - Reducing a model of sugar metabolism in peach fruit to explore genetic diversity
00:15	16:05	**Alan Robock** - Modeling the response of crops to rapid cooling from stratospheric aerosols	**Pierre Casadebaig** - Optimized cultivar deployment improves the efficiency and stability of sunflower crop production at national scale	**Livia Paleari** - Genotype-specific parameterization of functional-structural models using smart technologies: rice and leaf architecture
00:45	16:20	**Break**		
		Session V Chair: Dilys MacCarthy	**Session III** Chair: Vincent Vadez	**Session VI** Chair: Cheryl Porter
00:15	17:05	**Claas Nendel** - Future soybean productivity in Europe	**Karine Chenu** - Integrating crop modelling, physiology and genetics to aid crop improvement in changing environments	**Michelle Viswanathan** - Bayesian sequential updating for crop yield prediction in soil-crop-atmosphere systems
00:15	17:20	**Jonathan Ojeda** - Multi-resolution analysis of aggregated spatial data to simulate yield and irrigation water demand at regional scales	**Yutaka Tsutsumi-Morita** - Yield prediction based on QTLs for component traits in yield dissection models	**Daniel Wallach** - The AgMIP crop model calibration activity: documenting, evaluating, improving calibration techniques
00:15	17:35	**Rettie Fasil Mequanint** - Climate change impact on crop yield in Ethiopia: A multi-model uncertainty analysis	**Boris Parent** - A phenomics-based model to identify achievable ideotypes of leaf growth in the diversity of European environments	**Samuel Buis** - A new method for sensitivity analysis of models with dynamic and/or spatial outputs
01:00	18:00	**Poster Session - Model & Software Demonstrations**		
	19:00	**End of the Day**		

Tuesday 4 February

Plenary Keynotes
Chair: Marie Launay

00:30 09:00 **Graeme Hammer -** On the nature of crop models (and modellers) needed to advance crop adaptation and improvement
00:30 09:30 **Kerstin Wiegand -** Integrated modelling of ecological and socioeconomic functions of perennial tree crops at the landscape scale

		Session V Chair: Alex Ruane	Session I Chair: Kenneth Boote	Session II Chair: Marc Corbeels
00:15	10:10	**Babacar Faye** - Climate change impact on European crop yields: sensitivity to rotations and residue management	**Delphine Luquet** - Why and how crop models should account for C source-sink relationships better to address future agro-climatic challenges	**Keynote Session II** **Philippe Tixier** - Modelling in agroecology: from simple to complex models, and vice versa
00:15	10:25	**Dilys MacCarthy** - Impact of Climate scenarios on the yields of cereals among farms in Nioro, Senegal and Navrongo, Ghana, West Africa	**Sylvie Sabatier** - Modelling the Guayule plant growth and development with a Functional Structural Plant Model	
00:15	10:40	**João Vasco Silva** - Using farmer's field data and crop modelling to benchmark resource use efficiencies of arable crops in The Netherlands	**Christopher Bahr** - Shedding light on virtual Riesling canopies (*Vitis vinifera* L.)	**Laurène Perthame** - Which nitrogen fertilization techniques and crop traits to promote biological weed regulation by competition?
00:45	10:55	Break		
		Session V Chair: Alex Ruane	**Session I** Chair: Kenneth Boote	**Session II** Chair: Françoise Lescourret
00:15	11:40	**Jawoo Koo** - El Niño–Southern oscillation impacts on agriculture and the national economy in Ethiopia	**Ambra Tosto** - Developing a functional-structural plant model of cocoa to explore the interaction between pruning and shading	**Amos Ngwira** - Improving the productivity and resilience of smallholder farmers with maize-legume and legume-legume systems in Malawi
00:15	11:55	**Hermine Mitter** - Efficient land and water use under stochastic climate scenarios and groundwater restrictions in a semi-arid region	**Yi-Chen Pao** - Coordination between dynamics in canopy structure and photosynthetic acclimation strategy optimizes canopy productivity	**Meixiu Tan** - Modelling crop growth and water use in relay strip intercropping
00:15	12:10	**Davide Cammarano** - Response of grain yield and nitrogen to climate change in Scotland	**Shouyang Liu** - Improving the estimation of canopy light interception in wheat	**Frédéric Boudon** - Modelling of the mango tree – blossom gall midge system: in silico assessment of its functioning
00:15	12:25	**Paresh Shirsath** - Crop-loss Assessment Monitor (CAM): A Web based integrated platform to monitor yield losses for agricultural insurance	**Thuy Huu Nguyen** - Crop modelling of maize growth and gas fluxes considering plant hydraulic conductance	**Rasche Livia** - EPIC-GILSYM: Modelling crop-insect interactions and pest management with a novel coupled crop-insect model
00:15	12:40	**Peter Thorburn** - Can insurance help farmers mitigate nitrogen pollution from intensive cropping?	**Jonas Coussement** - Modelling maize leaf expansion under water limitations	**Zvi Hochman** - Ecological intensification of rainfed cropping systems in Australia's subtropical grain zone
01:30	12:55	**Lunch**		

Plenary Model & Software Presentations
Chair: Eric Justes

00:10 14:25 **Marcello Donatelli** - Overview of the Biophysical Model Applications (BioMA): engineering components and services
00:10 14:35 **Hélène Raynal** - Overview of the RECORD platform for modeling and computer simulation of farmning and agro-ecosystems
00:10 14:45 **Sabine Seidel** - Overview of SIMPLACE: a platform for advanced crop and ecosystem management
00:10 14:55 **Christophe Pradal** - Overview of OpenAlea: a visual programming and component-based software platform for plant modelling

		Session IV Chair: Elisabeth Pattey	Session III Chair: Xinyou Yin	Session II Chair: Vittorio Rossi
00:15	15:20	**Keynote Session IV** **Harry Vereecken** - Managing agricultural fields: from observation to prediction	**Livia Paleari** - Crop model-aided genomic prediction: a multi-model study on rice phenology	**Guillaume Jégo** - Challenges for simulating the long term effects of complex agroecological systems to support innovation in Canada
00:15	15:35		**Nimai Senapati** - Substantial increase in yield is predicted by designing wheat ideotypes for Europe under future climate	**Lalaina Ranaivoson** - Can legume crop residues contribute to sustainable intensification of rainfed rice production in Madagascar?
00:15	15:50	**Yvette Everingham** - A cybernetic precision sugarcane irrigation system informed by the IrrigWeb crop model	**Florian Larue** - Comparison of estimation methods to capture better the genetic variability within crop growth model parameters	**Kurt Christian Kersebaum** - Effects of climate change on crop rotations and their management across the Federal state of Brandenburg, Germany
00:15	16:05	**Christian Fournier** - Fitting a dynamic structural maize model on thousands of plants imaged in a high throughput phenotyping platform	**Chetan Deva** - Cool beans: modelling leaf temperature and breeding for heat avoidance	**Yin Xiaogang** - Uncertainties in simulating N uptake, net N mineralization, soil mineral N and N leaching in European crop rotations
00:45	16:20	**Break**		
		Session IV Chair: Yan Zhu	**Session III** Chair: Charlie Messina	**Session II** Chair: Gerrit Hoogenboom
00:15	17:05	**Luisa Leolini -** UNIFI.GrapeML: new capabilities for the simulation of vineyard systems	**Alex Wu** - Cross-scale modelling connecting photosynthesis with crop models to support yield improvement	**Nicolas Beaudoin** - Long term modelling of crop biomass, N fate and GHG balance of organic cropping systems with a research version of STICS
00:15	17:20	**Jean-Christophe Soulié** - Coupling of cropping system models with the AEGIS platform	**Scott Chapman** - Extending the phenotype - combining proximal sensing with crop models to characterise radiation use efficiency	**Max De Antoni** - Soybean fallows and nitrification inhibitors to reduce N_2O emission intensities in Australian sugarcane cropping systems
00:15	17:35	**Ryan McCormick** - Transcontinental prediction of soybean phenology via hybrid ensemble of knowledge-based and data-driven models	**Tom De Swaef** - Drought tolerance screening of soybean genotypes using UAV imagery and Functional-Structural Plant Modelling	**Nicolas Meyer** - Management of cover crops has to be climate and soil specific. A simulation approach
01:30	18:00	**Poster Session and Drinks**		
03:30	19:30	**Symposium Dinner**		

		Wednesday 5 February		
		Plenary Keynotes Chair: Senthold Asseng		
00:30	09:00	**Mark Cooper** - Connecting quantitative genetics with crop models to enhance prediction of long-term grain yield trends		
00:30	09:30	**Joanna Linnerooth-Bayer** - Crop insurance for the most vulnerable: Can it equitably address climate loss and damage?		
		Session V Chair: Christoph Müller	**Session I** Chair: Delphine Luquet	**Session IV** Chair: Peter Thorburn
00:15	10:10	**Heidi Webber** - Drought not heat stress driving yield losses in extreme years under climate change	**Keynote Session I** **Claudio Stöckle** - On the urgent need for improvement of crop models	**Tobias Weber** - Impact of pedotransfer functions on simulated crop growth in SW Germany with ExpertN-GECROS
00:15	10:25	**Benjamin Sultan** - Evidence of crop production losses in West Africa due to historical global warming in two crop models		**Enli Wang**- Process-based crop modelling enables inverse prediction of plant available water holding capacity across farm with yield
00:15	10:40	**Bahareh Kamali** - Spatio-temporal dynamic of crop drought vulnerability in Sub-Saharan Africa	**Gatien Falconnier** - Modeling of climate change impacts on maize yields in low-nitrogen conditions in Africa	**Karen Lammoglia** - Coupling Sentinel-2 images and STICS crop model to map soil hydraulic properties
00:45	10:55	**Break**		
		Session V Chair: Christoph Müller	**Session I** Chair: Delphine Luquet	**Session IV** Chair: Claas Nendel
00:15	11:40	**Budong Qian** - Quantifying the uncertainty introduced by internal climate variability in the projected Canadian crop yield changes	**Ioannis Droutsas** - New modelling methodology for improving crop model performance under stress conditions	**Joost Wellens** - Processing chain for parcel and regional crop monitoring (PROCCY): Open Data, Sentinel-2, AquaCrop and sugar cane
00:15	11:55	**Tommaso Stella** - Patterns and drivers of the risk of crop failure across Europe	**Kirsten Paff** - A new crop simulation model in DSSAT for Tef	**Christian Baron** - Remote sensing contributions to crop-yield simulation: bias and scarcity VS scale and predictive capacity issues
00:15	12:10	**Dorothée Kapsambelis** - Modelling drought and wetness events in 2050 and their impacts on agricultural yield losses	**Kenneth Boote** - Improving the CROPGRO perennial forage model for ability to simulate fall dormancy classes of Alfalfa cultivars	**Qingling Wu** - Regional yield prediction by assimilating Sentinel-2 reflectance into crop model with cloud platform
00:15	12:25	**Marc Corbeels**- Challenges of modeling climate change impact on smallholder agricultural systems in Africa	**Albasha Rami** - When would simulating temperature at the leaf-layer scale improve crop model performance? Conclusions from a wheat model	**Pepijn van Oort** - Calibration of the Tipstar potato model using remote sensing data
00:15	12:40	**Jonas Jägermeyr** - CMIP6 climate and crop model ensemble estimates of future extreme event impacts on crops	**Gabriela Naves Maschietto** - Phosphorus calibration in Century model in a French agricultural context	**Benoît Piquemal** - Data assimilation and sensor fusion in the CHN crop model for integrated monitoring of nitrogen fertilization in cereals
01:30	12:55	**Lunch**		
		Session V Chair: Dilys MacCarthy	**Session I** Chair: Claudio Stöckle	**Session II** Chair: Jochem Evers
00:15	14:25	**Ehsan Eyshi Rezaei** - Impact of changes in climate and cultivars on winter wheat phenology in Germany	**Xinyou Yin** - Can we learn from experiences in physics to improve crop models?	**Herman Berghuijs** - A minimalist mixture model for cereal-legume intercropping
00:15	14:40	**Ahmad Manschadi** - Integrating crop modelling in the smart farming project Farm/IT in Austria: Achievements and challenges	**Fulu Tao** - Why do crop models diverge substantially in climate impact projections?	**Rémi Vezy** - Implementation of new formalisms in STICS for intercropping modeling
00:15	14:55	**Morteza Mesbah** - Precipitation deficit indicators for rainfed crops; a revisit using model-based evapotranspiration	**Michael Dingkuhn** - Towards Simulation-Modeling of Rice Crop Lodging	**Gaëtan Louarn** - Individual-based modelling as a tool to identify combinations of traits promoting overyielding in grass-legume mixtures
00:15	15:10	**Folorunso Akinseye** - Predicting sorghum performance from big on-farm data in the savannah zone of northern Nigeria	**Madina Diancoumba** - Characterization of spatiotemporal changes in drought occurrence over Mali sorghum growing areas using modeling approach	**Emmanuelle Blanc** - WALTer: modeling the impact of competition for light on the regulation of tillering in wheat cultivar mixtures
01:00	15:25	**Break & Poster Session**		
		Plenary Keynotes Chair: Frank Ewert		
00:30	16:25	**François Tardieu** - Modelling the consequences of the genetic variability on yield: which scales, methods and degrees of abstraction?		
00:30	16:55	**Ken Giller** - Grand challenges for the 21st Century: What crop models can and can't (yet) do		
00:20	17:25	**Final plenary** Chair: Pierre Martre		
	17:45	**End of the Symposium**		

Monday 3 February

08:00 **Congress check-in & Poster installation** — Espace Joffre, level 1

Pasteur auditorium, level 1

09:00 **Welcome by the Symposium Chairs**

- **Eric Justes & Frank Ewert**

09:10 **Welcome by the Organizing Institutions**

- **Senthold Asseng** - AgMIP
- **Patrick Caron** - Montpellier University of Excellence
- **Michel Eddi** - CIRAD
- **Philippe Hinsinger** - INRAE

Plenary Keynotes

Chair: John R. Porter

09:45 • **Bruno Basso** - Integrating crop models, AI, and sensing for scaling sustainable agricultural systems

10:15 • **Amy Marshall-Colon** - Integrative modeling and visualization for the development of *in silico* crops

10:45 **Coffee break** — Espace Joffre, level 1

PARALLEL SESSIONS: V, I, VI

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Heidi Webber

Keynote

11:30 • **Frank Dentener** - Risks and opportunities for the European agricultural sector under 2050 climate change conditions

Presentations

12:00 • **Andy Challinor** - Crop modelling for sustainable nutrition security: lessons from UK Climate Change Risk Assessment and Africa projects

12:15 • **Alex Ruane** - Historical climate uncertainty in the AgMIP GGCMI ensemble of agricultural models

12:30 • **Taru Palosuo** - Combining stakeholder views and simulations to boost sustainable intensification of cereal production in North Savo

12:45 • **Stewart Jennings** - AFRICAP diets, impacts, mitigation modelling for climate smart food security in sub-Saharan Africa

Barthez room, level 2

Session I: Improvement of crop models

Chair: Reimund Rötter

Presentations

11:30 • **Simone Bregaglio** - Methodological advances to incorporate damage mechanisms from diseases in crop models

11:45 • **Sotirios Archontoulis** - Modeling shallow water table and impacts on soil, root, and plant processes using APSIM

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12:00 • **Jan Graefe** - An new efficient method for upscaling soil water flow to randomly dispersed or clustered roots

12:15 • **Montse Salmeron Cortasa** - Soybean multi-model sensitivity analysis for prediction of seed nitrogen, biological N fixation, and N cycling

12:30 • **Sibylle Dueri** - Evaluation of a new nitrification/denitrification/N_2O emission model in three different crop models

12:45 • **Tobias Weber** -Soil hydraulic properties matter: A physically comprehensive model for improving crop model simulations

Rondelet room, level 2

Session VI: Methods and software to support modelling activities

Chair: Roberto Confalonieri

Keynote

11:30 • **Pierre Martre** - Crop2ML: A Crop Modelling MetaLanguage shared between different crop simulation platforms

Presentations

12:00 • **Kyungdahm Yun** - Design of declarative crop modeling framework

12:15 • **Meagan Lang** - yggdrasil: A Python package for connecting models across programming languages in support of model reuse and modularity

12:30 • **Cheryl Porter** - New sources of data for crop model evaluation and improvement: recycling existing agronomic data using AgMIP protocols

12:45 • **Hélène Raynal** - AgGlob: Workflow for simulation of agronomic models at a global scale

13:00 **Lunch** Espace Joffre, level 1

Pasteur auditorium, level 1

Plenary Model & Software Presentations

Chair: Christophe Pradal

14:30 • **Gerrit Hoogenboom** - Overview of the Decision Support System for Agrotechnology Transfer (DSSAT)

14:40 • **Greg McLean** - Overview of the Agricultural Production Systems sIMulator (APSIM) platform for modelling and simulation of agricultural syste

14:50 • **Samuel Buis & Marie Launay** - Overview of STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard), a generic crop growth model

15:00 • **Claudio Stöckle** - Overview of CropSyst, a user-friendly multi-year and multi-crop crop growth model model

PARALLEL SESSIONS: V, III, VI

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Jørgen Olesen

Presentations

15:20 • **Marco Carozzi** - Potential GHG mitigation and carbon sequestration from European cropland by modelling crop residues management

15:35 • **Francisco Meza** - Vulnerability Map for Chilean Agriculture: Using crop and niche models to assess future impacts and adaptation options

15:50 • **Jose Guarin** - Impacts of tropospheric ozone and climate change on Mexico wheat production

16:05 • **Alan Robock** - Modeling the response of crops to rapid cooling from stratospheric aerosols

Barthez room, level 2

Session III: Linking crop/plant models and genetics

Chair: Karine Chenu

Keynote

15:20 • **Jana Kholova** - Utilization of crop modelling tools as a guiding principles in crop improvement programs; current status at CG-system

Presentations

15:50 • **Sandra Truong** - Adaptive landscapes to explore genetics and environment

16:05 • **Pierre Casadebaig** - Optimized cultivar deployment improves the efficiency and stability of sunflower crop production at national scale

Rondelet room, level 2

Session VI: Methods and software to support modelling activities

Chair: Cheryl Porter

Presentations

15:20 • **Hendrik Boogaard** - Application of the crop simulation model WOFOST at parcel scale through distributed cloud computing

15:35 • **Bahareh Kamali** - Future of permanent grasslands in Germany: implications for grassland management

15:50 • **Hussein Kanso** - Reducing a model of sugar metabolism in peach fruit to explore genetic diversity

16:05 • **Livia Paleari** - Genotype-specific parameterization of functional-structural models using smart technologies: rice and leaf architecture

16:20 **Coffee break** Espace Joffre, level 1

PARALLEL SESSIONS: V, III, VI

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Dilys MacCarthy

Presentations

17:05 • **Claas Nendel** - Future soybean productivity in Europe

17:20 • **Jonathan Ojeda** - Multi-resolution analysis of aggregated spatial data to simulate yield and irrigation water demand at regional scales

17:35 • **Rettie Fasil Mequanint** - Climate change impact on crop yield in Ethiopia: A multi-model uncertainty analysis

Barthez room, level 2

Session III: Linking crop/plant models and genetics

Chair: Vincent Vadez

Presentations

17:05 • **Karine Chenu** - Integrating crop modelling, physiology and genetics to aid crop improvement in changing environments

17:20 • **Yutaka Tsutsumi-Morita** - Yield prediction based on QTLs for component traits in yield dissection models

17:35 • **Boris Parent** - A phenomics-based model to identify achievable ideotypes of leaf growth in the diversity of European environments

Rondelet room, level 2

Session VI: Methods and software to support modelling activities

Chair: Cheryl Porter

Presentations

17:05 • **Michelle Viswanathan** - Bayesian sequential updating for crop yield prediction in soil-crop-atmosphere systems

17:20 • **Daniel Wallach** - The AgMIP crop model calibration activity: documenting, evaluating, improving calibration techniques

17:35 • **Samuel Buis** - A new method for sensitivity analysis of models with dynamic and/or spatial outputs

18:00 **Poster Session – Model & Software Demonstrations** Espace Joffre, Level 1

19:00 **End of the Day**

Tuesday 4 February

08:00 **Welcome desk opening** — Espace Joffre, level 1

Pasteur auditorium, level 1

Plenary Keynotes

Chair: Marie Launay

09:00 • **Graeme Hammer** - On the nature of crop models (and modellers) needed to advance crop adaptation and improvement

09:30 • **Kerstin Wiegand** - Integrated modelling of ecological and socioeconomic functions of perennial tree crops at the landscape scale

PARALLEL SESSIONS: V, I, II

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Alex Ruane

Presentations

10:10 • **Babacar Faye** - Climate change impact on European crop yields: sensitivity to rotations and residue management

10:25 • **Dilys MacCarthy** - Impact of Climate scenarios on the yields of cereals among farms in Nioro, Senegal and Navrongo, Ghana, West Africa

10:40 • **João Vasco Silva** - Using farmer's field data and crop modelling to benchmark resource use efficiencies of arable crops in The Netherlands

Barthez room, level 2

Session I: Improvement of crop models

Chair: Kenneth Boote

Presentations

10:10 • **Delphine Luquet** - Why and how crop models should account for C source-sink relationships better to address future agro-climatic challenges

10:25 • **Marc Jaeger**- Modelling the Guayule plant growth and development with a Functional Structural Plant Model

10:40 • **Christopher Bahr** - Shedding light on virtual Riesling canopies *(Vitis vinifera L.)*

Rondelet room, level 2

Session II: Crop modelling for ecological intensification

Chair: Marc Corbeels

Keynote

10:10 • **Philippe Tixier** - Modelling in agroecology: from simple to complex models, and vice versa

Presentation

10:40 • **Laurène Perthame** - Which nitrogen fertilization techniques and crop traits to promote biological weed regulation by competition?

10:55 **Coffee break** — Espace Joffre, level 1

PARALLEL SESSIONS: V, I, II

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Alex Ruane

Presentations

11:40 • **Jawoo Koo** - El Niño–Southern oscillation impacts on agriculture and the national economy in Ethiopia

11:55 • **Hermine Mitter** - Efficient land and water use under stochastic climate scenarios and groundwater restrictions in a semi-arid region

12:10 • **Davide Cammarano** - Response of grain yield and nitrogen to climate change in Scotland

12:25 • **Paresh Shirsath** - Crop-loss Assessment Monitor (CAM): A Web based integrated platform to monitor yield losses for agricultural insurance

12:40 • **Peter Thorburn** - Can insurance help farmers mitigate nitrogen pollution from intensive cropping?

Barthez room, level 2

Session I: Improvement of crop models

Chair: Kenneth Boote

Presentations

11:40 • **Ambra Tosto** - Developing a functional-structural plant model of cocoa to explore the interaction between pruning and shading

11:55 • **Yi-Chen Pao** - Coordination between dynamics in canopy structure and photosynthetic acclimation strategy optimizes canopy productivity

12:10 • **Shouyang Liu** - Improving the estimation of canopy light interception in wheat

12:25 • **Thuy Huu Nguyen** - Crop modelling of maize growth and gas fluxes considering plant hydraulic conductance

12:40 • **Jonas Coussement** - Modelling maize leaf expansion under water limitations

Rondelet room, level 2

Session II: Crop modelling for ecological intensification

Chair: Françoise Lescourret

Presentations

11:40 • **Amos Ngwira** - Improving the productivity and resilience of smallholder farmers with maize-legume and legume-legume systems in Malawi

11:55 • **Meixiu Tan** - Modelling crop growth and water use in relay strip intercropping

12:10 • **Frédéric Boudon** - Modelling of the mango tree – blossom gall midge system: in silico assessment of its functioning

12:25 • **Livia Rasche** - EPIC-GILSYM: Modelling crop-insect interactions and pest management with a novel coupled crop-insect model

12:40 • **Zvi Hochman** - Ecological intensification of rainfed cropping systems in Australia's subtropical grain zone

12:55 **Lunch** Espace Joffre, Level 1

Pasteur auditorium, level 1

Plenary Model & Software Presentations

Chair: Eric Justes

14:25 • **Marcello Donatelli** - Overview of the Biophysical Model Applications (BioMA): engineering components and services

14:35 • **Hélène Raynal** - Overview of the RECORD platform for modeling and computer simulation of farmning and agro-ecosystems

14:45 • **Sabine Seidel** - Overview of SIMPLACE: a platform for advanced crop and ecosystem management

14:55 • **Christophe Pradal** - Overview of OpenAlea: a visual programming and component-based software platform for plant modelling

PARALLEL SESSIONS: IV, III, II

Pasteur auditorium, level 1

Session IV: Linking crop models to data stream systems in the digital age

Chair: Elisabeth Pattey

Keynote

15:20 • Harry Vereecken - Managing agricultural fields: from observation to prediction

Presentations

15:50 • Yvette Everingham - A cybernetic precision sugarcane irrigation system informed by the IrrigWeb crop model

16:05 • Christian Fournier - Fitting a dynamic structural maize model on thousands of plants imaged in a high throughput phenotyping platform

Barthez room, level 2

Session III: Linking crop/plant models and genetics

Chair: Xinyou Yin

Presentations

15:20 • Livia Paleari - Crop model-aided genomic prediction: a multi-model study on rice phenology

15:35 • Nimai Senapati - Substantial increase in yield is predicted by designing wheat ideotypes for Europe under future climate

15:50 • Florian Larue - Comparison of estimation methods to capture better the genetic variability within crop growth model parameters

16:05 • Chetan Deva - Cool beans: modelling leaf temperature and breeding for heat avoidance

Rondelet room, level 2

Session II: Crop modelling for ecological intensification

Chair: Vittorio Rossi

Presentations

15:20 • Guillaume Jégo - Challenges for simulating the long term effects of complex agroecological systems to support innovation in Canada

15:35 • Lalaina Ranaivoson - Can legume crop residues contribute to sustainable intensification of rainfed rice production in Madagascar?

15:50 • Kurt-Christian Kersebaum - Effects of climate change on crop rotations and their management across the Federal state of Brandenburg, Germany

16:05 • Yin Xiaogang - Uncertainties in simulating N uptake, net N mineralization, soil mineral N and N leaching in European crop rotations

16:20 **Coffee break** Espace Joffre, Level 1

PARALLEL SESSIONS: IV, III, II

Pasteur auditorium, level 1

Session IV: Linking crop models to data stream systems in the digital age

Chair: Elisabeth Pattey

Presentations

17:05 • **Luisa Leolini** - UNIFI.GrapeML: new capabilities for the simulation of vineyard systems

17:20 • **Jean-Christophe Soulié** - Coupling of cropping system models with the AEGIS platform

17:35 • **Ryan McCormick** - Transcontinental prediction of soybean phenology via hybrid ensemble of knowledge-based and data-driven models

Barthez room, level 2

Session III: Linking crop/plant models and genetics

Chair: Charlie Messina

Presentations

17:05 • **Alex Wu** - Cross-scale modelling connecting photosynthesis with crop models to support yield improvement

17:20 • **Scott Chapman** - Extending the phenotype - combining proximal sensing with crop models to characterise radiation use efficiency

17:35 • **Tom De Swaef** - Drought tolerance screening of soybean genotypes using UAV imagery and Functional-Structural Plant Modelling

Rondelet room, level 2

Session II: Crop modelling for ecological intensification

Chair: Gerrit Hoogenboom

Presentations

17:05 • **Nicolas Beaudoin** - Long term modelling of crop biomass, N fate and GHG balance of organic cropping systems with a research version of STICS

17:20 • **Max De Antoni** - Soybean fallows and nitrification inhibitors to reduce N_2O emission intensities in Australian sugarcane cropping systems

17:35 • **Nicolas Meyer** - Management of cover crops has to be climate and soil specific. A simulation approach

18:00 **Poster Session and Drinks** Espace Joffre, Level 1

19:30 **Symposium Dinner** Salon central, level 3

Wednesday 5 February

08:30 **Welcome desk opening** — Espace Joffre, level 1

Pasteur auditorium, level 1

Plenary Keynotes

Chair: Senthold Asseng

09:00 • **Mark Cooper** - Connecting quantitative genetics with crop models to enhance prediction of long-term grain yield trends

09:30 • **Joanne Linnerooth-Bayer** - Crop insurance for the most vulnerable: Can it equitably address climate loss and damage?

PARALLEL SESSIONS: V, I, IV

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Christoph Müller

Presentations

10:10 • **Heidi Webber** - Drought not heat stress driving yield losses in extreme years under climate change

10:25 • **Benjamin Sultan** - Evidence of crop production losses in West Africa due to historical global warming in two crop models

10:40 • **Bahareh Kamali** - Spatio-temporal dynamic of crop drought vulnerability in Sub-Saharan Africa

Barthez room, level 2

Session I: Improvement of crop models

Chair: Delphine Luquet

Keynote

10:10 • **Claudio Stöckle** - On the urgent need for improvement of crop models

Presentation

10:40 • **Gatien Falconnier** - Modeling of climate change impacts on maize yields in low-nitrogen conditions in Africa

Rondelet room, level 2

Session IV: Linking crop models to data stream systems in the digital age

Chair: Peter Thorburn

Presentations

10:10 • **Tobias Weber** - Impact of pedotransfer functions on simulated crop growth in SW Germany with ExpertN-GECROS

10:25 • **Peter Thorburn** - Process-based crop modelling enables inverse prediction of plant available water holding capacity across farm with yield

10:40 • **Karen Lammoglia** - Coupling Sentinel-2 images and STICS crop model to map soil hydraulic properties

10:55 **Coffee break** — Espace Joffre, level 1

PARALLEL SESSIONS: V, I, IV

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Christoph Müller

Presentations

11:40 • **Budong Qian** - Quantifying the uncertainty introduced by internal climate variability in the projected Canadian crop yield changes

11:55 • **Tommaso Stella** - Patterns and drivers of the risk of crop failure across Europe

12:10 • **Dorothée Kapsambelis** - Modelling drought and wetness events in 2050 and their impacts on agricultural yield losses

12:25 • **Marc Corbeels** - Challenges of modeling climate change impact on smallholder agricultural systems in Africa

12:40 • **Jonas Jägermeyr** - CMIP6 climate and crop model ensemble estimates of future extreme event impacts on crops

Barthez room, level 2

Session I: Improvement of crop models

Chair: Delphine Luquet

Presentations

11:40 • **Ioannis Droutsos** - New modelling methodology for improving crop model performance under stress conditions

11:55 • **Kirsten Paff** - A new crop simulation model in DSSAT for Tef

12:10 • **Kenneth Boote** - Improving the CROPGRO perennial forage model for ability to simulate fall dormancy classes of Alfalfa cultivars

12:25 • **Albasha Rami** - When would simulating temperature at the leaf-layer scale improve crop model performance? Conclusions from a wheat model

12:40 • **Gabriela Naves Maschietto** - Phosphorus calibration in Century model in a French agricultural context

Rondelet room, level 2

Session IV: Linking crop models to data stream systems in the digital age

Chair: Claas Nendel

Presentations

11:40 • **Joost Wellens** - Processing chain for parcel and regional crop monitoring (PROCCY): Open Data, Sentinel-2, AquaCrop and sugar cane

11:55 • **Christian Baron** - Remote sensing contributions to crop-yield simulation: bias and scarcity VS scale and predictive capacity issues

12:10 • **Jérémie Haumont** - Data assimilation of crop models and drone images based on an iterative sensitivity analysis for precision fertilization

12:25 • **Pepijn van Oort** - Calibration of the Tipstar potato model using remote sensing data

12:40 • **Benoît Piquemal** - Data assimilation and sensor fusion in the CHN crop model for integrated monitoring of nitrogen fertilization in cereals

12:55 **Lunch** Espace Joffre, level 1

PARALLEL SESSIONS: V, I, II

Pasteur auditorium, level 1

Session V: Crop modelling for risk and impact assessment

Chair: Dilys MacCarthy

Presentations

14:25 • **Ehsan Eyshi Rezaei** - Impact of changes in climate and cultivars on winter wheat phenology in Germany

14:40 • **Ahmad Manschadi** - Integrating crop modelling in the smart farming project Farm/IT in Austria: Achievements and challenges

14:55 • **Morteza Mesbah** - Precipitation deficit indicators for rainfed crops; a revisit using model-based evapotranspiration

15:10 • **Folorunso Akinseye** - Predicting sorghum performance from big on-farm data in the savannah zone of northern Nigeria

Barthez room, level 2

Session I: Improvement of crop models

Chair: Claudio Stöckle

Presentations

14:25 • **Xinyou Yin** - Can we learn from experiences in physics to improve crop models?

14:40 • **Fulu Tao** - Why do crop models diverge substantially in climate impact projections?

14:55 • **Michael Dingkuhn** - Towards simulation-modeling of rice crop lodging

15:10 • **Madina Diancoumba** - Characterization of spatiotemporal changes in drought occurrence over Mali sorghum growing areas using modeling approach

Rondelet room, level 2

Session II: Crop modelling for ecological intensification

Chair: Jochem Evers

Presentations

14:25 • **Herman Berghuijs** - A minimalist mixture model for cereal-legume intercropping

14:40 • **Rémi Vezy** - Implementation of new formalisms in STICS for intercropping modeling

14:55 • **Gaëtan Louarn** - Individual-based modelling as a tool to identify combinations of traits promoting overyielding in grass-legume mixtures

15:10 • **Emmanuelle Blanc** - WALTer: modeling the impact of competition for light on the regulation of tillering in wheat cultivar mixtures

15:25 **Coffee break and Poster Session** Espace Joffre, Level 1

Pasteur auditorium, level 1

Plenary Keynotes

Chair: Frank Ewert

16:25 • **François Tardieu** - Modelling the consequences of the genetic variability on yield: which scales, methods and degrees of abstraction?

16:55 • **Ken Giller** - Grand challenges for the 21st Century: What crop models can and can't (yet) do

17:25 **Final plenary**

Chair: Pierre Martre

17:45 **End of the Symposium**

ABSTRACTS

PLENARY KEYNOTES

Integrating crop models, AI, and sensing for scaling sustainable agricultural systems

Basso Bruno (basso@msu.edu)

Earth and Environmental Sciences, Michigan State University, East Lansing, MI, United States

Introduction

Understanding and managing field variability can be a critical step to increase farmers' profitability and environmental sustainability. Recent studies (Basso et al., 2019, Maestrini and Basso, 2018) have shown that low productivity areas within the field are present rather consistently (defined as Low Yield and Stable areas), while other areas can vary from one year to the next (Unstable areas, some years are high yielding and some years are low yielding) and other parts of the fields that are constantly producing high/medium yield (High or Medium Yield and Stable area). This concept is extremely important to capture the synergies and feedbacks occurring in the systems and found to be useful to provide spatial inputs to crop models to evaluate agricultural systems sustainability across a range of different management scenarios. The objective of this presentation is to present a novel geospatial system approach composed by crop models, AI and sensing technologies to design, manage and scale sustainable agricultural systems.

Materials and Methods

The Basso Digital Agronomy and Spatial Analytics Lab, as results of different research projects, has collected yield monitor data at 2m resolution from over 1000 fields for the last 10 years. The fields are located across the US Midwest. The field sizes range from 5 acres ha to 500 acres with an average field size of 70 acres.
In addition to the yield maps of these fields, we have acquired optical and thermal remotely sensed imagery from different platforms (UAV, airborne, and satellites) for a total of nearly 20.000 images. The Big-Data was used to test a new procedure to scale yield stability map across nearly 40 million hectares (ha) of maize and soybean fields in US Midwest. The stability maps were developed satellite imagery and boundaries of fields following the procedure described in Basso et al., 2019. Furthermore, we quantified the causes of yield instability by accounting for topography, soil and management. The stability maps were also used to evaluate alternative land use on the within-field low productivity areas. Spatial inputs were used to simulate different management scenarios under current and future weather conditions using the SALUS model. The model was validated spatially using the large data set available as well as with county level yields and phenology data.

Results and Discussion

Figure 1 shows the field level yield stability maps across 40 M ha across the US Midwest. The stability maps from satellite were compared against the stability maps developed from the yield monitored data. The procedure showed that the stability maps from satellite reproduced satisfactorily well the spatial patterns of the different performance zones observed in the fields with an overall accuracy ranging from 50-80% despite several uncertainties' as described in Basso et al (2019). The results showed that ~50% of subfield areas can be characterized as stable high productivity areas, ~25% stable low productivity, and to remaining 25% unstable. Results shows that matching nitrogen use to crop yield stability class through the use of crop models and AI to design N rates could reduce regional reactive nitrogen losses by up to 1.38 Tg without affecting crop yields. Yield losses in unstable zones driven by water excess and deficits are shown to lag as much as 23-33% below the field average during drought years and 26-33% during deluge years.

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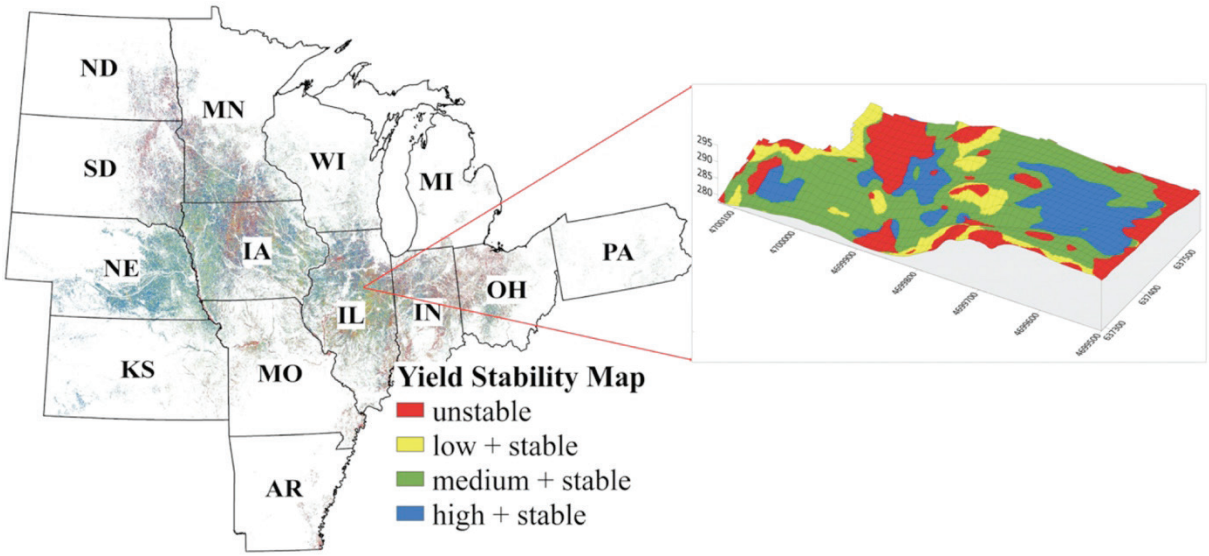

Figure 1. Field level 3D yield stability map for 40 million acres of maize and soybean across the US midwest.

Keywords: Sustainability, Scaling, Digital Agronomy, Data Analytics, Yield Stability.

References:

1. Basso, B., G. Shuai, J. Zhang, and G. P. Robertson. 2019. Yield stability analysis reveals sources of large-scale nitrogen loss from the US Midwest. Scientific Reports. 9:5774.
2. Maestrini, B., & Basso, B. (2018). Drivers of within-field spatial and temporal variability of crop yield across the US Midwest. Scientific Reports, 8(1), 2045-2322.

Integrative modeling and visualization for the development of *in silico* crops

Marshall-Colon Amy[1] (amymc@illinois.edu), Kannan Kavya[1], Wang Yu[2], Lang Meagan[3], Challa Ghana[1], Long Stephen[1]

[1] *Plant Biology, University of Illinois Urbana-Champaign, Urbana, IL, United States*; [2] *IGB, University of Illinois Urbana-Champaign, Urbana, IL, United States*; [3] *NCSA, University of Illinois Urbana-Champaign, Urbana, IL, United States*

Introduction

Current crop models predict an increasing gap between food supply and demand over the next 50 years. Technology is needed to predict the fitness of existing germplasm in response to global change, and also to design of crop ideotypes (Marshall-Colon et al., 2017). I will highlight our efforts to generate virtual plant models that capture whole system dynamics in response to *in silico* environmental and genetic perturbations, using the Crops *in silico* (Cis) computational framework.

Materials and Methods

We used the yggdrasil multi-scale modeling platform (Lang, 2019) to integrate models of gene expression, photosynthetic metabolism, and leaf physiology to evaluate the effect of photosynthesis and transpiration under various environmental conditions. Gene regulatory network analysis was used to predict changes in gene expression in response to an in silico perturbation. Updated gene expression levels were fed into the integrated model as inputs to estimate leaf-level changes in carbon assimilation in response to elevated [CO_2]. We are also combining modeling and advanced visualization approaches to make direct observations about changes in plant structure, light capture, biomass, and yield in response to environmental perturbations (Kannan et al., 2019).

Results and Discussion

Outcomes of these efforts include accurate prediction of soybean photosynthesis, in which the integrated model was capable of simulating photosynthetic acclimation under elevated [CO_2]. In silico perturbations were performed to identify transcription factors that potentially regulate photosynthesis. Specifically, the overexpression of GmGATA2 was predicted to increases photosynthetic rate under elevated CO_2.

Conclusions

The improved accuracy of model predictions and the realistic rendering of model simulated plants is a step toward the *in silico* "testing" of ideotype designs under different environmental conditions. This enables researchers to perform dozens of in silico perturbations to evaluate ideotype performance under varying scenarios. *In silico* exploration has the potential to help researchers target components of the underlying crop genetics for engineering, to ultimately enhance crop yield and nutritional quality.

Acknowledgements

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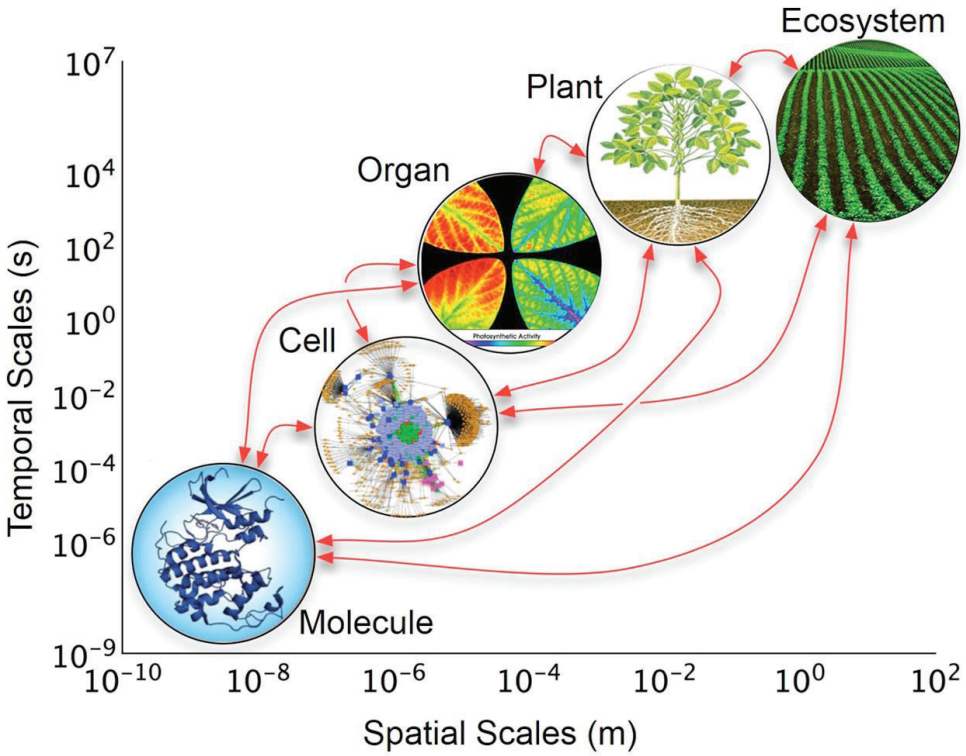

FIGURE 1. Layers of organization of biological models across temporal and spatial scales. The y-axis represents real-time in which changes occur at each biological level; the x-axis represents the relative size or space, which the biological level encompasses. The arrows indicate possible direct interactions among scales (Marshall-Colon et al., 2019).

Keywords: predictive modeling, photosynthesis, transcriptional regulation, soybean, advanced visualization.

References:

1. Kannan K, Wang Y, Lang M, Challa GS, Long SP, Amy Marshall-Colon A (2019) Combining gene network, metabolic and leaf-level models shows means to future-proof soybean photosynthesis under rising CO_2. in silico Plants, 1, https://doi.org/10.1093/insilicoplants/diz008.
2. Lang M (2019) yggdrasil: a Python package for integrating computational models across languages and scales. in silico Plants, 1, https://doi.org/10.1093/insilicoplants/diz001.
3. Marshall-Colon A, Long SP, Allen DK, Allen G, Beard DA, Benes B, von Caemmerer S, Christensen AJ, Cox DJ, Hart JC, Hirst PM, Kannan K, Katz DS, Lynch JP, Millar AJ, Panneerselvam B, Price ND, Prusinkiewicz P, Raila D, Shekar RG, Shrivastava S, Shukla D, Srinivasan V, Stitt M, Turk MJ, Voit EO, Wang Y, Yin X, Zhu X-G (2017) Crops in silico: generating virtual crops using an integrative and multi-scale modeling platform.

On the nature of crop models (and modellers) needed to advance crop adaptation and improvement

Hammer Graeme (g.hammer@uq.edu.au)

University of Queensland, Brisbane, QLD, France

Introduction

Modelling and simulation provide an avenue to advance crop adaptation and improvement. Serious play with dynamic crop growth and development models (CGM) enables one to explore consequences of potential agronomic and breeding interventions in design of crops for production systems. Using simplified mathematical representations of the interacting biological and environmental components of the dynamic soil–plant–environment system, CGM can reliably predict trajectories of crop attributes through the crop life cycle, i.e. the emergent phenotype. Environmental (E), genetic (G), and management (M) influences, and hence their dynamic interactions (GxExM), can be incorporated via the nature and coefficients of the response and control equations in the model and aspects of its initialization. Here, I will consider examples of applications relevant to agronomy and breeding (Hammer et al. 2016).

The potential to use CGM to advance such applications to crop adaptation and improvement requires a "credible" model that is fit for purpose along with informed users that are aware of the biological underpinning and functional dynamics of the CGM (Hammer et al. 2019). Here I will discuss these concepts in relation to the need to progress rigour and transparency in the effective future use of CGM technology.

An application in crop design (GxExM)

Productivity-risk trade-offs associated with cultivar choice and management decision options are critical in crop systems confronted with seasonal climate variability.

What is credible modelling?

For a model to be received credibly in relation to such crop design applications it must reliably generate the emergent phenotype relevant to the question at hand, be it for agronomy or breeding. This most often requires an ability to extrapolate predictions to new environments, traits, and situations. There are perhaps three aspects to testing model credibility –

Ability to predict phenotypic outcomes for experiments with high quality data;

Ability to generate known responses to key factors (e.g. N, maturity etc.);

Ability to predict emergent phenotypes and interactions associated with key traits.

These aspects all require close attention to the biological realism of the functions incorporated in the CGM and their grounding in solid experimental and theoretical evidence. However, high speed, parsimonious models are also required for dealing with the thousands of G and E combinations in modern breeding programs utilising genomic prediction technologies. It has been argued that biological reality and parsimony do not need to be independent and perhaps should not be (Hammer et al., 2019). Models structured to readily allow variation in the biological level of process algorithms, while using coding and computational advances to facilitate high-speed simulation, could well provide the structure needed for the next generation of crop models needed to support and enhance advances in crop improvement technologies.

Beyond model credibility is the requirement for modeller credibility, which demands that model users be aware of the biological underpinning and functional dynamics of the CGM and thus, what it can and cannot sensibly do. The need to engage transparently with ultimate decision-makers is critical. The key future role for the use of CGM in crop adaptation/improvement can only be jeopardized by naïve model use.

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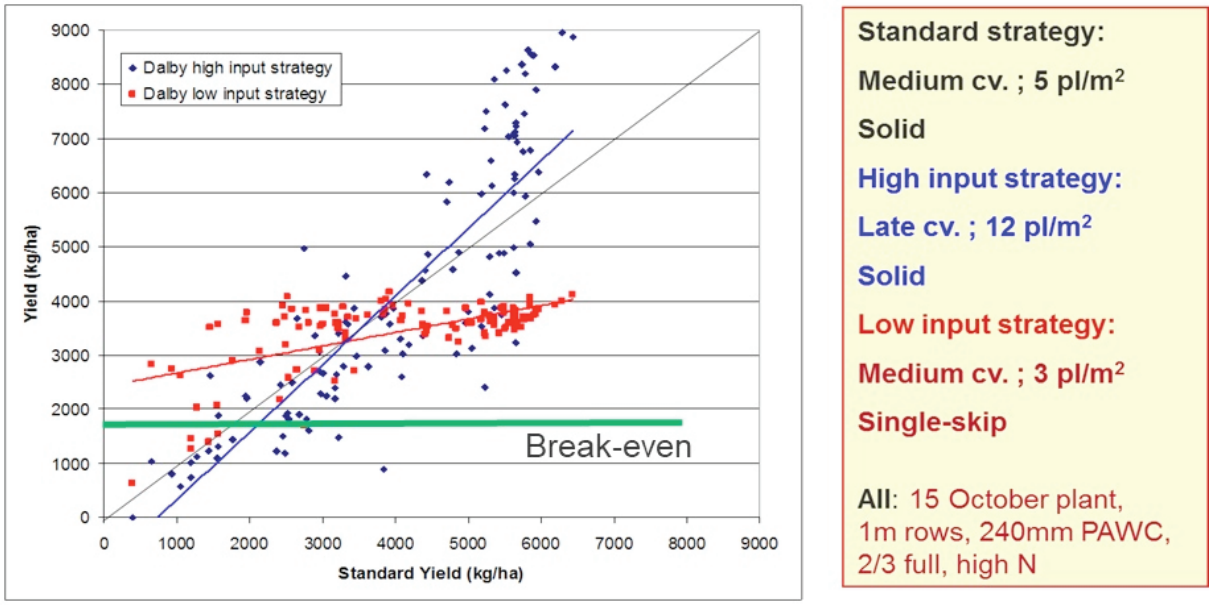

Figure 1. shows a 100-season simulation of the trade-off that occurs when potential water use intensity is varied by modifying cultivar maturity, plant density, and row configuration in ways that moderate canopy development above (high input) and below (low input) the standard GxM strategy. While the low input strategy is safer as the risk of low yield is much diminished, the high yields possible in favourable seasons with the high input strategy are foregone. The decision-maker's attitude to risk will ultimately determine the preferred decision.

Keywords: agronomy, breeding, emergent phenotype, biological reality, parsimony.

References:

1. Hammer G, Messina C, Wu A, Cooper M (2019) Biological reality and parsimony in crop models – why we need both in crop improvement! In Silico Plants 2019: diz010.
2. Hammer G, McLean G, Doherty A, van Oosterom E, Chapman S (2016) Sorghum crop modelling and its utility in agronomy and breeding. In: Prasad V, Ciampitti I, eds. Sorghum: State of the Art and Future Perspectives. ASA and CSSA, Madison, WI, USA. Agronomy Monographs 58.

Integrated modelling of ecological and socioeconomic functions of perennial tree crops at the landscape scale

Wiegand Kerstin[1] (KWiegan1@gwdg.de), Dislich Claudia[1], Lay Jann[2], Meyer Katrin[1], Salecker Jan[1], Tarigan Suria[3]

[1] *Ecosystem Modelling, University of Goettingen, Goettingen, Germany*; [2] *GIGA, Hamburg, Germany*; [3] *IPB, Bogor, Indonesia*

Introduction

Over the last decades, the lowlands of Jambi province in Sumatra (Indonesia) have undergone a major transformation from forests towards a predominantly agricultural, smallholder-dominated landscape mosaic. Arguably, current transformation is mainly focusing on economic benefits. Yet, the heterogeneous mosaic of different land uses provides opportunities to reconcile economically beneficial human activities, high levels of biodiversity, and ecosystem functions. EFForTS is a collaborative project of more than 160 researchers that investigate the ecological and socio-economic effects of such transformation focusing on smallholder systems. The goal of the EFForTS project is to understand and possibly find ways how to support biodiversity and ecosystem functioning while serving human needs. Here, I will give some general background on the EFForTS project and then focus on our modelling activities.

Materials and Methods

We have developed and are in the process of further refining EFForTS-ABM, an integrated ecological-economic land-use change model (Dislich et al., 2018, Figure 1). EFForTS-ABM is spatially-explicit and follows a combined agent-based and grid-based approach. Household agents own agricultural fields within a forested landscape and take farming and thus land-use decisions that affect diverse ecological and socio-economic functions. The model is spatially-explicit because relationships between the spatial composition and configuration of the landscape are expected to affect biodiversity, ecosystem functioning, and economic benefit. Our guiding question is what kind of landscape mosaic optimizes the ensemble of biodiversity, ecosystem functioning, and economic benefit. Model structure and parameterization are based on field data from multiple EFForTS projects. This includes experiments on the effects of plantation enrichment (based on an intercropping field experiment, EFForTS-BEE), oil palm management (field experiment EFForTS-OPMX), and landscape heterogeneity in the form of riparian areas on ecological and economic functions.

Results and Discussion

Model analyses focus on identifying and highlighting the major trade-offs and synergies between ecological and economic functions including an assessment of long-term drivers and consequences of land-use change. I will demonstrate model capabilities with results on household consumption and carbon sequestration from different output price and farming efficiency scenarios. The overall results reveal complex interactions between the economic and ecological spheres. For instance, model scenarios with heterogeneous crop-specific household productivity reveal a comparatively high inertia of land-use change.

Conclusions

While taking EFForTS-ABM as an example, I will give insights in general principles applied during model development and analysis and discuss potentials and limitations of integrated landscape-scale simulation models of perennial crops.

Acknowledgements

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Figure 1. Model overview of the agent-based land-use model (EFForTS-ABM). In the model, households take land management decisions which affect both their personal economic situation and the environment.

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Connecting quantitative genetics with crop models to enhance prediction of long-term grain yield trends

Cooper Mark[1] (mark.cooper@uq.edu.au), Messina Carlos[2], Hammer Graeme[1]

[1] *QAAFI, The University of Queensland, Brisbane, Qld, Australia*; [2] *Research and Development, Corteva Agriscience, Johnston, IA, United States*

We explore opportunities to improve yield prediction for both breeders and agronomists through connecting quantitative genetics with Crop Growth Models (CGMs). CGMs provide a mechanistic, biophysical framework to account for Genotype-by-Management-by-Environment (GxMxE) interactions for traits. Breeders have relied on quantitative genetics as a prediction framework. Quantitative genetics applies link functions to map Genotype-to-Phenotype (G2P models). However, these G2P models often have limited connection to the biophysical processes that determine GxMxE interactions for traits. We draw on examples from maize and sorghum to demonstrate connection of genes to CGMs using quantitative genetics methods to enhance prediction of long-term grain yield trends. Breeders and Agronomists bring different perspectives when investigating yield outcomes from alternative GxMxE combinations. Their interests intersect on the potential for GxMxE interactions to change relative yield outcomes. Their different perspectives shape how they sample each of the three dimensions to answer their respective questions. For both breeders and agronomists the vast number of the potential GxMxE factorial limits the reach of empirical approaches to tackle many of the relevant issues associated with GxMxE interactions and motivates the consideration of modeling solutions. Recent developments integrating CGMs into genomic prediction methodology have opened up new opportunities for application of CGMs in breeding and agronomy to improve yield prediction for GxMxE combinations. The connection of genetics to CGMs requires further consideration of the quantitative genetics prediction framework used by plant breeders. Quantitative genetics provides a theoretical framework for investigating the genetic architecture of traits, studying trait genetic variation within reference populations, predicting the expected response to selection, the design and optimization of breeding programs. An important consideration to enable inclusion of genetic contributions to modeling GxMxE interactions is how to sample effectively the ***Genotype-Dimension*** of the GxMxE factorial. We need to extend the sampling of the ***Genotype-Dimension*** to parameterize CGMs from a few genotypes to better align with how breeding programs navigate the ***Genotype-dimension***.

The ***Genotype-dimension*** is enormous and has multiple levels. We consider two levels to highlight important implications for sampling the ***Genotype-Dimension*** for connections with a CGM. The ***individual-level***. The individual can be a plant, line, variety or hybrid. Properties of the individual are measured to estimate genotype and phenotype values for traits. Historically, the ***Genotype-Dimension*** has been sampled at the ***individual-level*** for parameterization of CGMs. The ***gene-level***. The gene is a section of the DNA of chromosomes in the nucleus or within an organelle with a functional effect upon a trait (e.g., Gene ***A*** with alternative alleles ***0*** and ***1***). At the ***gene-level*** different combinations of the alleles determine the potential genotypes for an individual gene (e.g. for a diploid organism combinations of the alleles ***0*** and ***1*** for Gene ***A*** can generate genotypes ***00***, ***01*** and ***11***). These two levels of the ***Genotype-Dimension*** (gene and individual) are connected. The cumulative effects of all individual genes influencing the expression of the traits collectively determine the total genotype and breeding value of the individual and in combination with environment determine the trait phenotypes of the individual. The number of possible different genotypes represents the size of the ***Genotype-Dimension***. This is determined by the number of genes determining a trait and the fraction of these genes with alternative alleles that are segregating in the reference population of the breeding program; e.g. for a trait controlled by 100 segregating genes, with two alleles for each gene, the number of possible different genotype combinations is $3^{100} = 5.15 \times 10^{47}$. Plant breeders sort through these potential combinations using breeding programs that operate over multiple cycles. The breeding programs have two major components. First, a recurrent cycle involving mating of selected individuals to create new combinations of the alleles for multiple genes (recombinants) within new individuals for the next round of evaluation. Second, an evaluation process to compare new individuals (recombinants) with the current cohort of genotypes to determine whether any of the new individuals have superior trait performance. To investigate the potential contributions of genetics to long-term improvement of crop productivity it is necessary to consider both genotype levels when sampling the ***Genotype-Dimension*** to predict GxMxE interactions. To date most parameterizations of CGMs have focused on one or a few genotypes at the ***individual-level***. It is now possible to extend the parameterization of CGMs to the ***gene-level*** and more effectively sample the genotype dimension.

Keywords: Breeding, Agronomy, Genomics.

Crop insurance for the most vulnerable: Can it equitably address climate loss and damage?

Linnerooth-Bayer Joanne (bayer@iiasa.ac.at)

Risk and Resilience Program, IIASA, Laxenburg, Austria

Introduction

Agricultural impacts from climate extremes, including floods, droughts and tropical storms, affect more than 40 percent of farmers in developing countries (FAO 2018). Lacking public safety nets, resource-poor farmers typically adopt coping strategies, such as selling productive assets, that can trap them in poverty. Because insurance can guarantee post-disaster liquidity, as well as enable farmers to adopt riskier but more productive agriculture strategies, it figures prominently in climate negotiations on the Warsaw International Mechanism for Loss and Damage (WIM).

This presentation illustrates the role of crop models that account for the impacts of climate change, along with innovative satellite monitoring, for enabling insurance policy targeted at the most vulnerable. Specifically, the focus is on index-based insurance for smallholder farmers and regional insurance pools for vulnerable governments. In addition, the presentation asks whether insurance can meet the differentiated intentions of WIM – reducing losses (emphasized by the 'North') and compensating for climate-attributed losses (emphasized by the 'South').

Index-based micro-insurance and regional insurance pools

Index-based crop insurance products, which are written against a physical index that is correlated with yields, and not against losses, are less costly to administer and avoid moral hazard. They rely on models ranging from simple statistical relationships to complex process-based simulations to define the weather index that triggers payment. For example, on the basis of farmer interviews, agro-meteorological studies and models such as the FAO water satisfaction index, a rainfall index for maize production in Malawi was defined across the 130-day growing period, with higher weights given to critical periods (emergence and tasseling). Insurers set premiums based on catastrophe models that generate probabilistic loss distributions by combining probabilistic hazard estimates, exposure and crop vulnerability.

The uptake of index-based crop insurance, however, has not met expectations partly due to basis risk and uncertainty in loss estimates exasperated by climate change. Models and satellite data can be useful in counteracting basis risk, which is the potential mismatch between insurance payouts and farmer losses, by identifying optimal density for weather stations and measuring soil moisture (an alternative index to precipitation), vegetation and other parameters. Process-based models generally correlate better with yield losses than simple rainfall indices; yet, they are limited by available data. A second challenge is climate change, which will render historical-based probabilistic hazard estimates less valid.

Public authorities, too, face post-disaster liquidity problems, and many governments of small nations have formed regional index-based insurance pools. Each pool quantifies disaster risk to determine country payments into the pool using detailed mapping, data and modelling tools. A challenge is accounting for the dependencies in the 'fat tails' of the loss distributions, for example, with copula methodologies.

Can insurance meet the risk-reduction and 'fair compensation' expectations of the WIM?

Index-based programs have few explicit incentives for risk reduction beyond reducing moral hazard, even if their potential is promising (Linnerooth-Bayer, et al. 2018). One notable exception is the R4 Rural Resilience Initiative (R4) that offers drought insurance to over 40,000 farmers in food-insecure communities in Africa. Cash-constrained farmers pay the premium by working on projects that reduce risk in their community. This poses a challenge to crop and integrated household/farm modelling: how to assess the relationship between insurance premiums and damage/loss reduction?

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Concerning 'fair compensation,' developing countries question the fairness of shifting responsibility on to those least responsible for climate change, least able to shoulder the premiums, and in many cases least able to reduce their losses. While solidarity can be a conduit for fair compensation, framing support in terms of humanitarian assistance, and not liability, is controversial. This issue has been voiced with regard to the G7 Initiative on Climate Risk Insurance (InsuResilience), which has the ambitious goal of increasing access to climate insurance coverage for up to 400 million vulnerable households. Many voices have been forthright about the need to ground G7 financial support in ethical claims of accountability, which has unleashed a broad-ranging discussion on who should pay for insurance, sovereign risk transfer and social protection systems in light of climate change.

Keywords: climate change, WIM, rural poverty, farmer vulnerability, resilience.

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Modelling the consequences of the genetic variability on yield: which scales, methods and degrees of abstraction?

Tardieu François (francois.tardieu@inra.fr)

LEPSE, INRA, Montpellier, France

Growth under sub-optimal environmental conditions is controlled by a large range of physiological mechanisms (e.g. cell division, hydraulics, cell wall mechanics and metabolism), controlled by tens of hormones and involving the expression of hundreds of genes. Each of these mechanisms has its own genetic variability and operates over minutes, i.e. the half time of changes in evaporative demand, light or temperature sensed by plants. Indeed, expansive growth, transpiration and photosynthesis can change by one order of magnitude over less than one hour. Conversely, most plant traits are controlled over days to weeks, e.g. x-y-z final leaf dimensions, abortion rate or floral transition. Finally, yield is controlled over months, based on feedback loops between mechanisms/traits and environmental conditions sensed by plants (3). A tempting conclusion might be that all these processes need to be jointly modelled if one wishes to predict the consequences of the natural genetic variability on plant performance, for example from the control of every stomata to the transpiration of a field. However, this would generate a model prone to large errors with an unpredictable overall behaviour.

I propose the simplifying hypothesis (3,4) that evolution has selected plants in such a way that the many mechanisms involved in acclimation were constrained to collectively buffer rapid changes in water, carbon and nutrient status. This results, after temporal integration, in long-term controls that can be summarized by simple statements such as “growth must progressively decrease before soil water or nutrients get depleted”. Plants carrying combinations of alleles that did not result in such simple rules were eliminated after unfavourable years, but plants that were too parsimonious for a given site were overgrown by their neighbours. Hence, only a limited set of overall “metamechanisms” survived, with a limited number of modalities per environmental scenario. This generates a much simpler landscape, compatible with crop modelling (3,4).

A consequence of the latter statement is that the complexity of systems from cell to canopy is fractal-like. The control of one stomata involves about as many equations or parameters as does the transpiration of a canopy (3). The heritability of simple traits measured in phenotyping platforms and that of yield are most often similar (5). Hence, the plant community may well need to continue living with models at different scales. Crop model can predict yield based on feedbacks that cannot pretend to mimic gene action, whereas detailed hydraulic or metabolic models, which can describe gene action, cannot predict yield. Some ‘trans-scale miracles’ exist and will be presented.

The progress of phenomics (5) and of genomic prediction potentially allows one to reconcile scales from mechanisms to yield. It is now possible to directly measure (or infer based on mechanistic models) traits that are then used as model parameters, such as radiation use efficiency and its changes with light or nutrients, or the response of organ expansive rate to soil water potential. This can be performed for hundreds of varieties, but results can be used for training models of genomic prediction, resulting in vectors of model parameters for thousands of varieties (1). Yield corresponding to these varieties can then be predicted in thousands of fields by using either crop models or regression models (1,2). In principle, any measurable trait/parameter can be utilized in this way, provided that (i) it can be measured with the necessary precision and throughput (ii) it is explicitly involved in model equations. Indeed, many parameters of crop models are conceptual but cannot be measured.

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Hence, I argue here that the combination of models at different scales with phenomics and genomic prediction opens new avenues for predicting the performance of thousands of varieties in thousands of sites (1). It also allows modelling the complexity of allelic effects at organ, plant or canopy levels because the genomic prediction of parameters "summarises" the action of hundreds of genes. This approach disentangles gene action from the effect of predicted traits/parameters on yield, which depends on environmental scenarios in the considered fields. Finally, I propose that models at different scales, together with statistical models, will keep their role in the future, wheareas a single model that would cross all scales of complexity may well be a chimera.

Keywords: genetic variability, mechanism, yield, acclimation, scale.

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Grand challenges for the 21st Century: What crop models can and can't (yet) do

Giller Ken (ken.giller@wur.nl)

Plant Production Systems, Wageningen University, Wageningen, Netherlands

Grand challenges of achieving food and nutrition security for all in the face of climate change, while avoiding further land use change and loss of biodiversity, is what can be referred to as a perfect storm. Perhaps the most challenging perfect storm mankind has ever faced, in which crop production plays a central role. So what is the role of crop models and crop modelling in addressing these challenges?

It is safe to say that crop modelling has played a major role in our understanding of these challenges; for example, of the extent of existing yield gaps across the globe and the vulnerability of different regions to climate change to name but two. Yet considerable knowledge gaps remain. While approaches to simulation of crop response to nitrogen and water are well-established, much less attention has been placed on other limiting nutrients such as phosphorus and potassium, or on pests and diseases. Much of the focus has been on the major cereal crops - for good reasons. Crop models come in many forms and are designed for different purposes - ranging from understanding of physiological processes to the simulation of crop behaviour in the field. We recognise that 'model monsters' that attempt to simulate all possible processes and integration levels are undesirable.

Unravelling these grand challenges necessitates an understanding of constraints, synergies and trade-offs in crop production at different levels. Analyses of agricultural systems requires attention to the crop, the cropping system, the farm system (including livestock) and to farming systems. We are increasingly challenged to place our analyses in the broader context of food systems, and to address issues of nutritional quality of food produced. Different approaches to crop modelling are needed and it is important to choose the most appropriate tool depending on the question being addressed.

In my talk I will sketch out ideas on how crop modelling can contribute to addressing tissues the grand challenges we face. I will draw on ongoing research at Wageningen University on cassava and on perennial crops, East African highland banana, cocoa and oil palm. My views no doubt have some bias towards the problems faced of data-scarce environments in developing countries. Above all my aim during the conference is to listen and learn from presentations and discussions during the conference, to hear what others have to say, and to see if we can build a common vision of future priorities for crop modelling.

Keywords: food security, climate change, farming systems, perennial crops, research priorities.

ABSTRACTS PARALLEL SESSIONS

SESSION I

IMPROVEMENT OF CROP MODELS

While crop models have advanced considerably during the past five decades, their capability for assessing the current and future performance of crops and cropping systems under variable environmental conditions has sometimes been debated. Model improvement is certainly closely related to the availability and quality of data from experimentation and (remote/nearby) monitoring, although questions also exist on how to exactly measure model improvement. Process-based crop simulation models (CSMs) that aim to quantify current, and explore future genotype by environment by management (GxExM) interactions are in the focus here. Major challenges in improving description of the underlying mechanisms relate to predicting crop impacts caused by agro-climatic extremes and biotic stresses, in particular, interactive effects of drought and heat stress, biotic stresses, and their modification under enhanced atmospheric CO_2 concentration. Likewise, challenges exist to improve process descriptions regarding nutrient dynamics including soil water and nutrient uptake, especially for (sub-) tropical cropping systems. In order to improve crop models, it will also be necessary to judiciously assimilate different data types and consider the complementarity of CSMs with statistical/machine learning approaches to feed or substitute some parts of the CSMs in the era of big data.

The session invites papers that address the above-mentioned issues.

S1-Keynote

On the urgent need for improvement of crop models

Stöckle Claudio (stockle@wsu.edu)

Biological Systems Engineering, Washington State University, Pullman, WA, United States of America

Process-based crop simulation models (CSMs) integrate mathematical descriptions of the mechanisms leading to growth and yield of crops in response to environmental conditions and management. They are regarded as important tools for on-farm decision-making, analyses of agricultural systems, and as an aid in plant breeding. Although the experimental and conceptual understanding of processes for building models was available in the 1960s and 70s, it was not until the advent of personal computers in early 1980s that they were integrated into complete crop models. The ability to simulate cropping systems including rotations, tillage, nutrients, soil organic carbon, GHG emissions, and other aspects developed during the 1990s. Advances in sensors and remote sensing, spatial analysis tools, database management, and cloud and cluster computing have created new opportunities for potential model applications, including real-time management decisions and regional and global yield projections.

There is a tendency for optimistic assessments of crop model capabilities to meet current and future application challenges. These are based on studies showing reasonable performance of CSMs when adequate plant growth observations, good information on agronomic management and soil initial conditions, and on-site weather data are available for careful calibration. However, the performance tends to partially (or substantially) breakdown when calibrated models are applied to other spatial and temporal domains, suggesting that process representation may not be robust enough to fully capture responses to the environment and management. Due to limited resources, model calibration and evaluation studies are normally conducted for a limited number of years and locations, and one could hypothesize that further reduction of performance would occur in simulations including long-time series and multiple locations with diverse weather, soil, and management conditions.

In recent years, under the umbrella of AgMIP (Agricultural Model Inter-comparison and Improvement Project), the global crop modeling community has engaged in the evaluation of CSMs performance. Multi-model comparisons have been conducted for major staple crops, including wheat, maize, rice, and potato. The standard approach has been to calibrate the models in selected world sites with the necessary experimental observations. These comparisons have uncovered important departures between simulations and observations, and among models. For example, Bassu et al. (2014) compared 23 maize models in four locations representing a wide range of maize production conditions in the world, with individual models differing considerably in grain yield simulation. Similarly, Asseng et al. (2013) compared 27 wheat models at four sites, obtaining a large variation in simulated grain yields when limited information was provided for calibration. After full calibration the variation among models was reduced, and many models (>50%) simulated yields with uncertainties within 13.5%, indicating that model calibration and the choice of models for use in particular applications are important factors. The variation between models further increases when projections in response to changing climate scenarios (warming and elevated atmospheric CO_2, in particular) are compared, typically representing a greater proportion of the uncertainty than variations between general circulation models (e.g., Asseng et al., 2013). Important variation in growth and yield simulations have indeed been found in all multiple model comparison studies.

These results indicate the need for urgent efforts to improve individual processes in models. For example, 29 crop models simulating potential evapotranspiration (ETp) for maize in Iowa, state variable that essentially depends only on weather, provided daily estimates of ETp fluctuating between 1 and 7 mm/day and more (Kimball et al., 2019). Other issues include important differences in crop water uptake, leaf area index, and grain yield projections as well as lack of coupling between crop transpiration and biomass production and more. Understanding the underlying causes of such variations, identifying the best modeling approaches, and incorporating them in CSMs is extremely important for crop models to be able to fulfill their potential.

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S1-O.01

Methodological advances to incorporate damage mechanisms from diseases in crop models

Bregaglio Simone[1] (simoneugomaria.bregaglio@crea.gov.it), Savary Serge[2], Ferrise Roberto[3], Kersebaum Kurt Christian[4], Stella Tommaso[4], Willocquet Laetitia[5]

[1] *Agriculture and Environment, CREA, Bologna, Italia, Italy*; [2] *UMR AGIR, INRA, Catanet-Tolosan, France*; [3] *DAGRI, University of Florence, Firenze, Italy*; [4] *ZALF, Müncheberg, Germany*; [5] *INRA, Catanet-Tolosan, France*

Introduction

Plant diseases are a major cause for yield losses worldwide and an important, yet poorly documented, source of uncertainty in modelling outputs. Disease yield loss quantification – the difference between the attainable, uninjured yield, and the actual crop yield – is critical to inform decisions for disease management, from tactical, field-centred, to strategic decisions for priority setting and public policy. Yield losses can be simulated using agrophysiological models in which damage mechanisms, i.e., the physiological effects of diseases/pests have been incorporated (Savary et al., 2018). However, nearly none of the crop models designed primarily to address agrophysiological and agronomic factors take into account disease or pest effects. The objective of this work is to incorporate damage mechanisms into several wheat models, and to assess their behaviour in simulating the way crop growth and yield are affected by diseases. We report here the activities of the Pest and Disease Modelling intercomparison Project (PeDiMIP) of AgMIP and of the MACSUR Disease&Pest networks on wheat, considering four diseases: leaf rust (LR; brown rust), yellow rust (YR, stripe rust), septoria tritici blotch (STB), and powdery mildew (PM).

Materials and Methods

WHEATPEST is an agrophysiological wheat model designed to simulate yield losses, which incorporates the damage mechanisms associated with 11 diseases, pests, and weeds (Willocquet et al., 2008). The same damage mechanisms featured in WHEATPEST for LR, YR, STB, and PM were incorporated in three wheat models: HERMES (Kersebaum, 2007), SSM_wheat (Soltani et al., 2013), and WOFOST_GT (Stella et al., 2014). Two damage mechanisms were associated to wheat diseases: (1) the reduction in green LAI (coverage by lesions on leaves) and (2) the diversion of assimilates (used for the pathogen growth and reproduction). The intensity with which these damage mechanisms affect crop physiology depends on the specific disease, and is reflected by the parameterization of the damage mechanism. Simulations involved injury drivers (disease progress curves) for each disease, which were designed to reflect their documented epidemiological patterns.

Results and Discussion

A key objective in this work is to analyse how the dynamics of wheat growth are altered by a given level of injury, using models which strongly differ in the formalization of plant processes. Properly addressing this question requires models calibration to represent the same level of attainable growth. Attainable growth is then affected by disease injury to a varying degree, depending on the strength of the damage mechanism and on the dynamic pattern of the specific disease.

The presentation will report the results from simulation experiments with the four models and four wheat diseases, based on the same benchmark experimental data set from the Netherlands. Differences in the simulated effects of diseases on actual growth and yield were observed between the four models. The factors underlying these differences will be discussed, according to model structures, and to the simulated dynamics of wheat growth.

Conclusions

This work highlights the need to consider the effects of diseases and pests to address yield and crop production. It represents one useful step towards the analysis of impacts of wheat diseases under current and future environmental contexts, including technology shifts, climate change, and changes in plant disease patterns.

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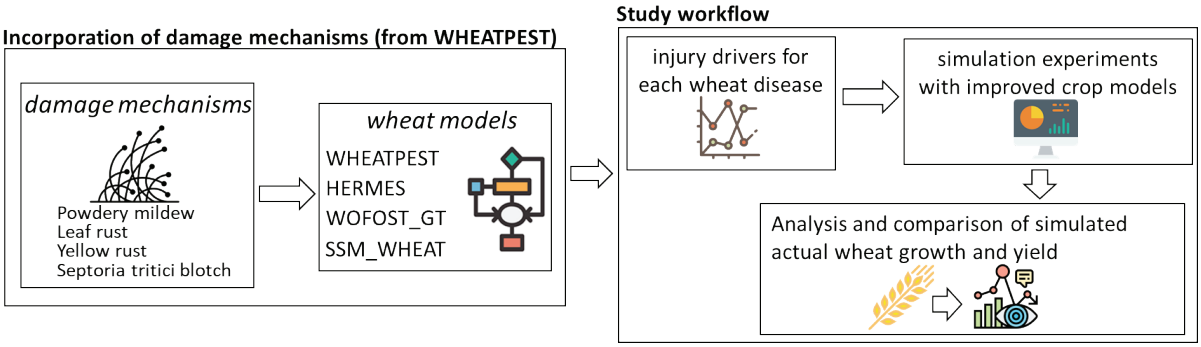

Figure 1. Stages in assessing the behaviour of wheat models incorporating damage mechanisms from diseases with respect to simulation of actual growth and yield of a wheat crop affected by injuries from wheat diseases.

Keywords: wheat, yield loss, plant pathogens, pests, yield-reducer.

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S1-O.02

Modeling shallow water table and impacts on soil, root, and plant processes using APSIM

Archontoulis Sotirios[1] (sarchont@iastate.edu), Huber Isaiah[1], Edmonds Pat[1], Pasley Heather[1], Huth Neil[2]

[1] *Department of Agronomy, Iowa State University, Ames, Iowa, United States*; [2] *CSIRO, Toowoomba, Australia*

Introduction

Shallow water tables (WTs) influence nearly 30% of the global land area including major production regions in the United States, Argentina, and Australia. In drought years shallow WTs benefit crop yields while in wet years shallow WTs reduce crop yields while increase environmental cost. The majority of today's crop models neither account for a shallow WT, nor have mechanistic algorithms to convert the positive and negative impacts of shallow WT into crop yield and soil health. Here, we have two objectives: 1) develop protocols to enable simulation of WT in crop models, and 2) develop new functions to account for excess water stress on root and plant processes.

Material and methods

To develop protocols to simulate WT we 1) synthesized daily WT data from 35 locations across the US Corn Belt, 2) compiled weather and soil profile data for each location, and 3) reviewed literature. We used APSIM version 7.9 soil water models SoilWat (tipping bucket), and SWIM (Richard equation) to perform the simulations. We explored various approaches, including different soil profile depths, manipulations of saturated hydraulic conductivity, drainable porosity (difference between saturation and field capacity) and four different methods to set up the model. Method 1, is a constant head approach using the SWIM module. This approach allows water to enter or exit through the bottom of the profile. Method 2, is a gravity driven free drainage approach using SWIM and water is only allowed to exit the profile. Method 3, is similar to Method 2, but the bottom layer is sealed. Method 4 is similar to Method 2 but it uses the SoilWat module. Simulated output was evaluated using the Nash-Sutcliffe efficiency (NSE). To develop functions to translate excess moisture impacts on soil, root and crop processes, we collected new experimental data from Iowa, USA and reviewed literature to expand the database for modeling. We improved the following functions: root growth, phenology, photosynthesis and N-fixation.

Results and Discussion

The WT fluctuated from 0 to 5 m in some sites and from 1 to 2 m in some other sites. We found that a 4 m profile was sufficient to represent WT fluctuations (Fig. 1). To create the 4 m profile, we used data from the last known soil layer (e.g. 1.5 m) and newly developed equations to estimate saturated hydraulic conductivity and saturation from 1.5 to 4 m depth. The long term average WT depth per site was used to inform the above equations. Among the 4 methods tested, all were able to simulate WT dynamics in the long term, however, the method 1 (SWIM with constant head) was found to be the most accurate (Fig. 1). This method had 74% of the simulations within the acceptable NSE score range (0 to 1). The addition of the new excess moisture functions greatly improved the simulation of root growth (Ebrahimi-Mollabashi et al., 2019), biomass, and yield (Fig. 1). Also, the improved model captured well the effect of timing and duration of excess moisture stress on crop growth (Fig. 1).

Conclusions

We concluded that both tipping bucket and Richard's equation 1-D soil water models can simulate water table fluctuations over time with appropriate model set up. The developed new protocols and functions can stimulate further research on this topic.

Acknowledgments

This work was funded by the Foundation for Food and Agricultural Research (FFAR), project "Improving simulation of soil water dynamics and crop yields in the US Corn Belt".

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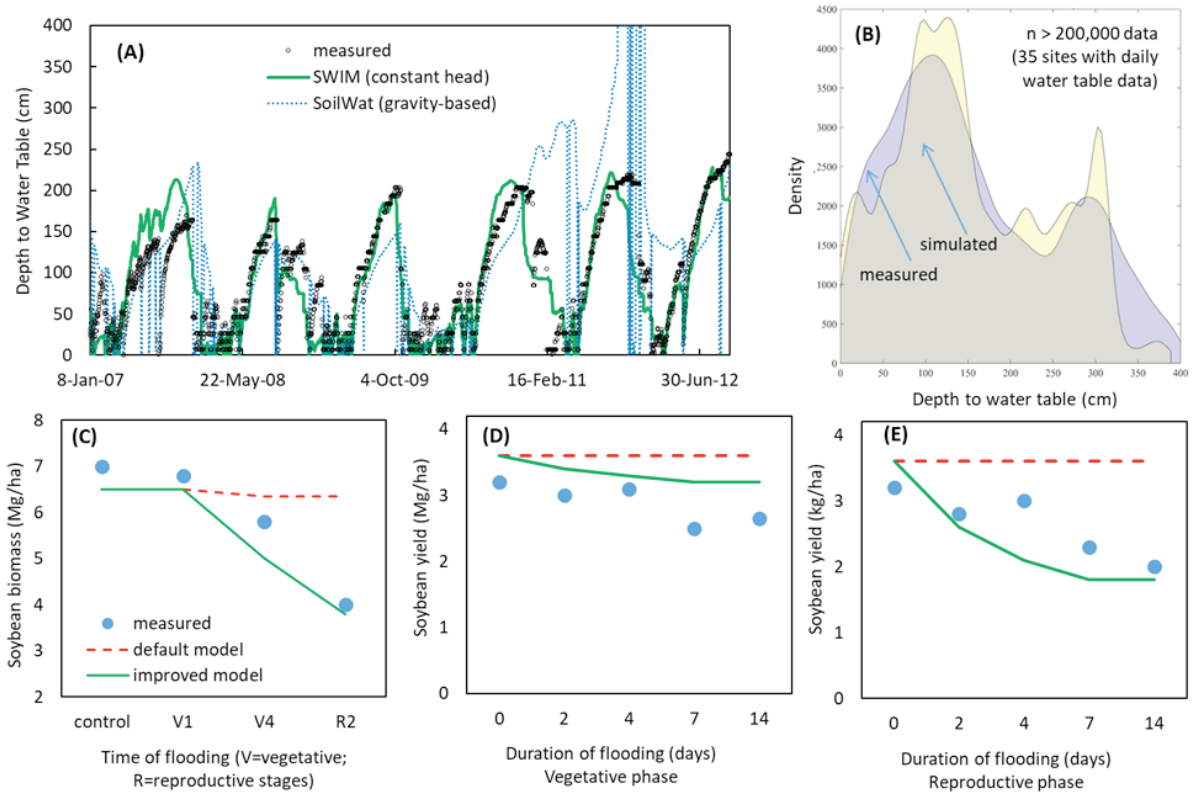

Fig 1. Panel A: observed WT data from northeast Illinois, US vs simulated using SWIM and SoilWat modules. Panel B: density plot with measured WT data from all sites and years versus SWIM with constant head approach. Panels C, D, E: measured soybean yield and biomass vs simulated using the default and improved APSIM soybean model.

Keywords: excess water, root growth, maize, soybean, crop yields.

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S1-O.03

An new efficient method for upscaling soil water flow to randomly dispersed or clustered roots

Graefe Jan (graefe@igzev.de)

IGZ Großbeeren, Großbeeren, DE (Deutschland), Germany

Introduction

Efficient and precise methods are required to estimate the soil to root water flow in plant science. One classical microscopic approach to approximate a complex three dimensional root system is the adoption of a radial-symmetric system of parallel aligned roots with half inter-root distances rm [L] and root length densities L [L L-3] (Gardner, 1960, rm = (πL)^(-0.5)). This one-dimensional approach enables efficient approximations of root water uptake, while assuming steady-state or steady-rate soil water content changes in the root depletion zone (de Jong van Lier et al., 2008). There have only been a few attempts to generalize these approaches to non-regularly distributed roots. Here, based on the theory of Rappoldt (1992), we developed and tested a simple one-dimensional root water uptake model, which accounts for randomly distributed roots and does not require explicit information on root distribution. Moreover, an extension for root clustering from a negative binomial point process is provided.

Materials and Methods

In order to provide more accurate solutions for randomly distributed roots, the point to root distance probability density function (pdf) is transformed to an equivalent cylinder size pdf (*f*C). *f*C was used for upscaling steady state and steady rate cylindrical root models while simple analytical solutions are derived. Solutions are worked out for the Poisson (i.e. randomly distributed) and negative-binomial (i.e. clustered distribution) distance distribution functions.

The Richards equation is solved in the two-dimensional (x, y) spatial domain without effects of gravity. Numerical solution is performed using MATLAB with the public domain class library OOPDE (Prüfert, 2015). A square box with side length of 25 cm is populated with roots having a radius of 0.1 cm which are distributed according to a spatial Poisson point process with different root densities L {0.25; 0.5; 1; 2; 4} cm cm-3. This rather large root radius was chosen to use a large spatial domain with a sufficiently refined spatial grid. A root thinning step was performed to ensure that the inter-distance between simulated root centers is at least 2.5 r0. The initial water content was set to the water content at field capacity (pF = 2) and the simulation proceeded at constant potential transpiration rates (T) representing high (0.6 cm d-1) and medium (0.3 cm d-1) atmospheric demands with an assumed rooting depth zR of 50 cm. Simulations were repeated four times with different random root distributions.

Results and Discussion

The old regular root distribution assumption leads to large overestimations (~50%) of root water uptake for randomly distributed roots. Several numerical comparisons with simulations of the 2D Richards equation over five different soil textures and five root densities show the good performance of the derived solutions both under limiting and non-limiting soil hydraulic conditions. Simulation of root water uptake of different 2D root maps generated by a Poisson cluster process shows the effectiveness of the derived approximation for clustered roots.

Conclusions

The proposed model enables the efficient and precise solution of water flow from the bulk soil to the root system. This can be used in root water uptake calculations or improved soil to root resistance formulations in the plant soil atmosphere continuum of water potential prediction.

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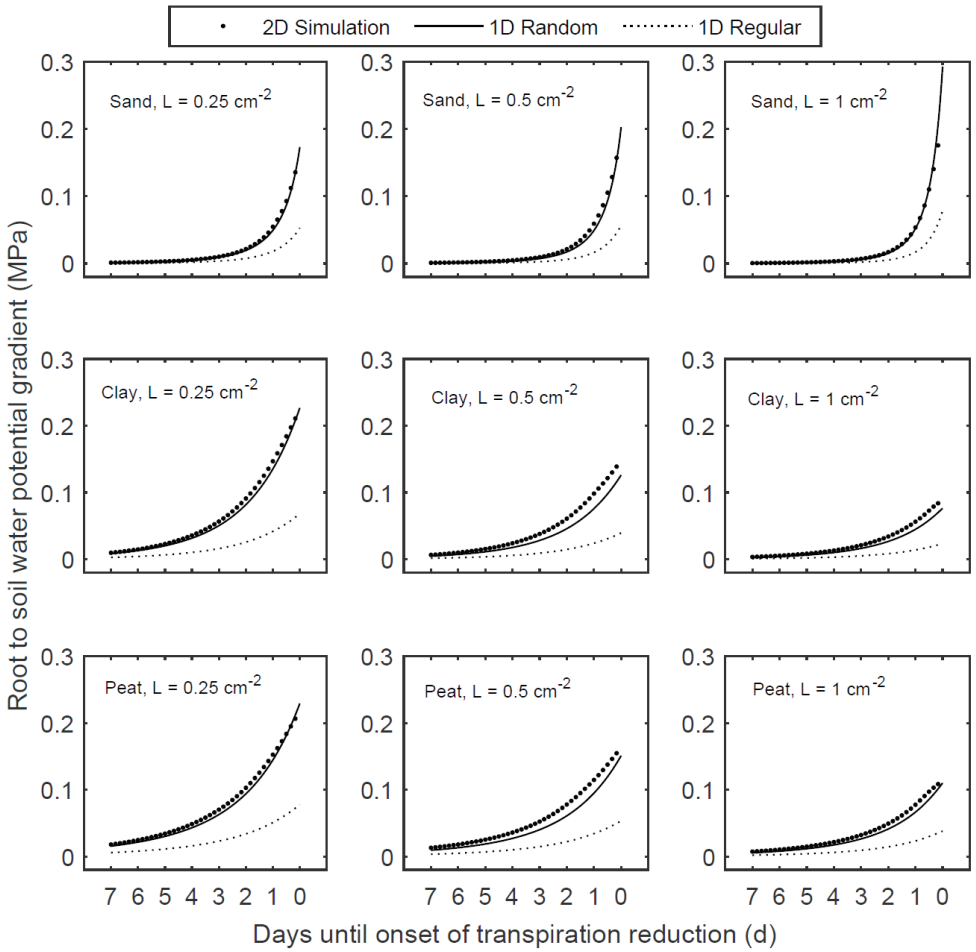

Simulated differences between root surface and bulk soil water potentials (MPa) for explicit two-dimensional simulations of randomly distributed roots ('2D Simulation'), steady state model integrated over a random root distribution ('1D Random') and the regular distribution ('1D Regular'). Different soils (sand, clay, peat) and root length densities L = {0.25; 0.5; 1.0} (cm-2) are indicated.

Keywords: roots, soil, water flow, root clustering.

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S1-O.04

Soybean multi-model sensitivity analysis for prediction of seed nitrogen, biological N fixation, and N cycling

Salmeron Cortasa Montse[1] (msalmeron@uky.edu), Kothari Kritika[1], Battisti Rafael[2], Boote Kenneth[3], Archontoulis Sotirios[4], Confalone Adriana[5], Cuadra Santiago[6], Debaeke Philippe[7], Faye Babacar[8], Grant Brian[9], Hoogenboom Gerrit[10], Jing Qi[11], Laan Michael[12], Macena Fernando[13], Nehbandani Alireza[14], Nendel Claus[15], Poffenbarger Hanna[1], Purcell Larry[16], Qian Budong[9], Ruane Alex[17], Silva Evandro[18], Smith Ward[9], Soltani Afshin[14], Srivastava Amit[8]

[1] *University of Kentucky, Lexington, USA*; [2] *Universidade Federal de Goiás, Goiânia, Brazil*; [3] *University of Florida, Gainesville, FL, USA*; [4] *Iowa State University, Ames, IA, USA*; [5] *Universidad Nacional de Buenos Aires, Buenos AIres, Argentina*; [6] *Empresa Brasileira de Pesquisa Agropec., São Paulo, Brazil*; [7] *INRA, Tolosan, France*; [8] *University of Bonn, Bonn, Germany*; [9] *Agriculture and Agri-Food Canada, Ottawa, USA*; [10] *University of Florida, Gainesville, USA*; [11] *Agriculture and Agri-Food Canada, Ottawa, Canada*; [12] *University of Pretoria, Pretoria, South Africa*; [13] *Empresa Brasileira de Pesquisa Agrope, São Paulo, Brazil*; [14] *Gorgan Univ. of Agric. Sci. and Nat. Res, Gorgan, Iran*; [15] *Leibniz Centre for Agric. Landscape, Müncheberg, Germany*; [16] *University of Arkansas, Fayetteville, USA*; [17] *NASA Goddard Institute for Space Studies, New York, USA*; [18] *University of São Paulo, São Paulo, Brazil*

Introduction

Soybean (*Glycine max* L. (Merr.)) is the fourth most widely grown crop and a legume that provides a major source of protein in our food system. Soybean yield projections from global models show the largest deficit relative to the expected demand by 2050 compared to other major crops (Rosenzweig *et al*., 2014). In addition, U.S. seed protein concentration shows a declining trend over time (Jin *et al*., 2010). Crop models can assist in developing strategies for improving soybean productivity and seed composition that maintain a sustainable nutrient balance in agroecosystems. However, model applications for this purpose are limited by the uncertainties in prediction of seed protein and nitrogen (N) concentration (grain N%), and N_2-fixation processes. The present study aims at identifying strenghts and limitations of existing soybean models and their uncertainty in prediction of seed N% and N_2-fixation under different levels of atmospheric carbon dioxide concentration [CO_2], Temperature, Water, and N fertilizer (CTWN sensitivity analysis).

Materials and Methods

Multiple soybean models were calibrated with data from five experiments (Azul, Argentina; Auzeville, France; Brasilia, Brazil; Ames, IA, and Fayetteville, AK, United States). The calibration was conducted in two stages: (1) with phenology data alone (blind calibration), and (2) with detailed observed data, including in-season biomass and seed/pod growth, grain N%, soil moisture and nitrogen data (full calibration). Thereafter, a CTWN sensitivity analysis was conducted, consisting of 30-yr simulations (1980–2009) for 124 combinations of [CO_2] (360 ppm to 720 ppm), temperature (−3 to +9 oC), water (−30% to +30% rainfall, and irrigated), and N fertilizer (0 and 400 kg N/ha).

Results and Discussion

After calibration with observed phenology data, models predicted grain N% with a normalized root mean square error of 31%. Results from the subsequent CTWN sensitivity analysis show that the median of grain N % predicted across models decreased with higher CO_2 levels, decreased with higher temperatures, and responded to N fertilizer applications depending on the irrigation management (Figure 1a,b). These results were due to the indirect effect of these treatments on yield and N availability from different sources. Model uncertainty for prediction of N% increased with CO_2 levels and under irrigation, but was reduced with higher temperatures and N fertilizer applications. The total N_2-fixed showed a strong interaction of temperature and CO_2 levels, combined with high model uncertainty (Figure 1c). Models were consistent in predicting an expected increase in N_2-fixation with irrigation and with lower rates of N fertilizer applied, showing the least uncertainty for the irrigated treatments overall (Figure 1d).

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Conclusions

Our preliminary results indicate a high RMSE in the prediction of grain N% after the blind calibration, that is expected to decrase under full calibration and influence results fromt he sensitivity analysis. The interactive effect of the CTWN treatments generated high variability in grain N% predictions, with predictions under different CO_2 and temperature levels showing the most uncertainty overall.

Acknowledgements

This work was supported by USDA-NIFA and by the University of Kentucky.

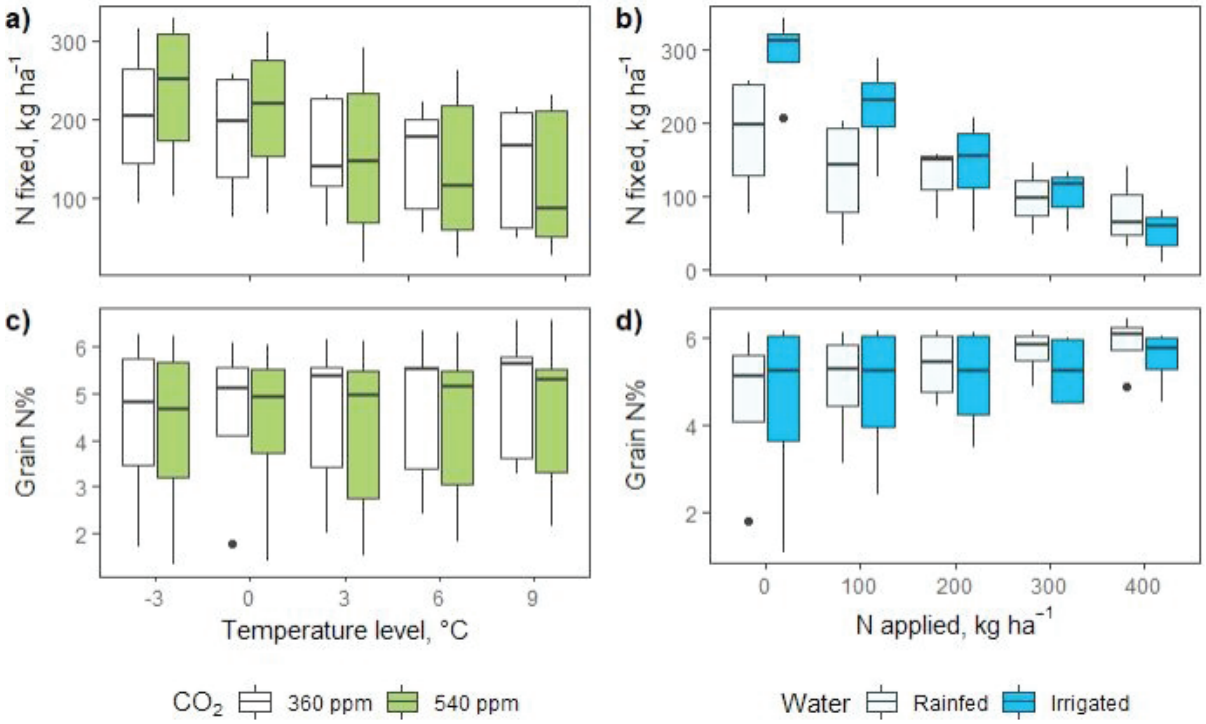

Figure 1. Preliminary data of nitrogen (N) fixed throughout the growing season and grain N concentration (grain N%) in Auzeville, France under different [CO_2], temperature, water, and N fertilizer levels (ensemble from six models). Data was generated after a blind calibration (with observed phenology only) and is averaged across 30-yr simulations.

Keywords: AgMIP-Soybean, N2 fixation, seed quality, protein.

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S1-O.05

Evaluation of a new nitrification/denitrification/N_2O emission model in three different crop models

Dueri Sibylle[1] (sibylle.dueri@inra.fr), Léonard Joël[2], Chlebowski Florent[2], Rosso Pablo[3], Berg-Mohnicke Michael[3], Nendel Claas[3], Fiona Ehrhardt[4], Martre Pierre[1]

[1] *LEPSE, INRA, Montpellier, France*; [2] *AgroImpact, INRA, Laon, France*; [3] *ZALF, Müncheberg, Germany*; [4] *CODIR, INRA, Paris, France*

Introduction

Nitrogen fertilization is a key agronomic lever for high agricultural productivity, but it is also an important driver of emissions of nitrous oxide (N_2O), a potent greenhouse gas with a warming potential 298 times greater than CO_2. Crop models are widely used to simulate N emissions (leaching, denitrification, nitrification) according to crop management. They may be valuable tools to optimize the timing and amount of fertilization to reduce N_2O emission. However, given the complexity of the processes involved in N_2O emission and their interactions, accurate simulation at field scale is still a challenge.

A given crop model can be viewed as an ensemble of coupled submodels, each representing a specific process. The performance of a submodel not only depends on the accuracy of the formalisms used to represent the processes, but also on the performance of the other sub models to which it is coupled. Here, we will first present a new N_20 model. We then show how the performance of this submodel is impacted by the choice of the crop model in which it is incorporated by evaluating the performance of a N_2O emission submodel coupled with three different crop models: MONICA (Nendel et al.,2011), *SiriusQuality* (Martre et al., 2006) and STICS (Brisson et al., 2009).

Material and methods

A new N_2O emission submodel was developed in the frame of crop model STICS and was then incorporated into *SiriusQuality*, and MONICA. It represents nitrification, denitrification and the associated N_2O emissions as a function of substrate availability (nitrate and ammonium concentration) and soil conditions (temperature, moisture and pH). Nitrification rate depends on ammonium concentration, pH, temperature and moisture, while denitrification rate depends on nitrate concentration, temperature and moisture. The N_2O emissions associated to nitrification are mainly influenced by soil moisture, while the fraction of denitrification ending as N_2O mainly depends on pH and soil moisture, and to a lesser extent on nitrate concentration.

The dataset used in this study includes six field experiments, located in Canada, India, Australia, Brazil and France (Estrées-Mons and Grignon) and focuses on two spring barley cultivars (Sebastian and RGT Planet), two spring wheat cultivars (ACBrio and PBW343) and five winter wheat cultivar (Cellule, Hartog, Quartzo, Premio, and Absalon). All together, the dataset comprised 31 combinations of year/treatment/cultivars. Soil, weather and crop management data for these experiments were compiled and standardized to provide the required model parameters and initial conditions.

Results and Discussion

Results will focus on i) measuring the difference in N_2O emissions associated to the incorporation of the same N_2O emissions submodel into three different crop models; ii) analyzing the causes of these differences, which may be associated both with the resolution and accuracy of the simulation of the different input variables (soil temperature, soil moisture, soil pH, as well as nitrate and ammonium concentration), and may also differ depending on the context of use of the model (climate, soil). We will also discuss the possibilities and limits of modular model development and submodel reuse in different crop models.

Acknowledgements

This study was supported by the Barley-IT project, funded by the EIT Climate-KIC.

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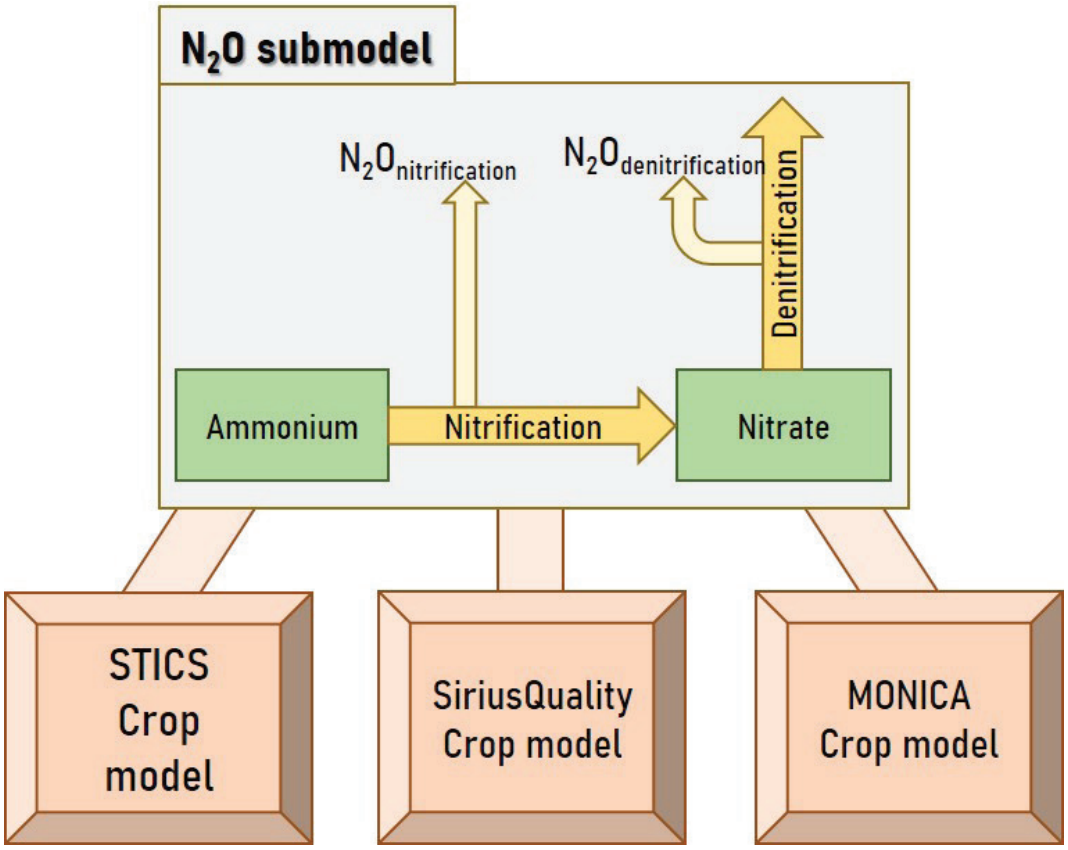

Figure 1: Schema of the N_2O submodel coupled with the STICS, SiriusQuality, and MONICA crop model.

Keywords: STICS, SiriusQuality, MONICA, model modularity.

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S1-O.06

Soil hydraulic properties matter: A physically comprehensive model for improving crop model simulations

Weber Tobias KD[1] (tobias.weber@uni-hohenheim.de), Gayler Sebastian[1], Streck Thilo[1], Diamantopoulos Efstathios[2]

[1] *Biogeophysics, University of Hohenheim, Stuttgart, Germany*; [2] *Agrohydrology and Biophysical Modelling, University of Copenhagen, Copenhagen, Denmark*

Introduction

The Richards equation (RE) is a standard process model for numerical simulations of transient water fluxes in variably saturated soils and as such is included in many physically comprehensive agro-ecosystem models. Accurate description of soil water is important for predictions and process identification of coupled processes in the soil-vegetation-atmosphere continuum. Most commonly, the van Genuchten Mualem model (VGM; van Genuchten, 1980) is used to parameterize the RE; however, it suffers from considerable deficiencies, particularly in dry soils. To overcome the deficiencies, a generalized modular framework for partitioning the soil hydraulic property functions into a capillary and a non-capillary part was developed (Brunswick-model (BW); Weber et al., 2019). With it, a physically complete, continuous, and flexible representation of the water retention curve (WRC) is achieved, ensuring zero water content at oven dryness. The new hydraulic conductivity curve (HCC) leads to consistent descriptions of large sets of observed data. This includes the often observed change of slope beyond -100 cm pressure head in the hydraulic conductivity curve. In comparison to the VGM, this can lead to higher and water recharge in the soil profile from the groundwater; thus, increase plant available water.

Material and Methods

Assisted by specifically newly developed pedotransfer function for the BW model, developed from a dataset containing 980 samples with laboratory measurements of the hydraulic conductivity and water retention, we quantified the effect of including the non-capillary part of the HCC on simulated crop growth, root water uptake, seepage, and nitrate leaching under field conditions in Southwest Germany. For this, the new model of the water retention curve was implemented into the agroecosystem modelling framework Expert-N (Figure 1), and compared to simulations based on the classical VGM approach.

Results and Discussion

In our contribution we show that under a range of conditions, simulated leaf area index, winter wheat yield and above ground biomass are positively influenced by the BW model. Inclusion of the BW model, with the help of the newly developed PTF, enables a better model-data match with measured data from research fields from the Kraichgau in Southwest Germany. The Kraichgau is a region which regularly faces dry conditions during late spring to early summer. Except for the simulated phenology, these results were achieved without inverse modelling, but purely based on parameter predictions from the PTFs and under the identical initial and boundary conditions. The remaining process model parameters for the crop, and carbon and nitrogen sub-models were kept identical. During dry growing season spells, the VGM model produced underestimations of yield and leaf area index.

Conclusions

Faced with climate change and continuing need for impact assessments, the BW model allows to model variably saturated flow also during dryer than today's conditions in Western Europe. These conditions already exist in many places of the world. The next step will be to test the effect on the larger scale under a range of environmental conditions and climate predictions.

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Acknowledgements
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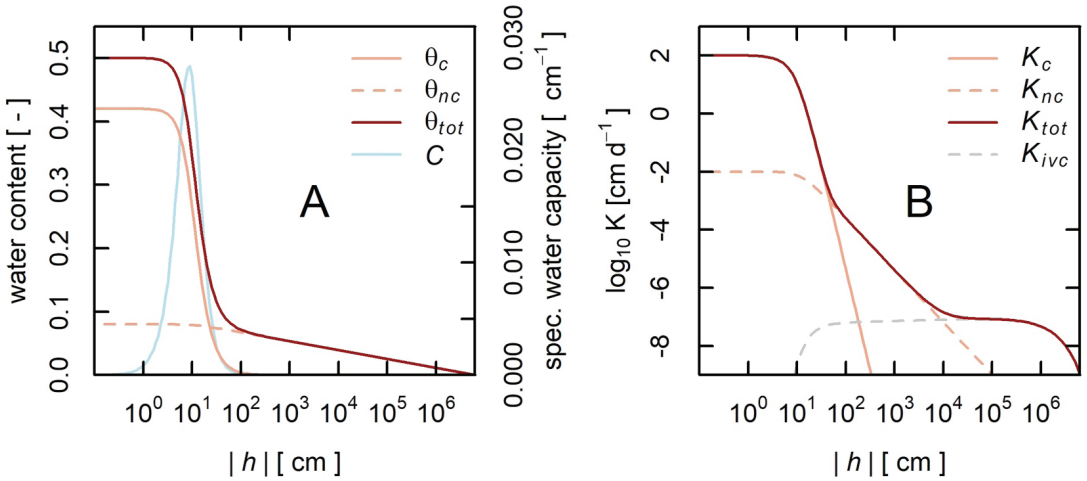

Figure 1: A) Water retention curve and B) hydraulic conductivity curve of the Brunswick model.
The water retention of the capillary part (suffix c) approaches zero at a pressure head of -100 cm. At this point the hydraulic conductivity of the non-capillary part (suffix nc) starts dominating the curve. It becomes clear, that under these conditions, the hydraulic uplift of groundwater is larger for pressure heads < - 100 cm, in comparison to the conductivity model by Mualem model (salmon colour line B).

Keywords: crop model improvement, soil hydraulic properties, impact assessment, climate change.

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S1-O.07

Why and how crop models should account for C source-sink relationships better to address future agro-climatic challenges

Luquet Delphine (luquet@cirad.fr), Larue Florian, Rebolledo Camila, Beurier Grégory, Dingkuhn Michael, Fabre Denis, Clément-Vidal Anne, Rouan Lauriane

[1] *CIRAD, Montpellier, France*

The integrative capacity of crop models is of great value to identify *in-silico* optimal combinations of traits (ideotypes) and traits x cultural practices in targeted agro-environments. This approach becomes even more challenging when considering the multiple environmental factors constituting future agro-climatic scenarios: increasing stress frequency and severity (e.g., heat, drought, wind, flooding); enhanced atmospheric CO_2 concentration (e-CO_2), and also adoption of more sustainable and resilient cultural practices (agroecology) combining of productivity with ecosystem services.

Several studies reported the weaknesses of crop models in predicting crop performance in response to climate change. While these limitations were until now mainly explained by poor simulation by crop models of physiological responses to heat and drought, crop model shortcomings of the representation of Carbon (C) source-sink relations and interactions, involving phenotypic plasticity of both source and sink, should explain this limitations and have received less attention (Chang and Zhu 2017).

Recent studies reported a down-regulation of C source capacity (i.e. photosynthesis) in C3 crops under e-CO_2 by sink limitation in the afternoon, involving low TPU levels (Triose Phosphate Utilization) (rice: (Fabre *et al.* 2019). (Fabre, in prep) indicated that high constitutive source-sink ratios increase photosynthesis under e-CO_2. Finally, (Kikuchi *et al.* 2017) demonstrated in a FACE trial that rice plants with high adaptive plasticity of tillering and panicle size respond better to e-CO_2. Although particularly relevant to C3 crops that respond strongly to e-CO_2, this also applies to C4 crops when they are C-sink limited (Oszvald et al., 2018).
Therefore, Carbon source-sink relationships and their physiological and morphological adaptability (feedbacks) are pivotal in predicting crop ideotypes in a climate change context.

In addition, the agro-ecological transition needs better crop models to design solutions for improving (1) crop energy and carbon use, (2) resilience under abiotic stresses, and (3) ecosystem services such as channeling assimilates into the roots/soil (4p1000 initiative: C sequestration and soil improvement). This implies to further model plant-plant and/or plant-soil interactions and related impacts on C source-sink relationships and competitions for (light) resources. Crop models should indeed be able to predict trade-offs among several crop performance objectives such as multiple production purposes (e.g., grain and biomass), between potential productivity and adaptation, and between productivity and ecosystem services such as C sequestration into the soil. For this, we will provide examples of analytical and modeling concepts.

More quantitative, extrapolatable evidence is needed to understand the importance of C source and sink traits, their adaptive plasticity as they interact during plant development, and their impact on crop performance under anticipated agro-climatic conditions. This requires a dialogue between experimental and modeling research for which we are presenting concepts here. Our laboratory focuses on rice (C3) and sorghum (C4) model cereals using crop models simulating sink- and source driven phenotypic plasticity, namely SAMARA (Kumar *et al.,* 2016) and Ecomeristem (Larue *et al.,* 2019). Some (experimental, modelling) preliminary results will be shown but a broader dynamics is needed. Once further improved, the models will be used to (i) estimate *in silico* the prediction errors caused by ignoring source-sink feedbacks and plasticity; (ii) predict the potential of improved trait combinations and plasticity on the performance of future crops; and (iii) propose how existing, generic crop models should be improved and what type of data will be needed for that.

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S1-O.08

Modelling the Guayule plant growth and development with a Functional Structural Plant Model

Sabatier Sylvie[1] (sylvie-annabel.sabatier@cirad.fr), Jaeger Marc[1], Hemery Nicolas[2], Mougani Christ[1], Abed Alsater Ali[1], de Reffye Philippe[1], Palu Serge[2], Brancheriau Loic[2]

[1] *UMR AMAP, CIRAD, Montpellier, France*; [2] *UR BioWooEB, CIRAD, montpellier, France*

Introduction

The Guayule (*Parthenium argentatum, Asteraceae*), is a small ramified tree native to the northern Mexico and southwestern United States. The guayule shows a growing interest in research and agriculture (Ray, 1993). However, the production itineraries in relation to latex production are still not assessed, and so far little studies were done on the plant structure and functioning. This study aims to propose a first FSPM of the species using the GreenLab model, calibrated from data issued from two varieties in different environmental conditions.

Materials and Methods

The studying methodology is first based on a qualitative architectural analysis (Barthelemy and al., 2007). Second, on the various axis typologies, the development and branching stochastic rules can then be retrieved from field internode distributions collections. Finally, the organ source and sink relations parameters can be fitted from dedicated dry weight measurements (Kang et al., 2018).
Experimental plots were hold south of France, close to Montpellier on two varieties CL1 and CLA1, with four environmental conditions related to density and hydric pressure (no stress, low stress and high stress).. The sampling was optimized to the plant structure and to quantify the polyisoprene and resins contents.

Results and Discussion

The guayule shows a sympodial development is composed of modules with terminal inflorescence. Its architecture corresponds to the Leeuwenberg's model (Hallé et al., 1978). The axes are constituted of successive modules. Studying the plant structure, we found out that the number of relay axis per module follows a binomial distribution. The modules are ordered from the plant base to the top. And these modules are composed of internodes whose number also follows a binomial law, which parameters are quite stable from one order to another. In the further modelling process, we thus did consider that the plant elementary unit was the module, called as a meta-phytomer. Under this assumption, we summarized the total dry weight of leaves and internodes per module to build the axis organic series (Buis and Barthou, 1984). Field measurements issued from these two series constituted then a target to be adjusted by the structural functional GreenLab model (Kang et al, 2018) in order to calibrate the organ source parameters. An initial analysis calculated the strength sink of leaves and internodes in a context of free growth and analysed the differences between the two varieties. We are currently applying the methodology to assess the impact on the parameters of development and growth, the effects of planting density and irrigation.

Conclusions

This first modelling study hold on two varieties on the Guayule tree shows that the plant structure can be efficiently modelled using a simple module approach. The development parameters, defining the module number of phytomers and branching rules are nearly stable and close for both varieties under the various environmental conditions. First functioning parameters were also retrieved from the measurements. These parameters make it possible to obtain the first stochastic 3D simulations of the Guayule's growth and architecture for both varieties.

Acknowledgements

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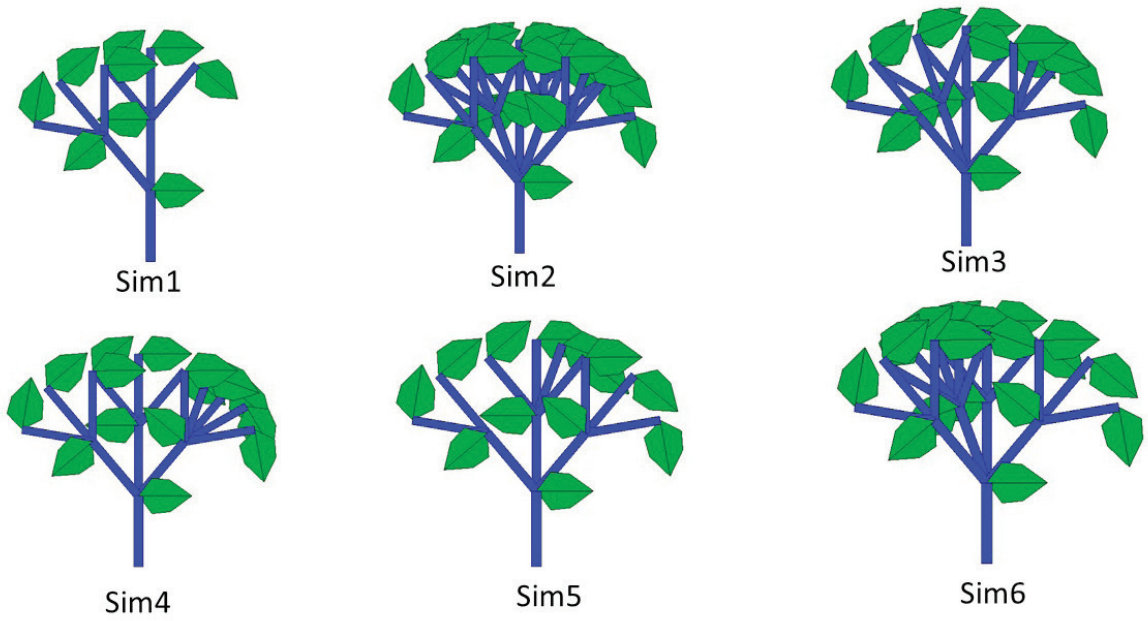

Six stochastic Guayule model simulation at age 5, using metaphytomers (each module with its leaves is replaced by a unique metaphytomer and a single leaf).

Keywords: Guayule, FSPM, GREENLAB, module, rubber.

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S1-O.09

Shedding light on virtual Riesling canopies (*Vitis vinifera* L.)

Bahr Christopher[1] (christopher.bahr@hs-gm.de), Schmidt Dominik[2], Friedel Matthias[1], Kahlen Katrin[3]

[1] *Dpt. of General and Organic Viticulture, Hochschule Geisenheim University, Geisenheim, Germany*; [2] *Dpt. of Modeling and Systems, Hochschule Geisenheim University, Geisenheim, Germany*; [3] *Dpt. of Vegetable Crops, Hochschule Geisenheim University, Geisenheim, Germany*

Light is a crucial player in grape quality and plant health (Friedel et al. 2015). The penetration of light into the grapevine canopy depends on many factors such as the trellis system, row spacing and azimuth, canopy height and width as well as the canopy's optical properties. In addition, seasonal plant manipulation practices such as leaf removal are means to improve fruit quality and plant health.

This study was designed to support knowledge gain on how the dynamic growth of grapevine might affect the light distribution within the canopy taking into account strategic and seasonal cultural decisions. We recently showed that the functional-structural model for Riesling, *Virtual Riesling*, allows us to assess the role changing temperatures for grapevine architecture and thereby considering management techniques (Schmidt et. al 2019). The model particularly accounts for the variability in temperature-sensitive morphological processes like bud break.

We extended *Virtual Riesling* by coupling it with a light model (Evers and Bastiaans 2016). In the virtual scene, simulated incoming direct and diffuse light from the sun of in total 20 Mio rays interacts with the virtual leaves of the canopy. Daily light intensity was estimated based on e.g. sun-earth geometry, whereas optical properties of the leaves were derived from literature (Cabello-Pasini et al. 2011). In the current version of the model, no further objects interact with the light model. The virtual vineyard consisted of 7 rows each of 10 plants, where the inner 40 plants were used for further data analysis. The daily course of the sun was integrated within one simulation step, representing a day. The model calculated absorbed PAR for each leaf during the time course of simulation. We ran 25 simulations for Riesling growth and development under temperature data of 2018 (resulting in 1000 plants for data analysis) to assess the light distribution over the whole canopy and canopy layers including the fruit zone exemplarily.

Our simulation study shows that total absorbed PAR (PAR_{abs}) by the average plant in 2018 is following an expo-linear trend over time, whereas single layers show saturating and diminishing pattern. The largest share of total intercepted radiation is absorbed in the upper layers of the canopy. Here, light interception increases over time in absolute terms. This is due to the increasing daily ambient PAR and canopy density, which is mainly dependent on the development of lateral shoots. As canopy development proceeds, light interception in the bunch zone gradually decreases in absolute and relative terms. Our simulation study also highlights a high plant-to-plant variability of PAR_{abs}, which is the highest around maximum PAR_{abs} per layer, and increases per plant with virtual growth period. In conclusion, the study showed that the extended *Virtual Riesling* model is a useful tool for assessing light characteristics within grapevine canopies under changing climatic conditions. This is the first study considering the dynamic growth of detailed grapevine architecture over time and thus enables the simulation of the microclimatic effects of cultural management practices like leaf removal or hedging in a VSP-type training system. Future work will consider additional practically relevant aspects (e.g. training systems) and the inclusion of additional parameters with relevance to canopy architecture.

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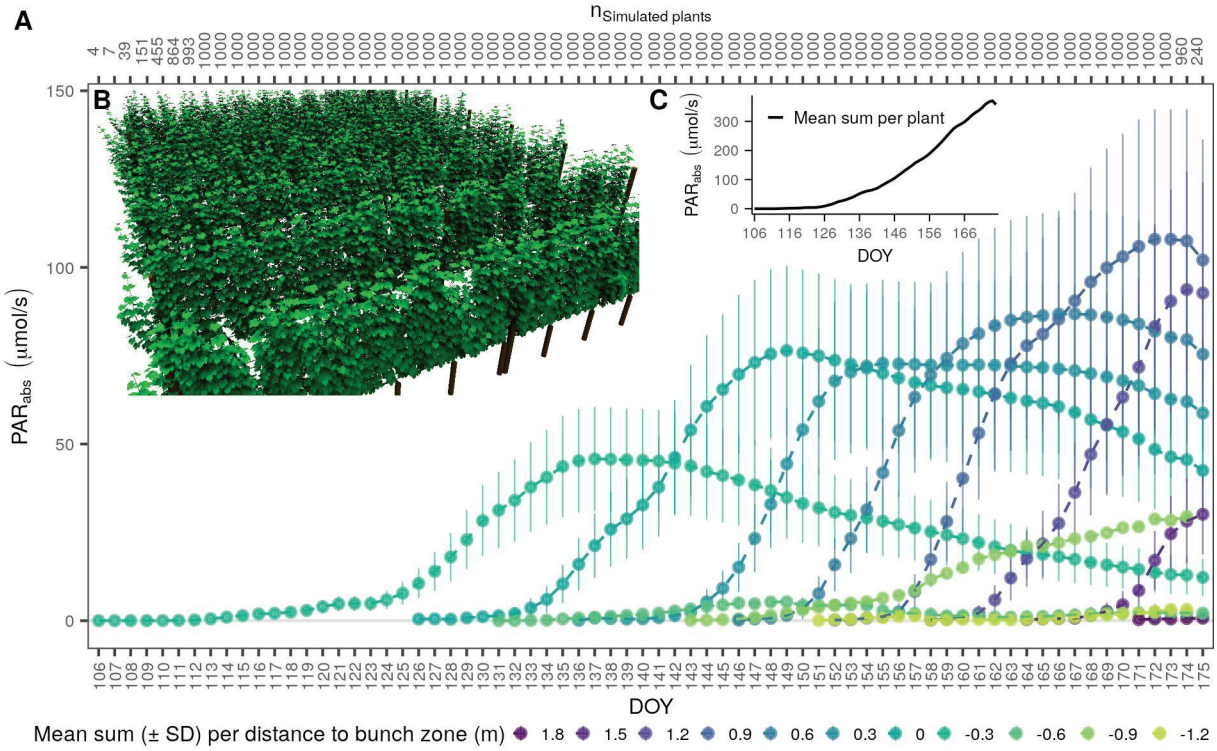

Temporal and spatial dynamics of Virtual Riesling canopy light absorption.
A: Mean sum and standard deviation (SD) of absorbed PAR (PARabs, µmol/s) for layers of 0.3 m height with layer center cooridnates given as the distance to bunch zone.
Results were derived from 1000 (25x40) simulated non-border plants over time (day of the year, DOY).
B: End of simulation rendering of an exemplary virtual vineyard with 7x10 plants.
C: Temporal course of mean sum of PARabs per simulated plant (µmol/s).

Keywords: Virtual Riesling, functional-structural plant model, light, dynamic model, plant architecture.

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S1-O.10

Developing a functional-structural plant model of cocoa to explore the interaction between pruning and shading

Tosto Ambra[1] (ambra.tosto@wur.nl), Zuidema Pieter A.[2], Anten Niels P. R.[1], Evers Jochem B.[1]

[1] *Centre for Crop System Analisys, Wageningen University & research, Wageningen, Netherlands*; [2] *Forest Ecology and Forest Management, Wageningen University & research, Wageningen, Netherlands*

Introduction

The increasing cocoa demand and the predicted shrinkage of suitable growing area due to climate change call for a urgent need of increasing the productivity of existing cocoa cropping systems. Cocoa systems range from full-sun monoculture to diverse agroforestry systems. Obtained yields lay far below potential yield due to low fertilizer input, pest and decease incidence and poor maintenance practice (Zuidema et al., 2005).

Pruning is considered a preliminary and essential maintenance practice to ensure the efficacy of fertilization and pest control and a way to ensure optimal distribution of light within the crown. The actual recommended pruning practice however lacks scientific support, and the interaction between pruning and shading levels is not well understood (van Vliet and Giller 2017). Pruning impacts tree functioning and tree architecture (Ferree and Schupp, 2003) that depend greatly on the plant light environment (Anten et al., 2003). To be effective, pruning practice must be tailored to the shade level of the cropping system.

Pruning and shading responses influence and are influenced by the 3D structure of the plant. Since experimental trials on pruning-shading interactions are constrained by plant size and the long life-cycle of cocoa trees, functional structural plant (FSP) models can be applied. FSP models dynamically simulate the development of plant 3D architecture as a result of physiological process, responses to light environment and interventions such as pruning (Vos et al.,2010).

Our aim is to develop an FSP model of cocoa to assess the effect of pruning practices on cocoa architecture and canopy photosynthesis at different shade levels. We present here the current state of model development.

Materials and methods

Our cocoa model simulates growth and development of cocoa architecture (fig. 1). Architectural and developmental characteristics specific to cocoa plants have been included, such as the dimorphism of orthotropic and plagiotropic branches, crown layer formation (jorquetting) and intermittent leaf production driven by thermal time (flushing).

Light interception is calculated at leaf level, driving leaf photosynthesis. Plant growth is an emergent property of source-sink driven allocation of assimilates. Different levels of homogeneous and heterogenous shade can be simulated. Model parameters have been estimated from architectural and physiological measurements on cocoa plants in experiments located in Ivory Coast.

Further development and evaluation.

Pruning events and responses in terms of new branch formation will be implement in the model. Removal of branches, or portions of branches, will modify the probability of break of dormant buds, resulting in emergent branching patterns. Model outcome will be evaluated against measurements of plant architecture and light interception measurement from two pruning experiments. We will present results of sensitivity analyses and model pruning experiments.

Conclusion

The cocoa FSPM will be a multipurpose tool to address relevant issues in cocoa production, such as optimal shading, pruning practice, planting design etc. It can serve as a tool for screening promising trial options as well as for ideotyping plant structure for breeding purposes. The 3D visual output make the model an effective communication tool for academic and non-academic audience.

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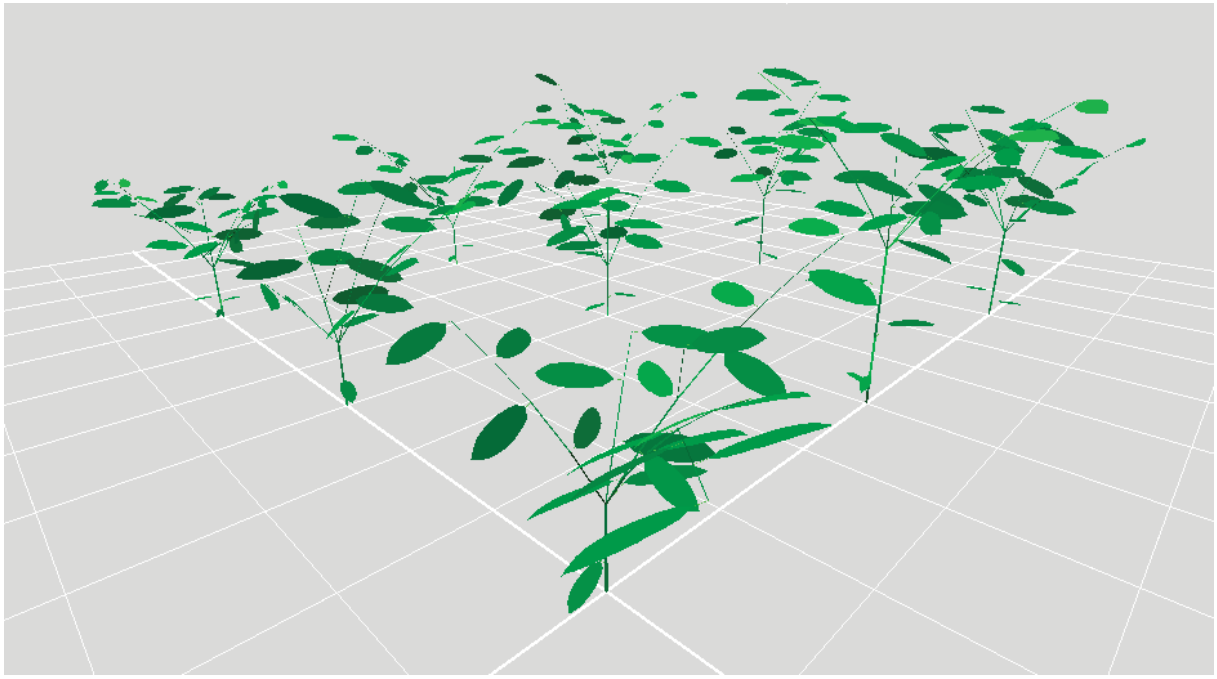

Figure 1. Example of 3D visual output.

Keywords: virtual plants, tropical perennial, Theobroma cacao, plant light evironment, plant architecture.

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S1-O.11

Coordination between dynamics in canopy structure and photosynthetic acclimation strategy optimizes canopy productivity

Pao Yi-Chen (pao@gem.uni-hannover.de), Chen Tsu-Wei, Stützel Hartmut

Leibniz Universität Hannover, Hannover, Germany

Introduction

Significant variations in canopy structure among genotypes result in different light distribution within their canopies. One can hypothesize that plants should develop different functional acclimation strategies according to their intra-canopy light distribution to maximize canopy photosynthesis. To test this hypothesis, we examined the response of leaf economics to light intensity in two cucumber cultivars having contrasting structural characteristics and used modelling approach to test whether their strategies of photosynthetic acclimation are beneficial for their specific canopy structure.

Materials and Methods

Using a 3D digitizer, canopy structure of cucumber cultivars 'SC50' and 'Aramon' were measured in a greenhouse experiment for four consecutive weeks (170-450°Cd after planting). This data was used to re-construct 3D canopy structures in *GroIMP* (Chen et al., 2014) to simulate intra-canopy light distribution and to quantify light extinction coefficients of the canopy.

Light response of leaf economic traits was quantified using leaves grown in climate chambers under three constant light levels (28.9, 14.2, 4.4 mol m^{-2} d^{-1}). Leaf mass per area (LMA), total leaf nitrogen, gas exchange were measured at 12 time points (leaf age between 45-558°Cd). Photosynthetic nitrogen was calculated from photosynthetic parameters estimated using gas exchange data (Buckley et al., 2013). Dynamics of LMA and photosynthetic nitrogen per mass (N_{pm}) were modelled using a revised model of Pao et al. (2019) to simulate daily canopy carbon assimilation under three plant densities (0.665, 1.33, 2.66 plants per m^2).

Results and Discussion

The canopy structure was different between two cultivars in leaf area and elevation angle. SC50 had more horizontal leaves (15-20°), which led to slightly higher light extinction coefficient than Aramon. However, the larger leaves and higher leaf area index of Aramon plant contributed to its overall low light intensity in the canopy. The most significant differences in the photosynthetic acclimation strategy to light were (1) Aramon invested more nitrogen in photosynthesis than SC50; (2) Aramon had more photosynthetic nitrogen (N_p) under low compared to high light availability, while N_p of SC50 did not respond to light; (3) SC50 partitioned more Np to light harvesting under low light and more N_p to Rubisco under high light - an efficient partitioning strategy (Buckley et al., 2013).

We simulated daily canopy carbon assimilation (DCA) for the combinations of the structural and functional characteristics of the two cultivars and calculated the change in DCA by matching the canopy structure of a genotype with the acclimation strategy of the other genotype. With the acclimation strategy of SC50, DCA of Aramon canopy decreased due to the decrease in plant photosynthetic nitrogen ($N_{p,plant}$) and increased daily photosynthetic nitrogen use efficiency (PNUEd), while DCA and $N_{p,plant}$ increased and PNUEd decreased in SC50 canopy with the acclimation strategy of Aramon.

Acclimation strategy also affects N_p distribution between leaves in the canopy (NDL) and the partitioning between photosynthetic functions in a leaf (NPF). To quantify the effect of NDL and NPF on DCA, we set Np,plant constant for a given structure but kept NDL and NPF as produced by exchanged strategy. Simulation results showed that SC50's NDL and NPF strategy increased DCA of Aramon canopy from the second week and this effect increased with plant density. With Aramon's NDL and NPF strategy, DCA of SC50 canopy decreased mainly from the fourth week and this effect did not vary with plant density. This suggested that (1) NDL and NPF had impact on DCA after canopy formation and under higher plant density; (2) SC50's NDL and NPF strategy was more closed to optimum than that of Aramon, and it increased DCA under strong light competition within SC50 canopy and between Aramon canopies.

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Conclusions

Aramon, the cultivar with larger leaves, developed a strategy to partition more nitrogen to photosynthesis and even more at the lower canopy where mutual-shading was severe. Model simulation suggested that this strategy of increasing nitrogen investment in photosynthesis improved daily canopy carbon assimilation regardless of structure but decreased photosynthetic nitrogen use efficiency. SC50 partitioned nitrogen between photosynthetic functions more efficiently and this strategy was beneficial for canopy carbon assimilation under strong light competition, which might be a key trait for improving crop productivity. Our model study highlights a novel aspect of coordination between dynamics in intra-canopy light distribution and photosynthetic acclimation strategies for optimizing canopy productivity.

Keywords: Leaf mass per area, Modelling, Multiple-layer canopy model, Photosynthetic nitrogen.

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S1-O.12

Improving the estimation of canopy light interception in wheat

liu Shouyang[1] (shouyang.liu@inra.fr), Baret Fred[1], Abichou Mariem[2], Andrieu Bruno[2], Martre Pierre[3]

[1] *CAPTE, INRA, Avignon, France*; [2] *EcoSys, INRA, AgroParisTech, Thiverval-Grignon, France*; [3] *LEPSE, INRA, Université Montpellier, Montpellier SupAgro, Montpellier, France*

Introduction

Crop growth models (CGMs) are promising tool for genotype to phenotype (G2P) predictions, which is of high interest for plant genetics and breeders. However, using CGMs for G2P prediction poses high requirements to capture the subtle differences between genotypes in response to the environment. To achieve that, ecophysiological processes in CGMs should be described with more biological realism. Among the ecophysiological processes, canopy light absorption is critical as it determines the energy accumulation by canopies for photosynthesis and transpiration. However, light interception modeling in CGMs remains empirical, thereby limiting their use for G2P prediction. The objective of this study was to improve the estimation of canopy light interception in wheat CGMs. Firstly, we reviewed the main approaches used in CGMs for computing the fraction of intercepted photosynthetic active radiation (PAR), FIPAR. Then, we investigated the distribution of leaf angle in wheat canopies grown in the field from digitalized three-dimensional (3D) canopies. Finally, we proposed a physics-based approach to model FIPAR that accounts for ellipsoidal leaf angle distribution and compared it with the approaches used in current wheat CGMs.

Materials and Methods

Experiments were conducted during the 2012-2013 growing seasons at Thiverval-Grignon, France. Five winter wheat cultivars with contrasted leaf stature were sown at a density of 200 seeds m^{-2} with two row spacing, either 17.5 or 35 cm. Canopies of each cultivars for the two row spacing treatments were digitalized at start of stem elongation) and flag leaf ligule just visible. Canopy structural traits, including green area index and average leaf angle, were derived from the 3D canopy. Then the 3D canopy was used as input of the Digital Plant Phenotyping Platform (D3P; Liu et al., 2019) to achieve the ground truth for the FIPAR over direct and diffuse condition, $FIPAR_{dir}$ and $FIPAR_{dif}$.

Results and Discussion

The main approaches used consider either a constant light extinction coefficient that range from 0.3 ($k_{0.3}$) to 0.6 ($k_{0.6}$) or a spherical leaf angle distribution (k_{sph}). Campbell et al. (1990) proposed an analytical expression of the ellipsoidal inclination distribution function and showed that FIPAR can be accurately modeled using this approach. However, to our knowledge this approach has never been used in CGMs. Therefore, we developed a simple model based on this approach either considering (k_{ell}^{*}) or not (k_{ell}) leaf clumping and compared it with the current approaches in wheat CGMs.

The leaf inclination angle distribution of the digitalized canopies was well described by an ellipsoidal distribution. The k_{ell}^{*} approach also provided accurate estimation of $FIPAR_{dir}$ over all the solar angles. Even without considering clumping effect, this approach outperformed the current approaches. Regarding $FIPAR_{dif}$, the k_{ell}^{*} and $k_{0.6}$ approaches performed the best, while the k_{ell} and k_{sph} approaches slightly overestimated $FIPAR_{dif}$.

Conclusions

The approach we proposed here to model FIPAR outperformed current approaches under most circumstances, while adding the feasibility to account for the actual leaf angle distribution. The main parameter of the ellipsoidal distribution model is the average leaf angle, which can be estimated in the field at high throughput for a large number genotypes (Liu et al., 2019). This study therefore will contribute to CGMs improvement but also to G2P prediction.

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Keywords: crop growth model improvement, ellipsoidal leaf angle distribution, light interception, wheat, FIPAR.

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S1-O.13

Crop modelling of maize growth and gas fluxes considering plant hydraulic conductance

Nguyen Thuy Huu (tngu@uni-bonn.de), Langensiepen Matthias, Gaiser Thomas, Hueging Hubert, Seidel Sabine, Ewert Frank

University Bonn, INRES, Bonn, Germany

Introduction

Leaf water potential (Ψleaf) and its critical thresholds (Ψthresholds) partially affect stomatal control of transpiration and differ for anisohydric (winter wheat) and isohydric (maize) plants. This phenomena has not yet been considered in crop models and tested under field conditions to characterize gas exchange and crop growth. The original LINTULCC2 crop model (Rodriguez et al., 2001) which calculates photosynthesis coupled with a stomatal conductance model was linked with Couvreur's root water uptake model (RWU) (Couvreur et al., 2014) and HILLFLOW 1D, a physically based water balance model (Bronstert and Plate, 1997) to explicitly represent whole plant hydraulic conductance (Kplant) and stomata regulation to water depletion through the use of Ψthresholds. The newly coupled model was able to simulate Kplant, gross assimilation rate (Pg), RWU, and soil water dynamics for winter wheat (Nguyen et al., 2019), but it has not been tested yet for isohydric crops like maize. This study investigates (i) whether the approach developed for winter wheat is also applicable to maize (ii) whether the simulations of crop growth and gas fluxes among plots with different water treatments and years can be improved when known parameters for anisohydric crops are adjusted to isohydric crops at field scale.

Materials and Methods

With the parameters Ψthresholds = -2 MPa and root hydraulic conductance Krs, normalized = 0.26 x 10-5 d-1 cm-1 cm^2 from winter wheat ("baseline parameters"), we calibrated the model for photosynthesis parameters based on maize field measurement of Pg, LAI, and crop biomass in the irrigated plot in 2017 (2017I). The model was then calibrated for Krs, normalized based on crop growth and gas fluxes from the rainfed plot with the first sowing date in 2018 (2018R1) to capture drought stress. The model was evaluated for the remaining plots (the rainfed plot in 2017 (2017R1); the irrigated plot with the first sowing date in 2018 (2018I); and the rainfed plot with late sowing date in 2018 (2018R2). A model sensitivity analysis was carried out with three Ψthresholds (-2.0, -2.6, and -1.5 MPa) and two Krs, normalizeds (baseline and calibrated Krs, normalized = 0.69 x 10-5 d-1 cm-1 cm^2).

Results and Discussion

Figure 1 shows the performance of the model after the calibration (Ψthreshold = - 2.0 MPa and the "calibrated" Krs, normalized). There is a satisfying agreement of simulated daily RWU with the sap flow measurements with an agreement index of 0.80, 0.86, and 0.66 for the 2017R1, 2018I, and 2018R2 plots, respectively. The model also showed a good performance in simulating dry matter and LAI. The model performed better for the plots with less soil water deficit (2017R1 and 2018I) than the drought plot (2018R2). Overestimation of RWU and Pg could be related to overestimation in soil water potential (SWP) in the soil profile because SWP is assumed horizontally homogeneous in soil layers.

Conclusions

The newly coupled model could be applied for maize representing an isohydric stomatal regulation, even if the species-specific parameters from anisohydric winter wheat are used. The simulations can be improved if winter wheat parameters are adjusted for isohydric maize. Future work might also require a finer spatial discretization in the perpendicular direction of the planting row that may improve the simulation of SWP heterogeneity for a wide-row crop like maize.

Acknowledgments

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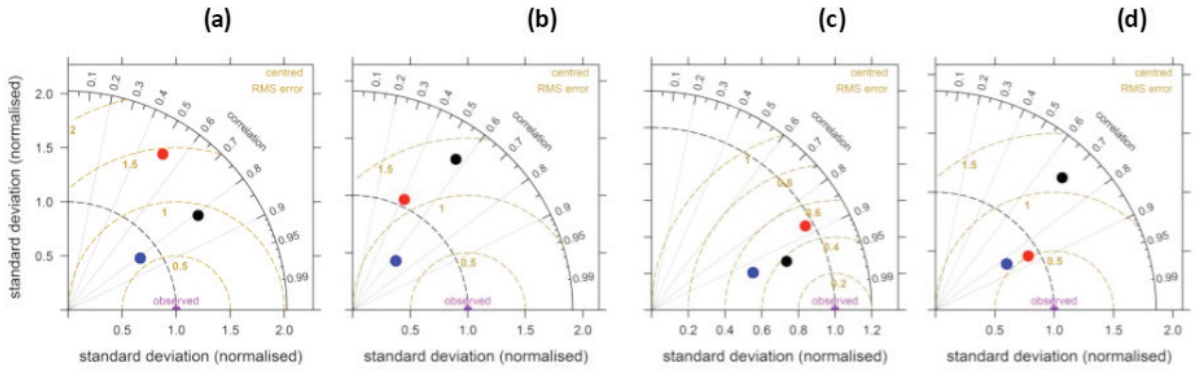

Figure 1. Model validation with the Taylor diagrams for different output variables (nomalised) (a) RWU, (b) gross photosynthesis rate, (c) biomass, and (d) LAI in different water treatments. The black, blue, and red closed circles denote for the rainfed plot in 2017 (2017R1), the irrigated plot with the first sowing date in 2018 (2018I), and the rainfed plot with late sowing date in 2018 (2018R2), respectively.

Keywords: anisohydric, drought, isohydric, model performance, transpiration.

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S1-O.14

Modelling maize leaf expansion under water limitations

Coussement Jonas R.[1] (Jonas.Coussement@UGent.be), Villers Selwyn[1,2], Nelissen Hilde[2], Inzé Dirk[2], Steppe Kathy[1]

[1] *Ghent University, Faculty of Bioscience Engineering, Laboratory of Plant Ecology, Ghent, Belgium;* [2] *Flemish Institute for Biotechnology (VIB), Technologiepark 71, Zwijnaarde, Belgium*

Introduction

Drought stress is one of the major limiting factors of maize yield worldwide and drought events are expected to only increase due to a changing climate. Understanding the response of maize to drought events is therefore crucial, as it affects many processes within the plant. Maize leaf expansion rate is one of the key processes impacting growth, yet there is currently no available model which realistically simulates the effect of water limitations on the different expansion zones within the leaf. Hence, we propose to introduce turgor-driven growth limitations on the leaf elongation model by Fournier *et al.* (2005) as a method to study the effect of drought during the different stages of leaf expansion.

Materials and Methods

The leaf elongation model by Fournier *et al.* (2005) describes the progression of three distinct cellular zones within a grass leaf, based on a combination of individual cell division, elongation, and cell differentiation from one zone into the next. The latter of these three factors is captured by specific parameters related to cell differentiation rate, but the first two factors are represented as fixed factors of relative elongation rate (RER). In reality, the RER of each of these zones will depend on the availability of water and the kinetics of the cell wall in each of these zones. This dependency was incorporated by introducing the Lockhart (1965) equation to represent leaf elongation in each zone. Further expansion of the model was done to incorporate turgor-driven kinetics in the transverse and normal direction of the leaf in order to fully capture the leaf expansion under water availability.

Results and Discussion

Theoretical simulations showed the models ability to simulate the diurnal patterns in wheat leaf elongation rate which can be observed in the field. A reduction in water availability was shown to interfere with the ability of the leaf to establish sufficient turgor. Depending on the timing of a short-term reduction in water availability, final leaf length can be drastically different due to the impact it has on cell differentiation at crucial times in the leaf's development. In the future, the model should be further supported by experimental data in which the progression of the different cell zones is monitored under different variations of drought stress. The model is built in such a way that it simulates the progression of leaf turgor, and thus expansion rate, in terms of sap flow and transpiration. As a result, it is compatible for usage in full plant models, such as functional-structural plant models, which want to specifically incorporate water limitations on plant growth.

Conclusion

A maize leaf expansion model is proposed which combines the contribution of water availability, cell wall kinetics, and leaf ontogeny. Using the established Lockhart (1965) equation, leaf expansion rate can be calculated in any dimension. This model can aid in studying the fundamental effects on drought stress severity and timing on leaf expansion rate. Alternatively, the parameters within the model would allow insight in which plant characteristics are most associated with drought-stress mitigation in terms of leaf expansion rate.

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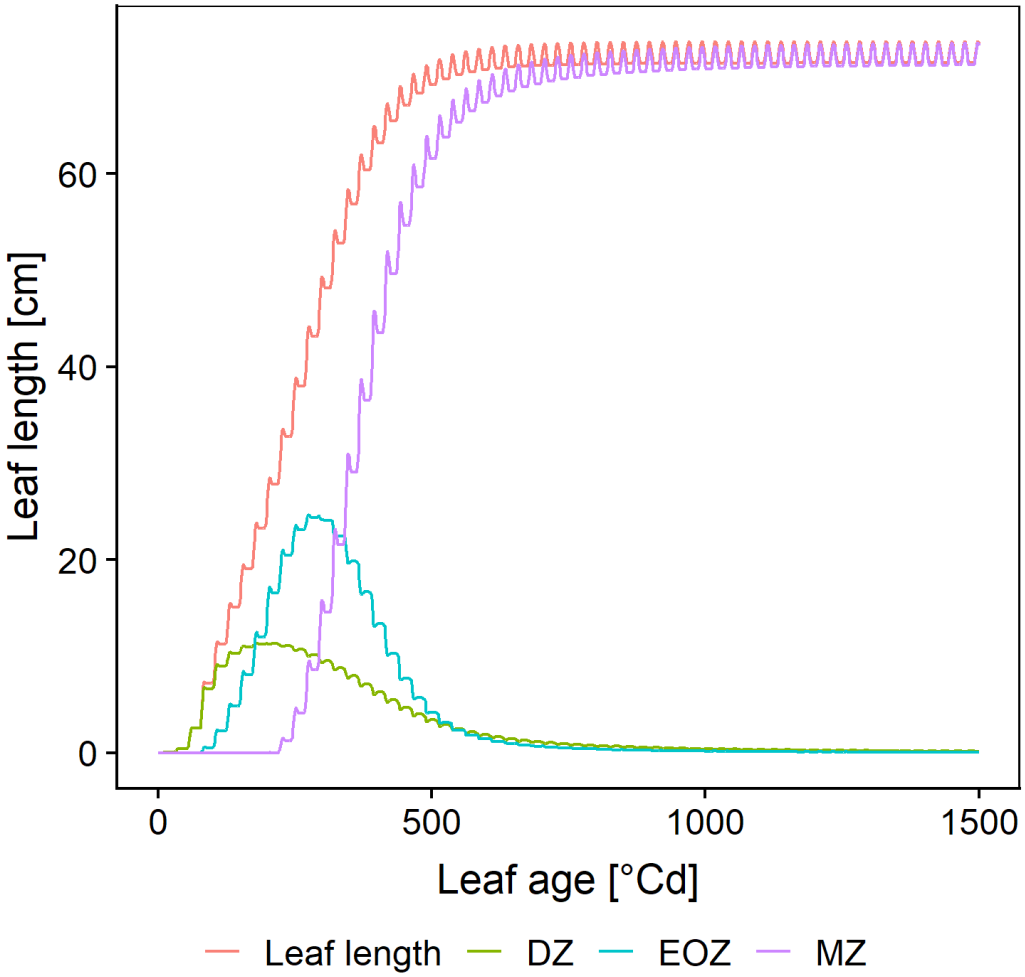

Figure: Progression of the leaf expansion model in terms of total leaf length and the respective length of the division zone (DZ), elongation-only zone (EOZ), and mature zone (MZ) in the leaf. Diurnal patterns of shrinkage and expansion are the result of a daily transpiration patterns which correspond to water loss within the leaf, which, in turn, results in a loss of turgor pressure and consequently elastic shrinkage.

Keywords: Drought, leaf elongation, turgor pressure, maize.

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S1-O.15

Modeling of climate change impacts on maize yields in low-nitrogen conditions in Africa

Falconnier Gatien (gatien.falconnier@cirad.fr), Corbeels M, Boote KJ, Ruane A, Whitbread AM, Adam M, Affholder F, Ahuja LR, Akinseye F.M., Alou IN, Amouzou KA, Anapalli S.S., Baron C, Basso B, Baudron F, Bertuzzi P, Challinor AJ, Chen Y, Deryng D, Elasayed ML, Faye B, Folorunso A, Gaiser T, Galdos M, Gayler S, Gerardeaux E, Giner M, Grant B, Hoogenboom G, Ibrahim ES, Justes E, Kamali B, Kersebaum KC, Kim SH, van der Laan M, Leroux L, Lizaso JI, MacCarthy DS, Maestrini B, Meier EA, Mequanint F, Ndoli A, Nendel C, Porter CH, Priesack E, Ripoche D, Sida T, Singh U, Smith W, Srivastava A, Sumit S, Tao F, Thorburn PJ, Timlin D, Traore B, Twine T, Webber H

Low-input Smallholder, AgMIP modelling team, International

Introduction

Smallholder farmers in sub-Saharan Africa (SSA) currently grow rainfed maize with limited inputs such as fertilizer. Maize is crucial for food security in SSA, and climate change may exacerbate current production constraints. Crop models can help quantify the potential impact of climate change on maize yields in these low-input systems. We performed a model intercomparison including 25 maize models to (i) evaluate their ability to predict observed yields in diverse cropping situations and (ii) test model responses to changing [CO_2], temperature and rainfall with different nitrogen (N) inputs (0, 80, 160 kg N ha-1). Models were calibrated with measured grain yield, plant biomass and N, Leaf Area Index, harvest index and in-season soil water content from two-year experiments in Benin, Mali, Ghana, Rwanda, Ethiopia. Soil Organic Carbon in the topsoil (0-30cm) was 0.28, 0.20, 0.57, 1.65 and 0.65% in Benin, Mali, Ghana, Rwanda, and Ethiopia respectively.

Results and Discussion

Calibrated models reproduced grain yield variations across sites and experiments well with average rRMSE of 26%. Two models did not simulate responses to N inputs, and hence the interaction between climate change and N input could not be analyzed. Three models simulated response to N inputs but without a daily N module. These models showed little or no interaction between N input and climate change, and a more variable response compared with the 20 models with a daily N module (Figure 1). The 20 models with a daily N module showed that when N was limiting (0 kg ha-1), maize (i) benefited less from an increase in atmospheric CO_2 concentration, (ii) was less affected by higher temperature (+4°C) or decreasing rainfall (50% of current), and (iii) was more affected by increased rainfall (150% of current) compared with higher N inputs (80, 160 kg N ha-1) (Figure 1). The simulations revealed that N inputs and soil N dynamics (e.g. leaching) play a crucial role in predicted climate change impacts.

Conclusion

More detailed crop field experiments are, however, needed to better understand how the interactions between N input and climate change operate in the real world. These interactions have strong implications for the design of robust adaptation practices to climate change across SSA, as farmers who intensify maize production with increased use of mineral fertilizer are likely to face different adverse effects of climate change.

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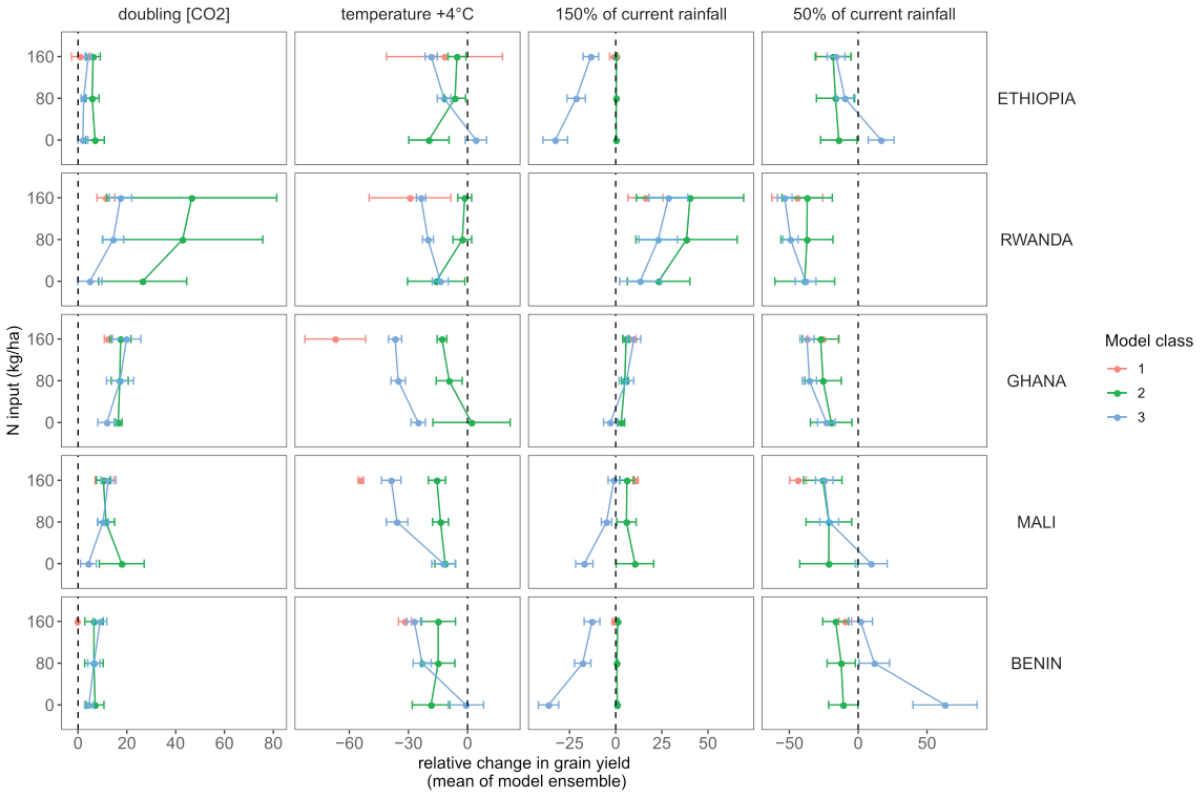

Figure 1: Mean (± SE) relative change in grain yield (compared with baseline climate) when doubling [CO_2], increasing temperature by +4°C, increasing and decreasing rainfall (150% and 50% of current) in five sites across sub-Saharan Africa and for three N inputs of 0, 80 and 160 kg N ha-1. Simulations are from maize models without simulation of a response to N input (class 1), with simulation of a response to N input without a daily N module (class 2) and with a daily N module (class 3).

S1-O.16

New modelling methodology for improving crop model performance under stress conditions

Droutsas Ioannis[1] (eegdr@leeds.ac.uk), Challinor Andy[1], Arnold Steve[1], Swiderski Mikolaj[1], Semenov Mikhail[2], Mikkelsen Teis N.[3], Hansen Emilie[4]

[1] *School of Earth and Environment, University of Leeds, Leeds, United Kingdom*; [2] *Rothamsted Research, Harpenden, United Kingdom*; [3] *Department of Environmental Engineering, Technical University of Denmark, Lyngby, Denmark*; [4] *Department of People and Technology, Roskilde University, Roskilde, Denmark*

Introduction

Crop models exhibit large uncertainty in the quantification of risks imposed to food production by climate change (Asseng et al., 2013). A significant step towards reducing this uncertainty is to improve model structure (Tao et al., 2018). Here, we present a new modelling methodology for improving crop model structure based on simultaneous solution of model equations. The new technique is called SEMAC (Simultaneous Equation Modelling for Annual Crops) and is implemented into the GLAM crop model, resulting in a new model version GLAM-Parti (i.e. GLAM Partitioning). The new model has improved structure, it gives a better connection between the model processes and leads to higher internal consistency. The model skill is significantly increased when tested under different stress environments (i.e. water and ozone stress).

Materials and Methods

SEMAC develops a system of simultaneous equations which accounts for all above-ground crop growth and development processes. It uses allometric relationships to connect the masses of all plant compartments, which allows the expression of above-ground biomass as function of leaf mass. SLA and daily biomass growth are set as function of LAI. This forms a system of equations with equal unknown variables which is solved simultaneously to return the values of all unknown variables. A detailed description of SEMAC as well as its incorporation into the GLAM crop model is given in Droutsas et al., 2019. Here, SEMAC is tested for its ability to capture stress due to water and ozone in turn.

Results and Discussion

GLAM and GLAM-Parti were tested for wheat under various levels of water stress and GLAM-Parti exhibited higher skill in all experiments. The total RMSE of GLAM-Parti was reduced by 45% for grain yield in comparison with GLAM (Fig. 1A). We tested the relative contributions of the simultaneous equation system and the model improvements and found that the model which had both (i.e. GLAM-Parti) improved upon the same model with sequential solution methodology (i.e. GLAM-Partiseq). The model calibration (i.e. GLAM-Partiseq-cal) can only partially but not fully compensate for the inconsistencies of the sequential method. In addition, ozone stress was tested under CEMAC using a new parameterisation for wheat, including the acclimation mechanism under chronic exposure to the pollutant. The model successfully reproduced the observed yield reduction under variable duration of exposure to ozone (Fig 1B).

Conclusion

SEMAC is a new modelling technique for the simulation of crop growth and development. Applying the methodology into a crop model overcomes structural limitations. The step-by-step way of solving the model equations is replaced by simultaneous solution. This provides higher internal model consistency and increases the model skill. In this study, GLAM-Parti improved upon GLAM in the simulation of wheat growth and yield in all levels of water stress. The model was also successfully tested for the effect of ozone on wheat yield. SEMAC could be applied in other crop models to see if similar improvements in skill result.

Acknowledgements

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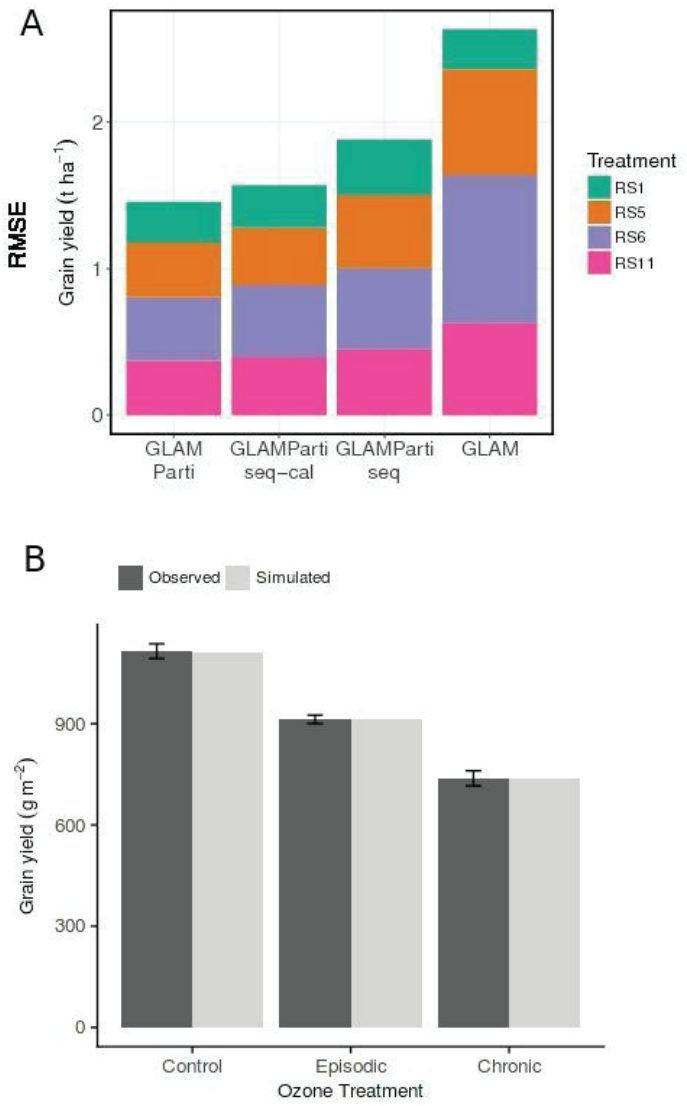

Fig. 1. A) Root mean square error (RMSE) between modelled and observed grain yield in the different water treatments: Control treatment (RS1), early drought treatment (RS5), late drought treatment (RS6), full drought treatment (RS11). Figure was extracted from Droutsas et al. 2019. B) Observed (wheat variety KWS Bittern) and simulated grain yield at harvest in Control, Chronic and Episodic O3 treatment. Error bars are standard errors of means in the observations.

Keywords: SEMAC, GLAM-Parti, Model improvement, Water stress, Ozone.

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S1-O.17

A new crop simulation model in DSSAT for Tef

Paff Kirsten (kirsten.paff@inra.fr), Asseng Senthold

Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States

Introduction

Tef (*Eragrostis tef* (Zucc.) Trotter) is an indigenous Ethiopian staple grain that provides food security and income for smallholders (Araya et al., 2011). Globally, tef is gaining popularity as fodder and a gluten free grain (Van Delden, 2011). Crop models simulate crop growth and yield under varying growing conditions. Our goal was to develop a comprehensive crop model for tef and to use that model to evaluate the performance of tef in comparison to wheat under varying growing conditions. Two tef models exist (Araya et al., 2010; Yizengaw and Verheye, 1994), but neither is suited for simulating N dynamics or photoperiod response.

Materials and Methods

The DSSAT NWheat model was used as a starting point for the new tef model, as DSSAT is a global modeling platform and NWheat has a robust structure that has been used across a wide range of growing conditions. NWheat was adapted to the short day C4 crop tef by altering the phenology, RUE, transpiration efficiency, and photoperiod and atmospheric CO_2 responses. These changes were based on observed tef data from ten locations in Ethiopia and the United States and other C4 crop models.

DSSAT-Tef and NWheat were used to simulate the effects of planting date, atmospheric CO_2, and N fertilizer on Ethiopian tef and wheat yields across a 30-year span (Paff and Asseng, 2019). Four Ethiopian locations were selected in major tef and wheat producing regions. The two sowing dates were July and June 1st. The CO_2 levels were 380 and 580 ppm. The four N rates ranged from 0 to 60 kg N ha-1. All treatments were rainfed with an average rainfall from 687 to 1662 mm.

Results and Discussion

DSSAT-Tef accurately simulated phenology and the observed response to changes in irrigation and N fertilizer. The grain yield RMSE of DSSAT-Tef was comparable to that of the existing tef models. DSSAT-Tef overestimated biomass. The model does not simulate biotic losses. Also, due to missing observed data, assumptions were made about the initial conditions and management practices.

Comparing observed yields showed that wheat consistently outperformed tef, but the simulations showed that tef could out yield wheat under marginal conditions. Wheat yields responded better to N fertilizer than tef yields (Fig. 1), due to wheat's higher HI. High rainfall reduced yields for both crops due to N leaching and planting early often resulted in more leaching. As a C3 crop, wheat was more responsive to higher CO_2 than tef, but in cases where N was limiting, wheat yields decreased in response to higher CO_2. Tef yields could be improved by breeding for lodging resistance and a higher HI, making tef more responsive to N fertilizer. Tef and wheat yields would be improved through more fertilizer and reduced leaching.

Conclusions

DSSAT-Tef can be used to evaluate tef growth and yields under different growing and management conditions, including different daylengths. Further research is needed to include a lodging routine and to verify the effects of elevated CO_2 on growth.

While wheat in general is higher yielding than tef, tef will remain an important part of Ethiopian agriculture, due to its ability to grow under marginal conditions and its higher cultural, nutritional, and economic value.

Acknowledgements

We thank B. Zaitchik for providing the CHIRPS weather data from Ethiopia and M. Eggen and N. Huth for providing access to tef field data. K. P. received funding from the University of Florida's Graduate Assistantship Program.

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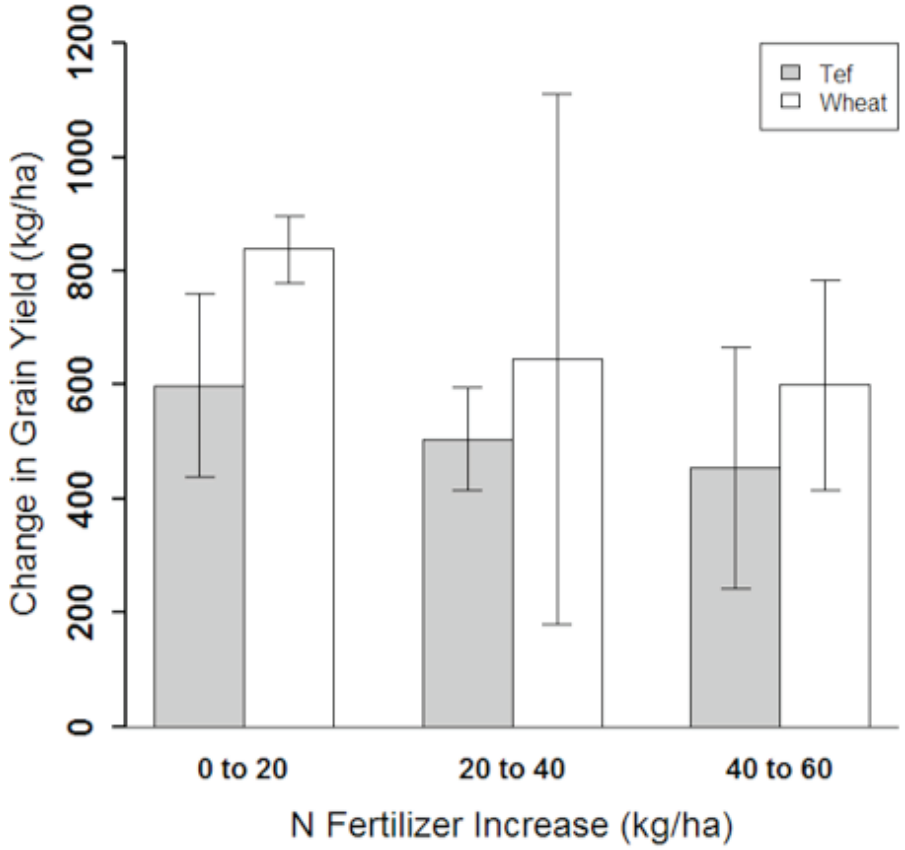

Figure 1. Simulated change in tef and wheat grain yield in response to increasing N fertilizer applications (0 to 20 kg N/ha, 20 to 40 kg N/ha, and 40 to 60 kg N/ha) averaged across all four locations. The error bars represent the mean +/- one standard deviation.

Keywords: Eragrostis tef (Zucc.) Trotter, Crop Modelling, Teff, Ethiopia.

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S1-O.18

Improving the CROPGRO perennial forage model for ability to simulate fall dormancy classes of Alfalfa cultivars

Boote Kenneth[1] (kjboote@ufl.edu), Malik Wafa[2], Ottman Michael[3], Torrion Jessica[4], Kisekka Isaya[5], Hoogenboom Gerrit[6]

[1] *Agric. and Biol. Engr. Dept., University of Florida, Gainesville, FL, United States*; [2] *CITA, Zaragoza, Spain*; [3] *University of Arizona, Maricopa, AZ, United States*; [4] *University of Montana, Bozeman, MT, United States*; [5] *University of Californa, Davis, CA, United States*; [6] *University of Florida, Gainesville, FL, United States*

Introduction

The CROPGRO Perennial Forage Model, released with DSSAT V4.7 software, is capable of predicting herbage harvests, herbage protein, and re-growth over multiple seasons for perennial forage grasses (*brachiaria* and *cynodon,* Pequeno et al., 2018), and alfalfa (*Medicago sativa*, Malik et al, 2018). The model has substantially modified code from the annual CROPGRO model, and includes a storage organ (rhizome, taproot, crown) with carbohydrate and N storage pools that provide the ability for re-growth despite zero leaf area index caused by harvest or freeze-loss of all leaf tissue (Rymph, 2004). Nevertheless, depletion of reserves from poor management and repeated defoliation and freeze damage can cause poor recovery and loss of the forage stand. The "species" file of the model includes rules for fall dormancy (FD), freeze thresholds, partitioning as a function of V-stage and daylength, re-growth, productivity, mobilization of carbohydrate and N from storage pools to drive re-growth, and re-fill of storage pools. The values of these parameters can be varied to mimic genetic variation among cultivars and dormancy classes.

Materials and Methods

Weekly growth data were collected on three FD-type cultivars grown in field experiments under two contrasting climates in Arizona and Montana, USA. We parameterized species relationships to improve cultivar performance for three FD type cultivars while maintaining good performance for the Spanish cultivar on which the original model was adapted.

Results and Discussion

Parameters of photosynthesis related to temperature response (base temperature as well as minimum night temperature effect) were modified to improve the contrast between Arizona and Montana (warm versus cool). Rate of leaf appearance was calibrated based on new data as there had been no prior data available. The parameterization of temperature effects on leaf area expansion were slightly re-calibrated to reduce leaf area expansion at low temperature to match the specific leaf area and leaf area index (LAI) differences across sites. In addition, partitioning to stem was increased and that to root was decreased to improve the percentage leaf and stem in the outputs.
The most important modification was varying the critical daylength (9.8 hr) at which allocation to storage taproot is most rapid (and less to shoot) and the opposing critical daylength (14.2 h) at which allocation is least rapid (more to shoot). In addition, the relative "strength" of daylength-driven partitioning to storage (RDRMT) was varied for the dormancy classes, with RDRMT of 0.500, 0.320, and 0.140 for FD 3, 6, and 10, respectively. These two features (daylength effect and its strength), along with minor variation in leaf photosynthesis (per FD) allowed productivity to vary across the FD classes 3 (Rugged), 6 (Cisco II), and 10 (CUF 101), as observed in the growth analysis data. The genetic potential light-saturated leaf photosynthesis was set at 1.32, 1.38, and 1.46 mg CO_2 m^{-2} s^{-1} for FD classes 3, 6, and 10, respectively. Simulated shoot mass (Figure 1) nicely shows FD differences of the three cultivars for the Arizona and Montana sites after calibration. The CROPGRO-Alfalfa model continues to perform well for the original Spanish data sets.

Conclusions

The CROPGRO Perennial Forage Model has been improved upon the original adaptation for alfalfa growth in Spain, and appears to work well for fall dormancy classes of cultivars grown in Arizona and Montana.

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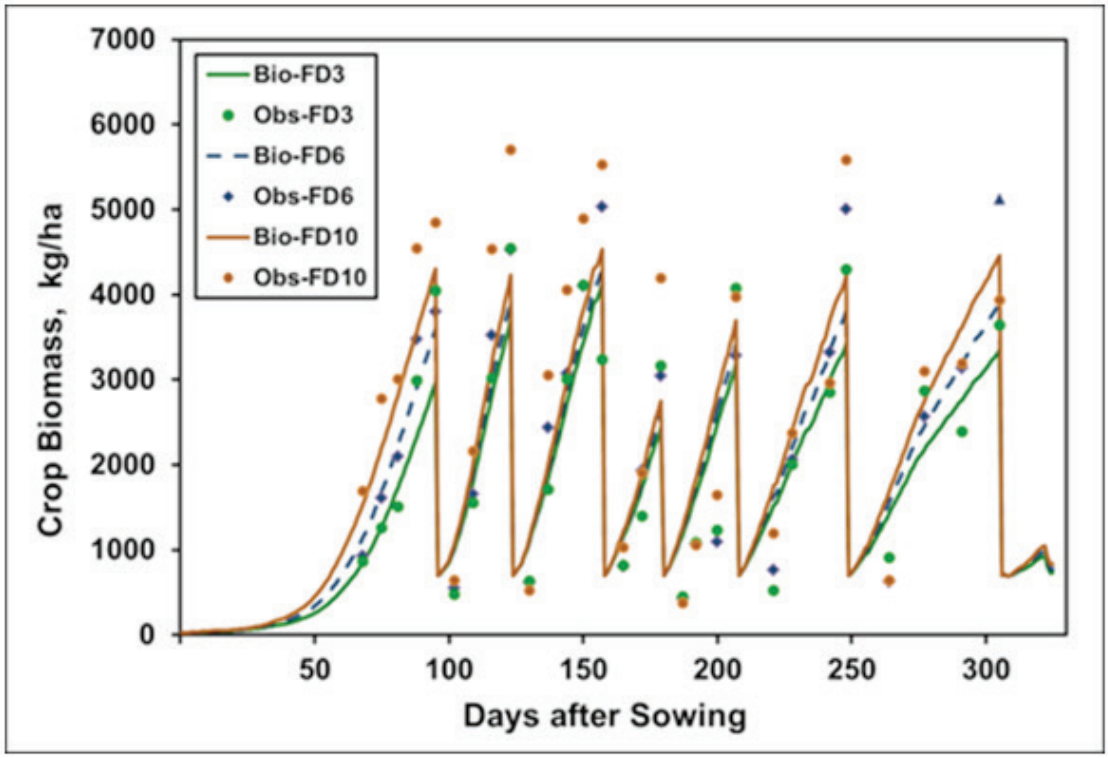

Figure 1 - Comparison between CROPGRO-Alfalfa simulated shoot biomass (lines) and observed shoot biomass (symbols) for fall dormancy classes 3, 6, and 10 at Arizona site in 2018 (RMSE=689 and d-stat=0.918 for shoot biomass).

Keywords: Regrowth, Leaf area index, Biomass.

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S1-O.19

When would simulating temperature at the leaf-layer scale improve crop model performance? Conclusions from a wheat model

Albasha Rami[1] (rami.albasha@itk.fr), Manceau Loïc[2], Martre Pierre[2]

[1] *ITK, Clapiers, France*; [2] *LEPSE, INRA, Montpellier, France*

Introduction

Modelling solutions are increasingly used to project the impact of climate change on crop yield production. Recent model inter-comparison studies have revealed however that strong uncertainties rely in yield predictions but also that there is space for reducing these uncertainties by improving crop temperature simulation.

Materials and Methods

We examined in this work whether calculating canopy temperature using a multi-component Penman-Monteith solution (Monteith, 1965) following Lhomme et al. (2013) would improve temperature prediction results in Sirius-Quality2 model (Martre et al., 2006) compared to the commonly used one-component Penman solution (Penman, 1948). We explored further whether decomposing the canopy into sunlit and shaded leaves fractions (Goudriaan and van Laar, 1994; de Pury and Farquhar, 1997) would bring further improvements to temperature predictions. That is, we examined 5 distinct modelling solutions as shown in Figure 1 (left column). The modeling solutions were evaluated using a dataset of hourly net radiation, latent, sensible and soil heat flux densities, and canopy temperature, collected in a free-air CO_2 enrichment experiment at Maricopa, Arizona, USA with different nitrogen fertilizer and irrigation scenarios. Simulated canopy and leaf to air temperature (Tc - Ta) and crop evapotranspiration (ET) were compared between the different modeling solutions.

Results and Discussion

The results indicate that multi-component Penman-Monteith solution reduced error predictions of Tc compared to the Penman solution (mid column in Figure 1). However, the multi-component solution tended to underestimate high temperature values (rows b, c and d in Figure 1) and this trend was only offset when the canopy was decomposed into sunlit and shaded leaves fractions (row e in Figure 1). Finally, our results indicated that canopy evapotranspiration predictions were improved regardless of canopy composition using the multicomponent solution regardless of canopy composition (right column in Figure 1).

Conclusions

We conclude that replacing the commonly used Penman solution by a multicomponent Penman-Monteith solution for simulating canopy temperature is only sound when canopy sunlit and shaded leaves fractions are considered separately.

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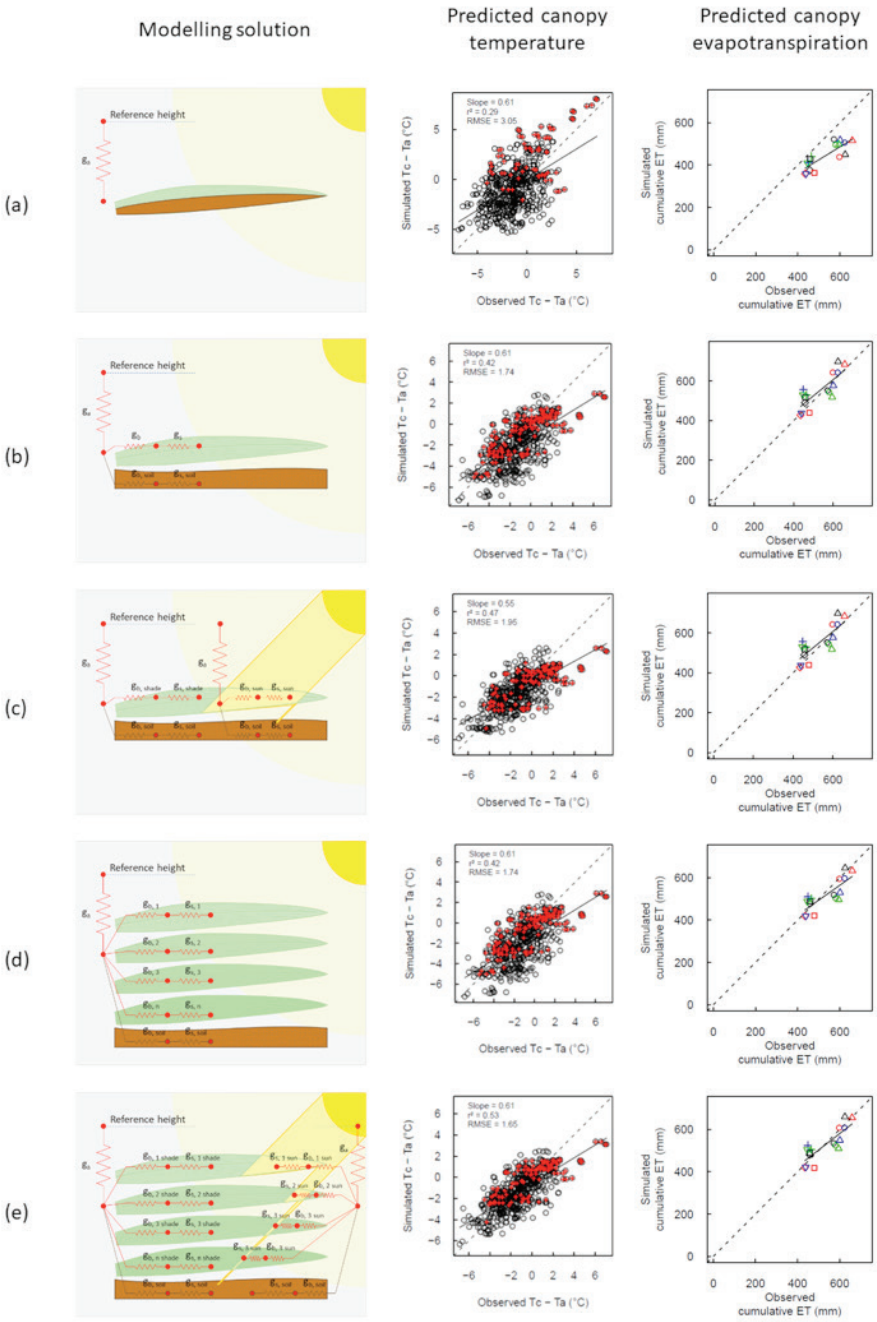

Figure 1: Illustration of the different modelling solutions. ga is the aerodynamic resistance, gb is the boundary layer resistance, and gs is the surface resistance. “sun” and “shade” indices refer to sunlit and shaded leaves fractions, respectively.

Keywords: Energy balance, sunlit-shaded leaf classes, wheat.

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S1-O.20

Phosphorus calibration in Century model for a French agricultural context

Naves Maschietto Gabriela*[1] (gabriela.naves-maschietto@veolia.com), Chen Yaxian[1], Bisinella-De-Faria Ana-Barbara[2], Orvain-Jouault Marie[2], Jaffrezic Marie-Pierre[1], Chenu Damien[2], Poitrenaud Maelenn[3], Le Stum Jacques[4], Albuquerque Maria[2]

[1] *Veolia Research and Innovation, Maisons-Laffitte, France*; [2] *Veolia Research and Innovation, Limay, France*; [3] *SEDE, Cergy, France*; [4] *SEDE, Arras, France*

Introduction

French agriculture largely used mineral fertilizers (*nitrogen* (N), *phosphorus* (P) and *potassium* (K)) in order to ensure their availability to crops. Today, the French context reinforces the interest of waste organic products valorization in agriculture, because they enriche the soil of organic matter (OM) while contributing to crops fertilization. It is important, however, to master the prediction of OM long-term evolution and nutrients availability throughout crop development.

The modified Century simulation model (Parton et al., 2019) predicts carbon, N, P and K dynamics in soil and plant systems. In order to confirm Century's predictions for the French context, the model must be calibrated and validated. It is important because the simulated results are far from the observed data and some model input data have no direct value since some aspects of the reality are not measurable. (Yebli et al., 2017) proposes a first calibration by considering data from three field trials. To improve their calibration, this work proposes a more efficient approach to explore parameters values. In addition, data from two new fields are considered.

Materials and Methods

The calibration aims to determine values for 12 parameters in order to minimize Century's P prediction error. Five field trials data are considered and represent 44 scenarios: 34 used for calibration and 10 for validation.

A surrogate function is considered in order to reduce simulation calls, facilitating tests of different parameter value sets. In this approach, the P prediction error is computed in less than one second. The surrogate function is initially defined based on Latin hypercube sampling. This method represents well the exploration domain with a limited number of samples. Each sample is represented by a set of parameter values and by a prediction error value. The best solution available in the samples set starts the optimization procedure that seeks to minimize the P prediction error.

Results and Conclusion

The Century's prediction error of P in soil is reduced by an average of 32.5% without significantly affecting other nutriment soil-plant dynamics errors. Figures 1.a and 1.b show the P content in soil for two validation scenarios. The violet dots are the measured data, the orange and green curves are the results predicted by, respectively, the model previously calibrated and the model calibrated in this work. Observation data dynamics are better represented by the solutions obtained with the new set of parameter values.

Acknowledgements

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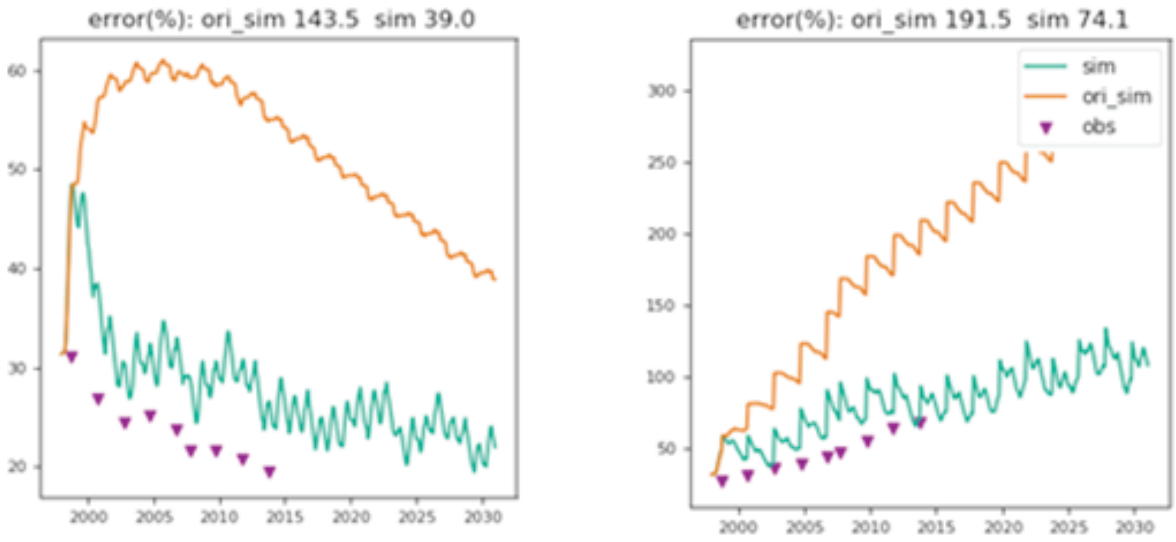

a) control plot with low nitrogen fertilization

b) plot with mud compost and green waste amendment with low nitrogen fertilization

Figure 1: P content in soil, results of model calibrated in 2017 (orange), and in 2019 (green).

Keywords: Optimization, Compost, Fertilizers, Prediction error.

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S1-O.21

Can we learn from experiences in physics to improve crop models?

Yin Xinyou (Xinyou.yin@wur.nl), Struik Paul

Centre for Crop Systems Analysis, Wageningen University & Research, Wageningen, The Netherlands

Major crop models were developed several decades ago and many of their algorithms are (semi-)empirical. These models may need improving to face new challenges in crop science (Boote et al., 2013), such as how to handle genotype-environment-management (G×E×M) interactions. However, opinions differ on how to improve crop models. In the wake of the success of -omics sciences, many propose a bottom-up approach, trying to assemble all biological elements from genome up to crop level (e.g. Chew et al., 2017). The danger of this approach is that models become increasingly clumsy in modelling complex traits of the crop level: even small errors, which seem to occur inevitably along biological scales, accumulate to an extent that the aggregated model is probably less accurate than existing crop models.

Crop yield formation results from complex feedback, feedforward, and regulation mechanisms along both temporal and spatial cascades of the crop, and these mechanisms engender multiple complex interactions such as G×E×M interactions. We argue that to capture these interactions in a simple yet accurate manner, crop modellers should learn from experiences in physics. Physicists, such as Albert Einstein, used sound theories and solid mathematics in thought experiments, and came up with seemingly simple equations (such as $E = mc^2$) to explain the behaviour of sub-atomic particles and (parts of) the universe. These equations show that there is beauty, simplicity, and regularity, at every level, from the smallest particles to the largest clusters of galaxies.

Likewise, a crop as a system is a masterpiece. Its growth involves many interacting yet contrasting elements (such as carbon and nitrogen, source and sink, shoot and root, structure and reserves), and each of these contrasts plays a part in forming the regularity and symmetry of the crop. Some of the biological mechanisms underlying this regularity and contrast are quantified, whereas others are yet to be quantified or even totally unknown. We will outline examples, where biological insights and mathematical analytics are combined to derive simple equations that apply to different biological levels. Our experiences here suggest that numerically incorporating every detail of underlying biology *per se* into a crop model is not always necessary because the biological details are already considered in steps for mathematical derivations of the end equations.

The essence of this metaphysically based crop modelling approach is *beauty*, *simplicity* and *robustness*. The advantages of the approach are multi-fold: (i) principles of classical crop physiology can still be explored as overarching guidelines (as used in conventional crop models), yet new biological understandings are introduced to the models in a modular manner; (ii) a clumsy, excessively numerical, modelling approach can be avoided; and (iii) models integrating those known equations can be used to generate hypotheses to assist the unravelling of the unknowns. This approach is a hindsight reflection of our experiences in developing the crop model GECROS (Yin and Struik, 2017). The model applications in both up- and down-scaling between leaf photosynthesis and crop yield (Gu et al., 2014; Yin and Struik, 2015), and emerging properties from these scaling analyses, will be illustrated.

Keywords: metaphysically-based modelling, beauty, simplicity, regularity.

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S1-O.22

Why do crop models diverge substantially in climate impact projections?

Tao Fulu[1] (fulu.tao@luke.fi), Palosuo Taru[1], Rötter Reimund P.[2], Díaz-Ambrona Carlos Gregorio Hernández[3], Mínguez M. Inés[3], Semenov Mikhail A.[4], Kersebaum Kurt Christian[5], Cammarano Davide[6], Specka Xenia[5], Nendel Claas[5], Srivastava Amit Kumar[7], Padovan Gloria[8], Ferrise Roberto[8], Martre Pierre[9], Rodríguez Lucía[3], Ruiz-Ramos Margarita[3], Gaiser Thomas[7], Höhn Jukka G.[1], Salo Tapio[1], Dibari Camilla[10], Schulman Alan H.[1]

[1] *Natural Resources Institute Finland, Helsinki, Finland*; [2] *Georg-August-University of Göttingen, Göttingen, Germany*; [3] *Universidad Politécnica de Madrid, Madrid, Spain*; [4] *Rothamsted Research, Herts, United Kingdom*; [5] *Leibniz Centre for Agricultural Landscap, Müncheberg, Germany*; [6] *The James Hutton Institute, Dundee, United Kingdom*; [7] *University of Bonn, Bonn, Germany*; [8] *University of Florence, Florence, Italy*; [9] *Univ. Montpellier, INRA, Montpellier Sup, Montpellier, France*; [10] *University of Florence, Firenze, Italy*

Introduction

Robust projections of climate impact on crop growth and productivity by crop models are key to designing effective adaptations to cope with future climate risk. However, current crop models diverge strongly in climate impact projections (Asseng et al., 2013, 2015). Previous studies tried to compare or improve crop models regarding the impact of one single climate variable (Asseng et al., 2013, 2015; Wang et al., 2017; Durand et al., 2018). However, this approach is insufficient, considering that crop growth and yield are affected by the interactive impacts of multiple climate change factors and multiple interrelated biophysical processes.

Materials and Methods

Here, a new comprehensive analysis was conducted to look holistically at the reasons why crop models diverge substantially in climate impact projections and to investigate which biophysical processes and knowledge gaps are key factors affecting this uncertainty and should be given the highest priorities for improvement. First, eight barley models and eight climate projections for the 2050s were applied to investigate the uncertainty from crop model structure in climate impact projections for barley growth and yield at two sites: Jokioinen, Finland (Boreal) and Lleida, Spain (Mediterranean). Sensitivity analyses were then conducted on the responses of major crop processes to major climatic variables including temperature, precipitation, irradiation, and CO_2, as well as their interactions, for each of the eight crop models.

Results and Discussion

The results showed that the temperature and CO_2 relationships in the models were the major sources of the large discrepancies among the models in climate impact projections (Figure 1). In particular, the impacts of increases in temperature and CO_2 on leaf area development were identified as the major causes for the large uncertainty in simulating changes in evapotranspiration, above-ground biomass, and grain yield (Figure 1). Our findings highlight that advancements in understanding the basic processes and thresholds by which climate warming and CO_2 increases will affect leaf area development, crop evapotranspiration, photosynthesis, and grain formation in contrasting environments are needed for modelling their impacts.

Conclusions

We indicated that the temperature and CO_2 relationships in the models were the major sources of the large discrepancies among the models in climate impact projections. In particular, the impacts of increases in temperature and CO_2 on leaf area development were identified as the major causes for the large uncertainty in simulating changes in evapotranspiration, above-ground biomass, and grain yield.

Acknowledgements

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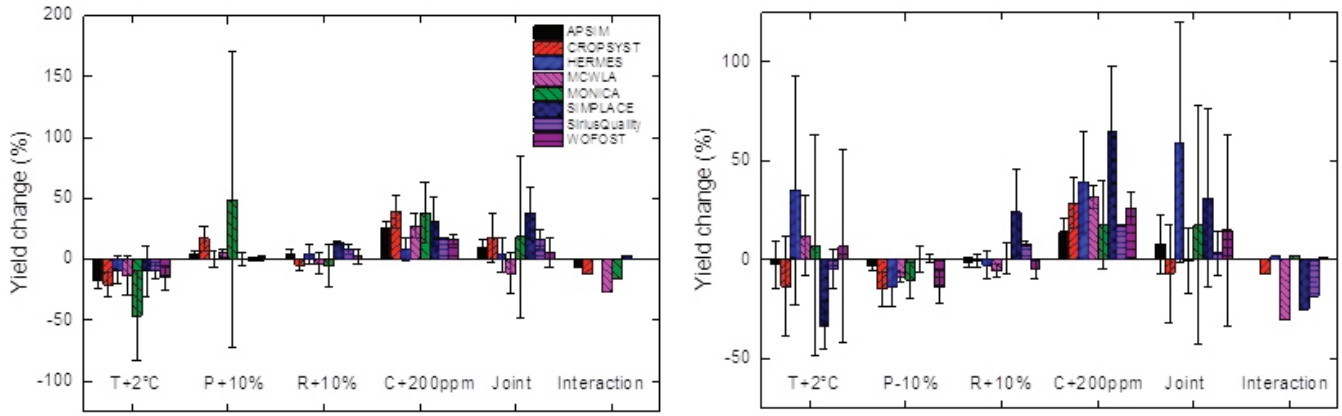

Figure 1. Simulated yield responses to changes in temperature, precipitation, solar radiation, and CO_2, singly or in combination, as well as their interactions, by eight crop models at Jokioinen (a) and Lleida (b).
The error bars represent the standard deviations of estimates based on the 30 years simulation results.

Keywords: Agriculture, climate change, crop growth simulation, model improvement, uncertainty.

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S1-O.23

Towards simulation-modeling of rice crop lodging

Dingkuhn Michael[1] (michael.dingkuhn@cirad.fr), Laza Ma Rebecca[2], Shestha Suchit[3]

[1] *Umr AGAP, CIRAD, Montpellier, France*; [2] *Rice C4 project, IRRI, Los Banos, Philippines*; [3] *Nepal liaison, IRRI, Kathmandu, Nepal*

Introduction

Field lodging of rice, a major yield reducing factor, occurs when a tall and/or heavy crop is exposed to wind forces and/or wetting by rains, particularly during grain filling. Crop models would be useful if they can predict (1) varietal lodging resistance (LR) from phenotype and eventually, genotype; and (2) cultivar-specific lodging risks as they depend on climate and crop management factors.

Materials and Methods

Field studies on genotypic LR were conducted in the Philippines using the Blaster, a new mobile device generating a 1-m wide wind channel and simulated rain (Shrestha et al., 2020). Twenty contrasting, transplanted rice genotypes were observed for lodging response to Blaster at 3 wind speeds (30, 45, 60 km/h), and compared with morphological and chemical crop traits studied in 2 dry seasons (DS). Validation for a subset of height cultivars was done for natural lodging in two wet seasons (WS) over three sowing dates.

Crop model SAMARA (Kumar et al. 2016 & 2017) was adapted to simulate LR dynamics using stem vigor (stem dry wt / length), plant height, vegetative biomass and panicle wet wt. Cumulative lodging incidence was simulated daily as an empirical function of current crop LR and wind x rain exposure. SAMARA simulates the plasticity of plant morphology as affected by competition among plants and among organs in variable resource and spacing situations, representing simplified crop architecture.

Results and Discussion

The experimental results were presented in more detail by Shrestha et al. (2020) whereas the modelling work is unpublished. Induced lodging was generally irreversible. Bending moment (BM) of stem base explained ~50% of genotypic variation in LR, and stem diameter explained 46% of BM. Lodging resistance index (LRI = BM / [plant height * weight]) explained 75% of Blaster-induced lodging. Effects of stem chemical traits on LR were significant but weaker than effects of morphology. Lodging induced by Blaster in DS was highly correlated with natural lodging in WS ($P<0.01$), the lower Blaster wind speeds being most predictive.

The LR state variable predicted by SAMARA follows the concept of LRI (see above). When calibrated on 2014 phenology and morphology, the LR simulated for mid grain filling stage correlated well with Blaster-induced lodging for 2014 (Fig. 1, top) and for the validation data set for 2015 (bottom), particularly for 30 km/h Blaster treatment. One of 20 genotypes (V18) lodged much more in 2015 than in 2014, causing poor correlations at high Blaster wind speeds. Preliminary results (not shown) indicate that SAMARA could predict genotypic differences in natural lodging for 2014 WS (which was affected by a tropical storm during grain filling), but not for 2013 WS (which was not affected by a storm).

Acknowledgements

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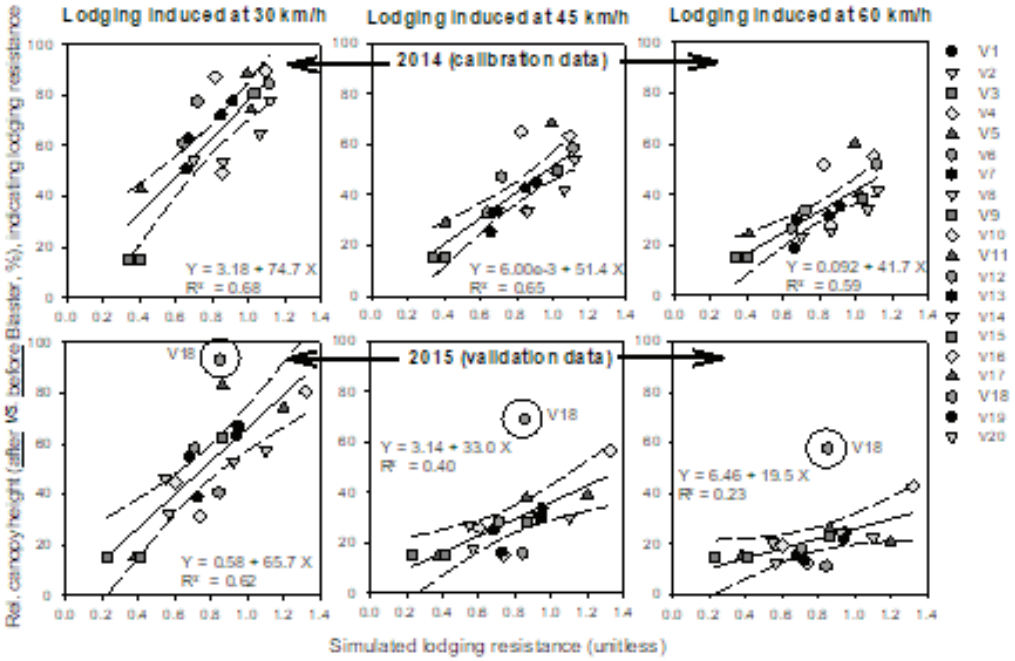

Figure 1. Lodging resistance as observed by Blaster treatment (Y) vs. simulated lodging resistance (X), for three Blaster wind speeds (left to right), two years (top, bottom) and 20 genotypes.

Keywords: Oryza sativa L., stem lodging, Blaster, SAMARA model, stem stability traits.

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S1-O.24

Characterization of spatiotemporal changes in drought occurrence over Mali sorghum growing areas using modeling approach

Diancoumba Madina[1] (m.diancoumba@cgiar.org), Kholova Jana* (J.Kholova@cgiar.org)[2], Adam Myriam[3], Vadez Vincent[4], Hammer Graeme[5]

[1] *Crop Physiology, Icrisat, Bamako, Mali*; [2] *Crop Physiology Laboratory, Icrisat, Patancheru, India*; [3] *CIRAD, Bobo, Burkina Faso*; [4] *IRD, Montpellier, France*; [5] *University of Queensland, Brisbane, Australia*

Introduction

Drought stress is a prevalent feature of semi-arid tropical climates which often reduces crops yield but its frequency of occurrence, type and effect on yield remains largely not characterized (Kholova et al., 2013). In West Africa, understanding the prevailing genotype-by-environment (G×E) interactions remains a limitation for targeting the suitable crop cultivars to environmental context which could enhance crop production and resilience. The complexity of such interactions over time and space remains a challenge this study tackles using crop simulation modelling to follow up plant growth and development and derive a water stress index over the seasons.

Materials and Methods

For this, we chose the APSIM-sorghum platform where we attempted to parameterize 3 genotypes typically grown in the main Mali sorghum production belt (Sahelian, Sudanian and Guinean zone represented by (CSM63E, CSM335 and IS15401, respectively). To sensibly reflect these photoperiod sensitive genotypes into APSIM we enhanced the released v.7.6 with algorithms re-constructing canopies based on the individual leaf area (ILA) (Van Oosterom et al., 2001) instead of the total plant leaf area (TPLA) function (Hammer et al., 2010).

The model was consequently run for CSM63E and CSM335 across the Malian sorghum production belt – i.e. 22 locations with available historical weather records resulting in 1059 simulations. These simulations were used to reconstruct the agronomic crop performance as well as the crop water use dynamics during the season using the indicator of water stress [soil water supply/plant water demand; S/D].

Results and Discussion

ILA function had mechanistically captured the changes in canopy size due to changes in crop-phenology depending on photoperiod and corresponded much closely to observed values. Nevertheless, implemented ILA algorithms could reproduce the canopy growth of the crop only up to 26 leaves and more observations are needed to validate the drafted algorithms for crops with higher leaf numbers.

Water stress trajectories were clustered into the distinct stress scenarios across the geographies-crop-soil-season combinations and the frequency of occurrence of seasons belonging to particular scenario was expressed; (i) scenario with no-stress , (ii) an early pre-flowering terminal stress and (iii) a drought stress with onset around flowering. Generally, the no-stress scenario was most frequent in between the Sudano-guinean zone and confirmed that water deficit was not the major limiting factor to limiting production of tested genotypes in these regions. On the other hand we found occurrence of water stress scenarios in the Sahelo-sudanian zone was much higher as compare to the Sudano-guinean zone and that points out the need of identifying genotypes that segregate the water conservative traits such as transpiration efficiency that was found to positively impact crop production.

Conclusions

The established framework lays the base for further testing the crop production limitations and so could help prioritizing the integrated crop improvement strategies.

Acknowledgements

GLDC, US-AID (resilient sorghum).

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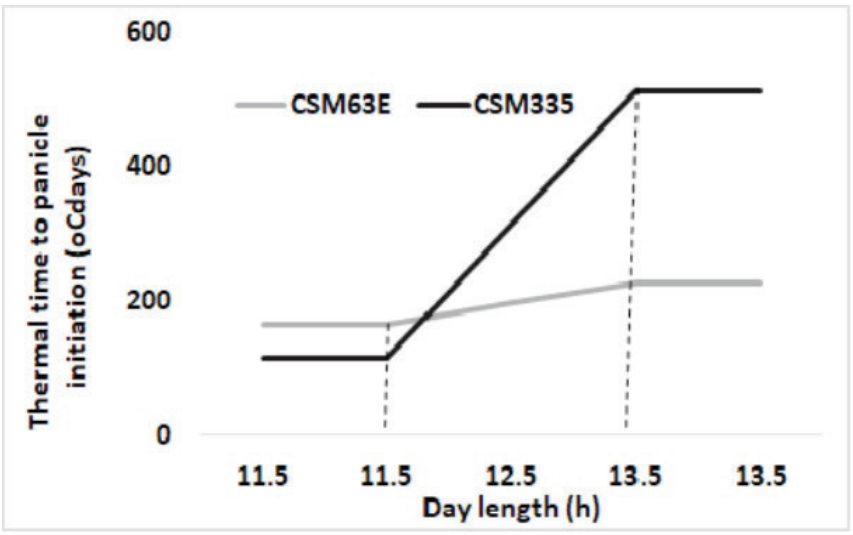

Figure 1. Relationship between day length and the accumulated thermal from end-juvenile phase to panicle initiation.

Keywords: Sorghum production, GxE interaction, APSIM model, Drought stress, Characterization.

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Challenges and new opportunities for crop-soil systems modelling

Wang Enli[1] (Enli.Wang@csiro.au), Brown Hamish E.[2], Hunt James[3], Zhao Zhigan[1], He Di[1], Bloomfield Maxwell T.[3], Oliver Yvette[4], Zheng Bangyou[5], Huth Neil[6], Hyles Jessica[1], Trevaskis Ben[1]

[1] *CSIRO Agriculture and Food, Canberra, ACT, Australia*; [2] *Plant & Food Research Limited, Christchurch, New Zealand*; [3] *Animal, Plant and Soil Sciences, La Trobe University, Melbourne, VIC, Australia*; [4] *CSIRO Agriculture and Food, Perth, WA, Australia*; [5] *CSIRO Agriculture and Food, Brisbane, QLD, Australia*; [6] *CSIRO Agriculture and Food, Toowoomba, QLD, Australia*

Crop modelling has been increasingly recognised as an effective means to assist in crop design, in-field tactical management decisions, and policy development to increase productivity and sustainability of agricultural systems in response to climate and global change. The widening areas of model applications demand crop modelling to correctly capture biophysical interactions at scales from gene, organ, crop to soil-plant systems. This requires further development of current models to capture down-scale processes (e.g. genetic controls) and up-scale responses at systems level (e.g. response to soil-climate change). We then face the challenge that any down-scaling would likely involve additional parameters that could introduce difficulties for up-scale predictions across environments. For example, a model with more detailed organ-level processes linking to underlying genetic controls would have more parameters not readily available for widely used cultivars; a model with a key focus of crop physiology but neglecting the importance of soil processes could lose robustness for crop yield response predictions across contrasting soil, climate and management conditions.

Here we use the development of APSIM model as an example to show how we deal with such challenges and create new research opportunities in the process of model improvement. One example is improved modelling of flowering time of wheat, through redesigning the crop phenology model in APSIM to better capture the impact and interactions of vernalisation, photoperiod and thermal time on development towards flowering, which enables derivation of model parameters under controlled environments and further links to molecular marks of the genotypes. This can potentially lead to a step improvement in modelling flowering time of wheat and rapid parameterisation of new released cultivars. The second example shows how improved modelling of soil-crop interactions enables accurate simulations of crop growth dynamics and yield across a wide range of environments. This creates new opportunities for using readily available crop measurements to inversely predict soil functional properties that are difficult to measure, e.g. plant available water holding capacity (PAWC) of soils, which in turn further contributes to improved modelling of soil and crop processes, including crop yield, C&N cycling, N leaching and greenhouse gas emissions. These examples demonstrate crop-soil systems models with scientific vigour enable new opportunities to be created to better address productivity and sustainability issues in the new digital era.

Keywords: model improvement, wheat, flowering, soil PAWC, APSIM.

ABSTRACTS PARALLEL SESSIONS

SESSION II

CROP MODELLING FOR ECOLOGICAL INTENSIFICATION

Ecological intensification aims to harness ecological functions and subsequent ecosystem services to sustain agricultural production while minimizing adverse effects on the environment. Crop models can help in the design and evaluation of ecologically intensive cropping systems, whilst increasing our understanding of the underlying ecological process dynamics. Presentation and discussion of such models is the topic of this session. We invite contributions that show recent advances in modelling:

1. intercropping and agroforestry systems and their ability to use land, water, nutrients, and biodiversity more efficiently;
2. crop-weed competition and pest and disease damage to crops;
3. emergent patterns and processes that result from crop diversification, including a greater ability to suppress weeds and pest outbreaks or greater resilience to weather variability and extreme events; and
4. tradeoffs between crop yields and regulating ecosystem services and/or negative environmental externalities.

The modelling studies can address different scales, from plant, field, regional to global scale, and can potentially be linked to other models, such as farm or landscape models.

S2-Keynote

Modelling in agroecology: from simple to complex models, and vice versa

Tixier Philippe (tixier@cirad.fr)

UPR GECO, CIRAD, Montpellier, France

The rise of agroecological cropping systems led to increase their complexity. Compared to conventional systems, they usually include richer communities of plants, e.g. mixed-cropping and agroforestry systems. In these systems, more diverse associated communities are involved in key processes including natural control of pests and diseases or nutrient cycling. Modelling these complex agroecosystems implies taking into account a network of interactions between plants, pest and diseases, regulating communities, water, nutrients and radiative resources. This complexity also includes the spatial and temporal organization of fields that tends to be more heterogeneous than in conventional systems; this is particularly the case in multistrata and agroforestry systems. This heterogeneity is also important at the level of the assemblages of cultivated and associated plants that hugely varies across the infinite possible combinations of plants. Agroecology also relies on more diverse plant species that did not always received an extensive effort of parameterization in current models. Most common models used to simulate agrosystems, e.g. crop models, rely on relatively simple hypotheses such as the homogeneity of the canopy that is unlikely to be valid in more complex agrosystems. Initially built in limited biotic stresses, such models rarely take into account the effect of pest and diseases nor their regulations, which are key processes when dealing with zero pesticide systems. The temptation for modelers in agroecology would be to increase models' complexity as agrosystems complexity increases.

This presentation questions the type of models needed to address the issues related to the agroecological transition. I support the idea that modelling agroecological systems implies rethinking the models rather than just making existing ones more complex. Another change in modelling agroecological systems is in the use of models; it may not be as linear (parametrization, simulation, yield prediction) as usually done in many conventional agriculture approaches but may be done in order to address questions that are specific to agroecological systems. For instance, in agroecology we rather question: "what is the optimal plant community and its spatio-temporal organization that optimize its resilience to pest and diseases and to inter-annual variations?" than raw yield prediction. After briefly reviewing existing models in agroecology, I will present some successful examples of simple models that address key questions on complex agroecosystems (Poeydebat et al 2016). Bridging the statistical and process-based approaches is proposed as a relevant mean to address the issue of species diversification and of spatial heterogeneity. For instance, individual based models, which take the best of both approaches, can be applied to simulate tropical agroforestry systems. It illustrates how relatively simple models can represent complex canopies and pest regulation processes through i) statistical spatial relationship between plants and ii) the growth of each plant following resource-partitioning mechanisms. Finally, I will draw some perspectives of how interaction network models (Tixier et al 2013) can renew modelling approaches dedicated to highly complex assemblages of plants.

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How to model highly diversified cropping systems such as this agroforestry system in the region of Talamanca in Costa Rica?

Keywords: spatial heterogeneity, individual based models, agroforestry systems.

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S2-O.01

Which nitrogen fertilization techniques and crop traits to promote biological weed regulation by competition?

Perthame Laurène (laurene.perthame@inra.fr), Moreau Delphine, Maillot Thibault, Colbach Nathalie

Agroécologie, AgroSup Dijon, INRA, Univ. Bourgogne Franche-Comté, Dijon, France

Background and Aims

The necessary reduction of herbicide use may result in a residual weed flora in arable fields. Moreover, the use of mineral fertilizer must be reduced for environmental reasons. Thus, crop-weed competition for nitrogen might increase.

Nitrogen competition among plants is driven by soil nitrogen availability and plants traits related to nitrogen nutrition. Selecting species for their nitrogen nutrition traits and adapting nitrogen fertilization (rate, date, number of nitrogen applications, straw burial or export) could change competitive relationships between plants. Weeds with high nitrogen nutrition requirements are often hard to manage and could be hampered by such changes. This study aimed to identify which traits and which nitrogen fertilization options can reduce weed harmfulness while maintaining crop production in the long term.

Material and Methods

A maize monoculture from Aquitaine (France) was simulated over 15 years and 5 weather repetitions using FLORSYS (Gardarin *et al.* (2012), Munier-Jolain *et al.* (2013), Colbach *et al.* (2014)). This process-based model simulates crop growth and weeds dynamic over the years with a daily time step from cropping system, pedoclimate and species traits. We simulated numerous combinations of nitrogen fertilization (nitrogen input date and rate, straw burial vs export) and initial soil nitrogen content with 3 maize varieties (1 actual, 2 virtual) differing by their trait values related to nitrogen nutrition. The effects of fertilization, soil nitrogen supply and maize variety on weed disservice and service indicators were studied (Figure 1B).

Key results

The simulations showed that service indicators were often positively correlated to disservice indicators (Figure 1A). The sensitivity analysis revealed that maize variety and initial soil nitrogen content were the variables that affected the most weed impact indicators. The interactions between maize variety and nitrogen fertilization techniques were strong.

Compared to the actual maize variety, one virtual variety improved weed (dis)services except nitrate leaching (Figure 1B). The other virtual variety had the opposite effect. The effect of nitrogen application date was different for all 3 varieties, except for bee food which decreased with the lateness of application, regardless of the variety. For the actual variety, increasing nitrogen rate decreased weed harmfulness over the long term, and increased weed services (except bee food). The 2 virtual varieties showed the opposite for weed services and a similar behavior as actual variety on disservices.

Increasing the initial soil nitrogen content decreased current but increased future weed harmfulness (Figure 1B). On the long term (beyond 15 years), a high initial soil nitrogen content might increase the weed soil seed bank and thus decrease grain yield loss.

Further analyses and simulations will be carried out to (1) disentangle the effects of fertilization techniques from maize variety and initial soil nitrogen content and (2) identify which weed traits drive weed (dis)services in these maize-based cropping systems.

Conclusions

The preliminary results of these simulations of maize cropping systems showed that choosing varieties based on their nitrogen nutrition traits can reduce weed disservices. However, it was almost impossible to conciliate reduction of weed harmfulness and increase of weed services in these systems.

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(A) Spearman's correlations		Weed service indicators			Weed disservice indicators (harmfulness for crop production)		
		Wild plant species richness	Bee food	Reduced nitrate leaching	Field infestation	Grain yield loss	Weed seed production (proxy for future yield loss)
Species richness		1	0,22	-0,41	-0,53	0,42	-0,28
Bee food			1	-0,09	-0,06	0,02	0,10
Reduced nitrate leaching				1	0,27	0,24	0,38
Field infestation					1	0,63	0,42
Grain yield loss						1	0,38
Weed seed production							1
(B) Sensitivity analysis							
Maize Varieties (compared to actual maize)	Maize virtual 1						
	Maize virtual 2						
Maize Varieties x N input date delayed	Maize						
	Maize virtual 1						
	Maize virtual 2						
Maize Varieties x increased N rate	Maize						
	Maize virtual 1						
	Maize virtual 2						
Increased initial soil N content							

Figure 1. (A) Spearman's correlations between weed impact indicators simulated with FLORSYS for maize monoculture cropping systems. Blue values indicate positive correlations, orange values indicate negative correlations.
(B) Effect of maize variety (1 actual, 2 virtual differing by their nitrogen nutrition trait values) and initial soil nitrogen content on disservice and service indicators simulated with FLORSYS in a sensitivity analysis (analysis of variance).
Red cells indicate a deterioration for the indicator (decrease of service indicators and increase of disservice indicators) and green cells the opposite. Grey cells indicate non-significant effects.

Keywords: Simulation, Process-based model, Sensitivity analysis.

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S2-O.02

Improving the productivity and resilience of smallholder farmers with maize-legume and legume-legume systems in Malawi

Ngwira Amos[1] (A.Ngwira@cgiar.org), Nelson William[2], Snapp Sieglinde[3], Chikowo Regis[3], Rao Karuturi[4], Whitbread Anthony[4]

[1] *ICRISAT, Lilongwe, Malawi*; [2] *TROPAGS, Georg-August-Universitaet, Goettingen, Germany*; [3] *Plant, Soil and Microbial Sciences, Michigan State University, Michigan, United States*; [4] *ICRISAT, Hyderabad, India*

Introduction

Smallholder farmers in southern Africa must cope with declining soil fertility and production risks associated with frequent droughts (Jayne et al., 2014). Legume integration through rotations or intercropping in maize-based farming systems are promoted to increase crop diversification and soil fertility. A novel strategy, doubled up legumes, could help develop production systems that fulfil sustainable intensification (SI) indicators. It is however crucial to understand resource competition in mixed cropping systems under variable soil and climate conditions.

Materials and Methods

We used agronomic data from participatory farmer trials to parameterise the Agricultural Production systems SIMulator (APSIM) and evaluate its performance simulating observed treatments at three locations from 1986-2019 in central Malawi. The calibrated model was used to simulate groundnut-pigeonpea intercropping, maize-pigeonpea intercropping and maize-groundnut rotation, soybean-maize rotation and continuous maize under a range of N fertiliser inputs.

Results and Discussion

Simulated maize and legume grain yields were generally in-line with observed yields from seasons 2012/2013 to 2017/2018 (RMSE = 1317 and 274 kg/ha for maize and groundnut), confirming observations that APSIM is able to predict maize yield response to fertility inputs, rotations and intercrops (Carberry et al., 1989; Robertson et al., 2005). Maize yields declined by around 30% in intercrops with pigeonpea compared with sole maize. Low maize yields were compensated for by pigeonpea yields. Averaged across sites, maize after sole groundnut gave similar yields to maize receiving the full fertiliser rate. Hence, the nutrient gap for maize across sites was largely filled by legume rotation treatments receiving 50% of the fertiliser rate - a huge saving in fertiliser costs for maize production - setting aside opportunity costs of forgone maize in the preceding season (Kiwia et al., 2019). The coefficient of variation for all systems tested was around 10%, in contrast to earlier, similar reports that showed stable maize yields in rotations with grain legumes (Chimonyo et al., 2019).

The integration of legumes into the maize systems slightly reduced the magnitude of the decrease in soil organic C (witnessed in sole maize rotations), especially when pigeonpea was added to the system. This highlights the importance of grain legumes in sequestering soil C and the sustainability of such cropping systems. This result is in-line with Smith et al. (2016) that reported higher total C and N levels in doubled up legume systems compared with sole maize.

Conclusions

Maize-legume rotations or intercrops can assist farmers in southern Africa to achieve similar maize yields with moderate N fertiliser inputs. In addition, integrating pigeonpea in maize systems increased total soil C compared with continuous sole maize. These systems therefore have the potential to improve soils and reduce chemical fertiliser input.

Practical experimentation is required to determine site-specific suitability for resource-limited farmers, which should be part of a strategy to build soil fertility and provide immediate household needs.

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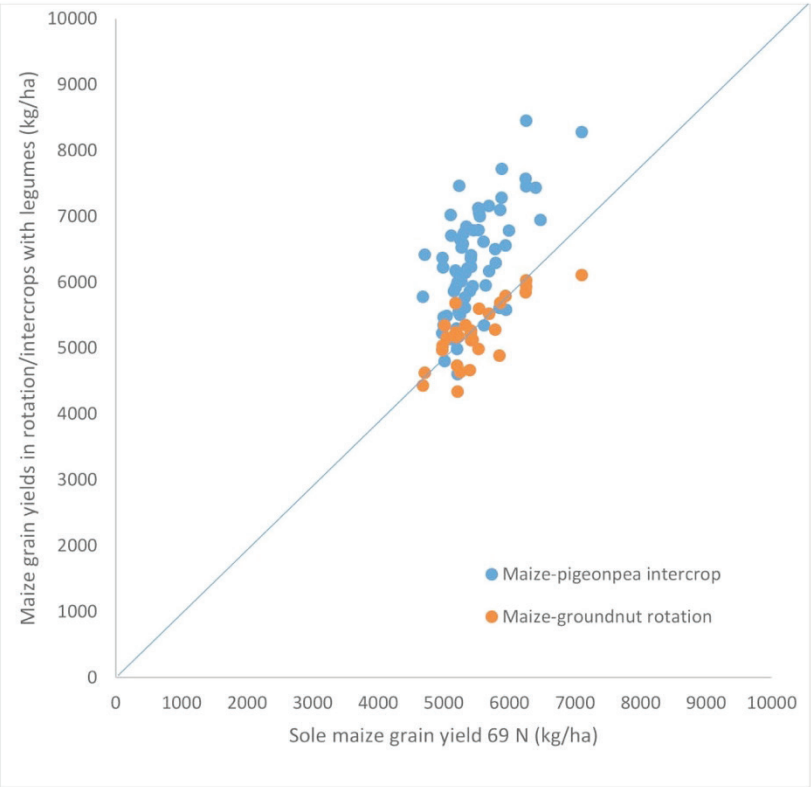

Figure 1. Maize grain yield (kg/ha) comparison between sole and intercrop/ rotations systems simulated under farmer's conditions in Malawi (1986-2019). Dots represent maize-pigeonpea intercrop (blue), and maize-groundnut (orange). Maize-pigeonpea intercrop and maize-groundnut received 35 kg N/ha (12 at sowing, 23 as a top dressing, 21 days after sowing) and sole maize received 69 kg N/ha (23 at sowing and 46 as a top dressing, 21 days after sowing).

Keywords: APSIM, Sustainable Intensification, Climate Variability, Legume Rotation, Intercropping.

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S2-O.03

Modelling crop growth and water use in relay strip intercropping

Tan Meixiu (meixiu.tan@wur.nl), Gou Fang, Stomph TjeerdJan, van der Werf Wopke

Wageningen University, Wageningen, Netherlands

Introduction

Intercropping is the cultivation of two or more crop species simultaneously in the same field. Strip relay intercropping increases radiation capture and productivity compared to sole crops. There are currently no simulation models for relay strip intercropping. Here, we developed a process-based model to simulate crop growth and water use in strip-relay intercropping, and used the parameterized model to assess the water use characteristics of this system.

Materials and Methods

The model contains a crop growth module and a water balance module. The crop growth module simulates biomass, leaf area index (LAI) and fraction of light interception (FINT) using a daily time step (Gou et al., 2017). The water balance module simulates the water balance of the soil and the water uptake by sole crops and intercrops, following principles of the FAO model for water limited crop growth, described in Steduto et al. (2009) and Raes et al. (2009), and concepts for water limited intercrop growth (Miao et al., 2016). The two modules are linked via light interception and water stress (Figure 1). We used four years of experimental data to parameterize and validate the model.

Results and Discussion

The parameterized model gave satisfactory predictions for crop growth and water use. Modelled land equivalent ratio (LER) and water equivalent ratio (WER) corresponded well with the observed values. The high values of LER (1.40-1.69) indicate a high land use efficiency of the wheat-maize relay strip intercropping system, while the values of WER (1.01-1.20) indicate that water is used more efficiently in the intercrop of wheat and maize than in the corresponding sole crops.

Conclusions

A mechanistically based crop model with water limitation was developed to simulate relay strip-intercrops by combining concepts for light interception in heterogeneous canopies (Gou at al., 2017) with concepts for water use in sole crops (Steduto et al., 2009; Raes et al., 2009) and intercrops (Miao et al., 2016). The fraction of light interception from the crop growth determines the actual transpiration and evaporation rate; water stress coefficient computed by soil water depletion gives feedback to transpiration and radiation use efficiency. Validation showed good performance of the model, and suggests that this model may be used for land and water use studies.

Acknowledgements

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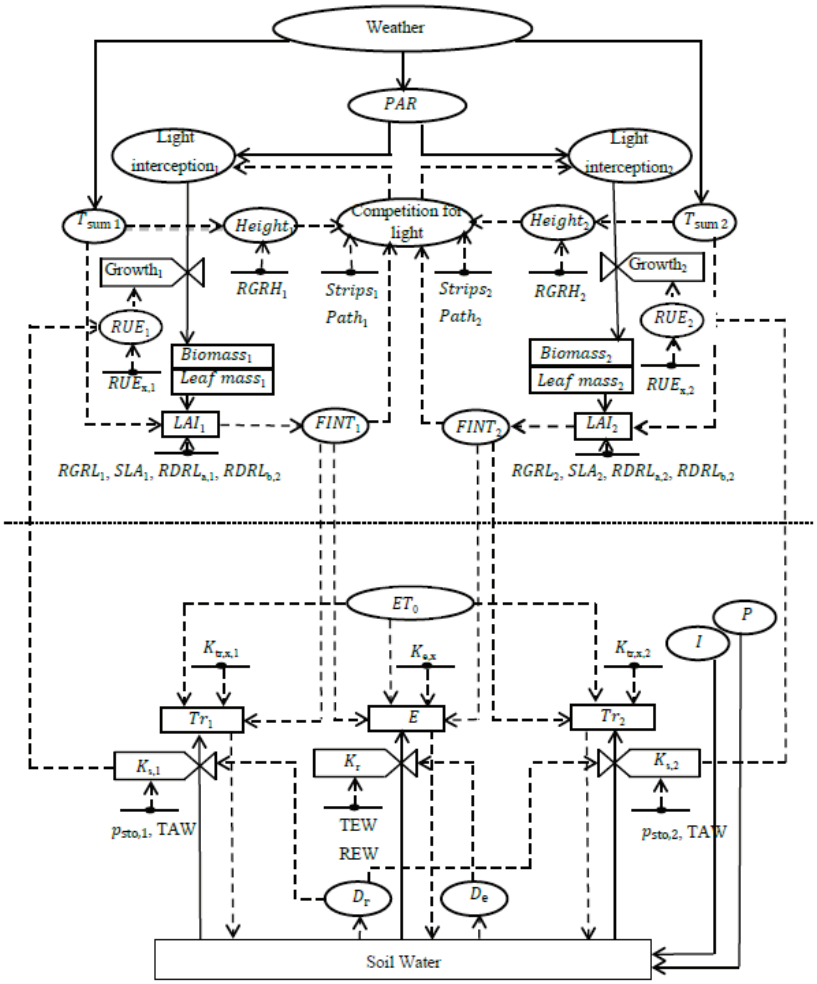

Functional relationships between the crop growth module (above the horizontal dotted line) and water balance module (below the dotted line).

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S2-O.04

Modelling of the mango tree – blossom gall midge system: *in silico* assessment of its functioning

Boudon Frédéric[1] (frederic.boudon@cirad.fr), Reyné Bastien[2], Saint-Criq Laurie[2], Memmah Mohamed[3], Ratnadass Alain[2], Normand Frédéric[2], Grechi Isabelle[2]

[1] *UMR AGAP, CIRAD, Montpellier, France*; [2] *UPR HortSys, CIRAD, Saint-Pierre, Réunion*; [3] *UR PSH, Inra, Avignon, France*

Introduction

Mango (Mangifera indica L.), a major fruit production in tropical and subtropical regions, is facing many production constraints. In particular, mango tree exhibits phenological asynchronisms that result in long periods of susceptibility to pests and diseases. Among them, the mango blossom gall midge (BGM, Procontarinia mangiferae Felt) (Amouroux, 2013) can cause significant yield losses by damaging mango inflorescences to lay eggs. The last instar larvae of BGM leave the inflorescences, drop to the ground and bury themselves into the soil to pupate. Then adults emerge from pupae in the soil. The life-cycle lasts less than one month (Prasad, 1971). Management solutions for the mango crop are required to control BGM. Currently, some pesticide-free levers are considered relying on soil mulching (Brustel, 2018). Mulching is used as a physical barrier to break the BGM life-cycle, by preventing BGM larvae from burying into or adults from emerging from the soil. BGM population being only estimated indirectly with larvae trapping, the objective of this study was to develop a quantitative modeling approach of the mango-BGM system that integrates knowledge on the BGM life cycle and assess the effect of mulching on it.

Materials and Methods

Data were collected in 2017 in a mango orchard (cv. 'Cogshall') located at Saint-Paul, Réunion Island. The orchard was split into three patches with different soil mulching treatments including low weed cover, high weed cover and synthetic mulching with plastic cover. BGM larval population was monitored twice a week from July to October with 60 traps positioned under inflorescences. Additionally, burst and death dates of sampled inflorescences were also monitored weekly.

The mango-BGM model simulates the dynamics of BGM populations of an orchard at a daily time-step during the period of mango flowering. The model is defined at the patch scale and considers: i) age-structured inflorescence population dynamics, ii) stage-structured BGM population dynamics, iii) orchard colonization by exogenous BGM individuals and individuals emerging from diapause, and iv) movements of endogenous individuals between patches. Model inputs are the daily numbers of bursting inflorescences. A set of parameters are defined controlling for instance the survival probabilities of larvae for each soil mulching, etc. Calibration of these parameters was made using the multicriteria optimization algorithm NSGA-II (Deb et al., 2002) to minimize difference between simulated and observed BGM larval population dynamics.

Results and discussion

Model simulations makes it possible to investigate the responses of the mango-BGM system to mulching treatments. Different hypotheses were also tested to improve the model such as the effect of temperature on diapause. These hypotheses make it possible to capture increase of population according to inflorescence dynamics but failed to capture the rapid decrease of the BGM population at the end of the season. This seasonality modulation can still be modelled and quantified but open questions on the biological processes controlling this phenomenon.

Conclusion

This model allows to represent the main processes of BGM life cycle and test their impact of the population dynamic. Next step will be to test *in silico* alternative BGM management levers such as the manipulation of mango phenology to reduce the flowering period, which could be achieved using pruning (Persello et al., 2017).

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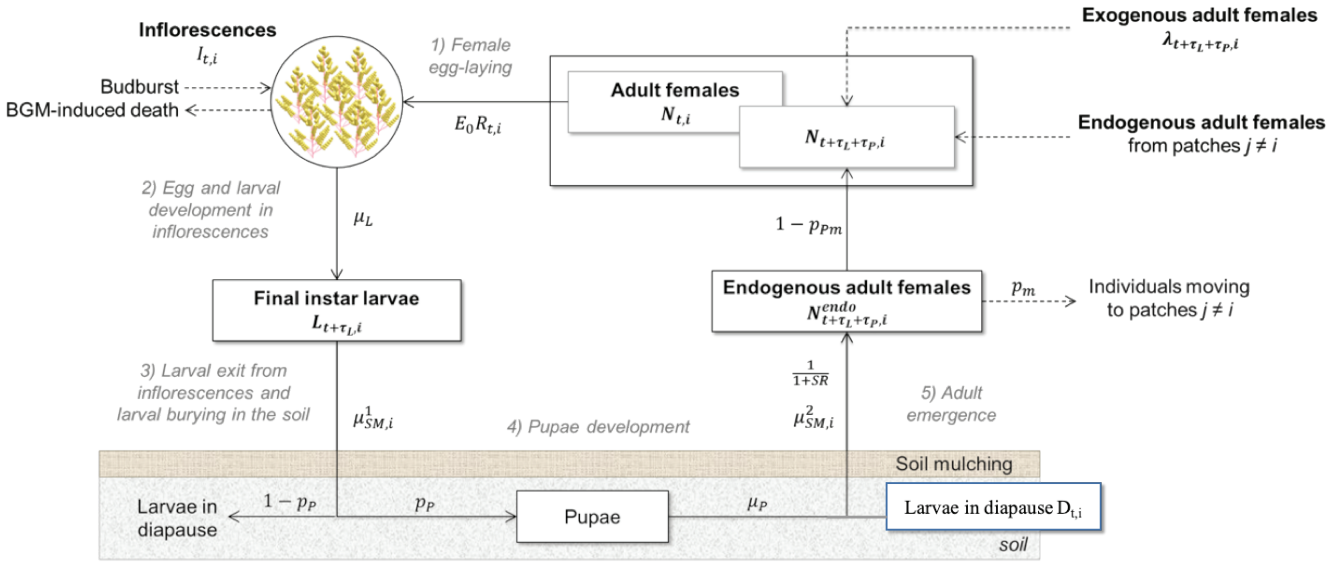

Modelling of the BGM life cycle and its interaction with mango inflorescences and soil mulching.

Keywords: crop-pest interactions, population dynamics, soil mulching, Mangifera indica, Procontarinia mangiferae.

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S2-O.05

EPIC-GILSYM: Modelling crop-insect interactions and pest management with a novel coupled crop-insect model

Rasche Livia[1] (livia.rasche@uni-hamburg.de), Taylor Robin[2]

[1] *Universität Hamburg, Hamburg, Germany*; [2] *Ohio State University, Wooster, United States*

Introduction

Modern intensive agriculture relies heavily on pesticides to control weeds, pathogens and insect pests. Forecasting and managing the impact of pests and pesticides on crop production is challenging. Since pest control tactics not only affect the target pest, but also initiate feedbacks within the field community, proper modelling of pest management requires functions in at least two trophic levels.

Methods

To respond to this challenge, we integrated a process-based insect population dynamics model and a process-based crop model. The coupled model was then used to simulate eight field trials on five different sites across the US, testing the efficacy of five different pesticides against six different pests as well as the yield response.

Results

The results showed that the model performed robustly on the different sites and under different climatic conditions (eight years spanning a period from 1985 to 2014). For armyworm and black cutworm, the simulated yields per hectare, the number of insects per plant and the response to insecticide treatments closely matched the reported numbers. For the European corn borer, the number of insects per plant differed between simulated and field data, but the response to the insecticide treatment showed an adequate match. Simulations for the bean leaf beetle and stalk borer yielded similar results. The comparison between simulated and measured adult potato leafhopper numbers revealed that even though numbers did not match closely in two of three years, they were in the same range, and the measured and simulated impacts were almost identical for all three used insecticides.

Discussion and Conclusions

The novel coupled crop-insect model EPIC-GILSYM realistically simulates two trophic levels (insects and plants), their interactions, and the effect crop management has on both levels. It has been successfully tested against field trial data collected in eight different years on five plots in different parts of the US. With careful calibration and validation to other sites and climates, it may become a valuable tool in the assessment of insect pest impacts and appropriate control measures.

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Insect	Crop	Year	Source	Yield [t/ha]		Insects/plant*		Impact on yields [%]	Impact on insects [%]
				Tr	Co	Tr	Co		
Armyworm	Corn	1987	Field	8.848	8.127	0.5	1.25	+8.2	-60.0
			Simulation	9.942	8.926	0.34	1.56	+10.2	-78.0
Bean leaf beetle	Soybeans	2005	Field	2.58	2.58	36.5	1.30	0	-96.4
			Simulation	2.97	2.80	51369	2586	+0.06	-95.0
Black cutworm	Corn	1994	Field	9.1	7.53	-	-	+17.3	-
			Simulation	10	8.42	0.01	0.48	+15.8	-97.2
European corn borer	Corn	1988	Field	-	-	0.2	0.53	-	-62.3
			Simulation	4.06	4.05	0.02	0.16	+0.3	-89.4
Stalk borer	Corn	1985	Field	7.78	8.57	-	-	-10.2	-
			Simulation	9.692	9.69	0.53	0.53	0	0

*in the case of bean leaf beetle, this number refers to insects/10 sweeps for the field data and adult insects/ha for the simulation

Impact of insecticide applications on yield and/or insect numbers, as reported in the field trials and as simulated with the coupled crop-insect model. Tr: treatment, with insecticide application; Co: control, no insecticide application. Missing yield or insect/plant data were not reported in the description of the specific field trial.

Keywords: yield loss, field trials, insecticides, pest management, trophic levels.

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S2-O.06

Ecological intensification of rainfed cropping systems in Australia's subtropical grain zone

Hochman Zvi (zvi.hochman@csiro.au), Whish Jeremy, Horan Heidi, Navarro Garcia Javi

Agriculture and Food, CSIRO, St Lucia, QLD, Australia

Introduction

The limits to ecological intensification of cropping systems in Australia's rainfed subtropical grain zone can be redefined by considering the water-limited potential of crop rotations rather than the sum of water-limited yields of individual crops. Trade-offs between productivity of these systems and their impacts on the environment can be quantified. Here we present a case study of 26 crop rotations that were evaluated in silico in terms of productivity indicators such as energy, protein, revenue, profit and downside risk, and ecological indicators such as N applied, Fallow herbicide applications, NO_3 leached, and greenhouse gas emissions.

Materials and Methods

Twenty-six rotations that represent current practice in the subtropical cropping zone were selected through interviews with six focus groups of growers and consultants. These rotations vary in their complexity, cropping intensity, crop types and growing season. To determine water-limited yields and sustainability of the 26 rotations, simulations were run for at least 30 years at 858 weather stations with up to 3 soil types per weather station (> 8M simulation years). Simulation outputs include: Yield, biomass, grain N, grain protein, grain oil (canola), NO_3 leached, and greenhouse gas emissions (CO_2 equivalents). Post simulation processing enabled calculation of additional outputs such as energy, protein, revenue, gross margins ($/ha/yr.) and the risk of any crop returning a GM below an acceptable threshold value. Outputs were mapped onto the grains cropping area. Rotations can be compared based on multiple (production and sustainability) attributes to identify the most desirable rotation for any attribute and location. Trade-offs between attributes, particularly between productivity and the intensity of negative environmental indicators were quantified and presented as sustainability polygons (Ten Brink et al., 1991). Results and Discussion Each production and environmental attribute of the 26 rotations was mapped separately onto each weather station (location) within the crop land use area of the northern grain zone. These maps were then aggregated so that the 'best' rotation for that attribute was mapped to each location. This is illustrated for revenue in Figure 1. Maximum revenue varies spatially from 800-2000 AUD/ha and while 3 different rotations dominate across locations, for most of the area, the most revenue is produced by the sorghum/fallow/Mungbean/wheat/fallow/chickpea rotation (4 crops in 3 years). Specific trade-offs for each location may be represented by sustainability polygons in which the various attributes of any rotations may be visualized. For example, the most profitable rotation at a given location may also be the most favourable in terms of revenue, drainage, runoff, N leached, greenhouse gas emissions and herbicide use but less favourable than the next two most profitable rotations in terms of protein and energy produced and the risk of profit being below a threshold value.

Conclusions

Describing yield gaps in a whole cropping system context provides a richer appreciation for the challenge of sustainable intensification. While no single rotation is best for all attributes, sustainability polygons offer a decision framework for selecting the most suitable rotation for any location. Maps and polygons can serve as boundary objects for discussions between researchers and other stakeholders such as farmers, advisers and policy makers.

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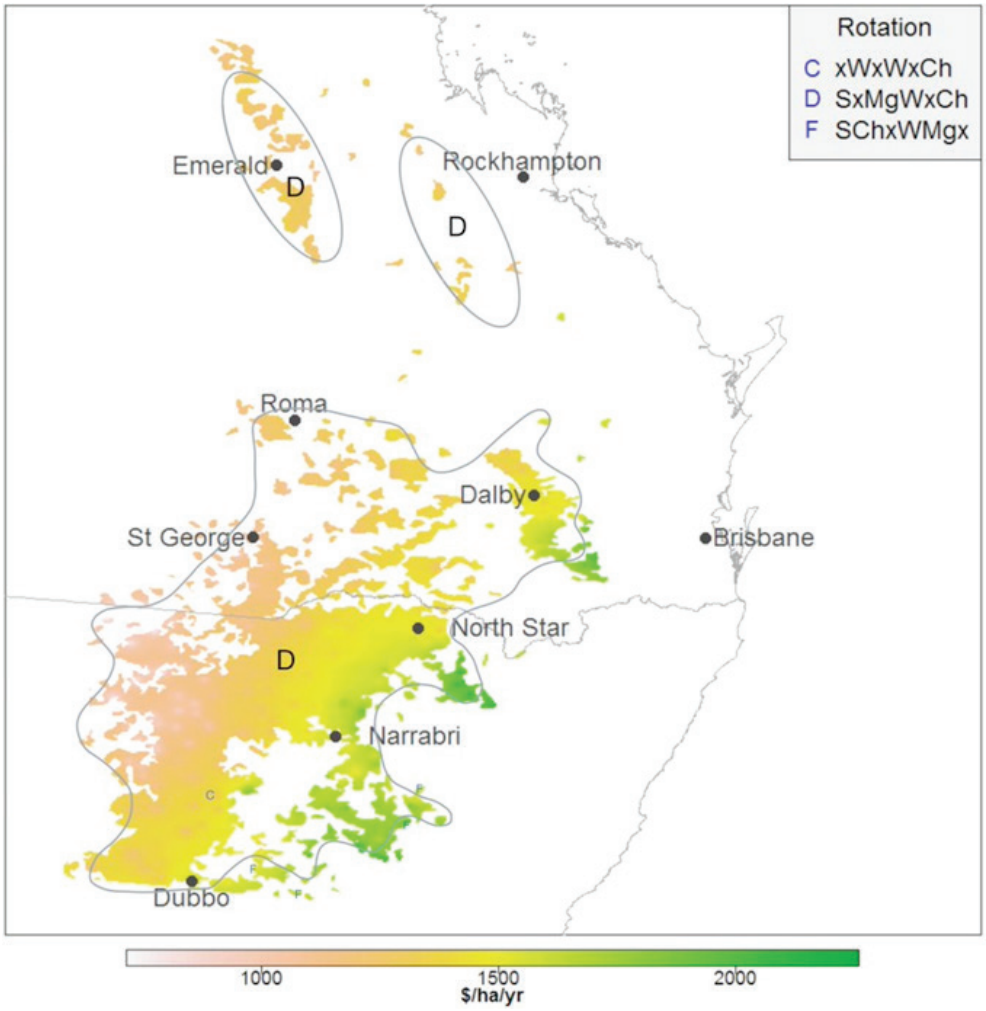

Figure 1. Map of the maximum achievable revenue in Australia's Northern Grain Zone. The optimal rotation for each location is identified by their designated letter (C, D, F). The specific crop states within the rotation were identified by the abbreviations (W=wheat; S=sorghum; Ch=chickpea; Mg=mungbean; x=fallow).

Keywords: Sustainability polygons, trade-off, crop rotations, water-limited yield.

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S2-O.07

Challenges for simulating the long term effects of complex agroecological systems to support innovation in Canada

Jégo Guillaume[1] (guillaume.jego@canada.ca), Delmotte Sylvestre[2], Gariépy Stéphane[1], Largaespada César[3], Larbi-Youcef Yasmina[3]

[1] *Agriculture and Agri-Food Canada, Quebec, QC, Canada*; [2] *Consultant in participatory modelling, Quebec, QC, Canada*; [3] *Union des Producteurs Agricoles, Saint-Hyacinthe, QC, Canada*

Introduction

Innovative agroecological systems are complex and unstable. Their advantages can become visible for the farmers only after a couple of years. Furthermore, they require farmers to shift of paradigm and practices without a long-term view of the consequences. The use of modelling tools, embedded in a participatory approach, can support farmers to take the turn toward agroecology by capturing the complexity of the systems and providing an overview of their long-term effects. However, for the farmers to trust the model outputs, the efficiency of the model to capture the main processes associated to the current and agroecological systems has to be demonstrated. In this paper, we present how we parameterised and used the STICS model in support of a participatory prototyping approach in Quebec (Canada) during which we designed agroecological cropping systems and evaluated their impacts on crop performance, nitrogen and carbon cycles.

Materials and Methods

In the Huron River watershed (74 km2) in Quebec, Canada, cultivated lands cover 78% of the watershed. Three successive workshops were held with local stakeholders (dairy and cash crop producers, farm advisors, watershed committee, and researchers), to design agroecological cropping systems including cover crops and no-till.
The innovative cropping systems include annual and perennial crops, cultivated in pure or intercropping systems, and green manure. For example, for a cash crop farmer, the initial rotation was Corn/Corn/Soybean/Spring Wheat (CCSW) while the prototype was Corn-raygrass/ Corn-raygrass/ Soybean / Winter wheat - forage pea (CrCrSWp).
The STICS soil-crop model (Brisson et al., 2009) was used to simulate the long term effects of these cropping systems (30 years). It has been calibrated and validated to simulate several of the main annual and perennial crops used in Eastern Canada (e.g. Jégo et al. 2010, 2011). We faced different issues related to reproducing adequately in the model important processes of agroecological systems, notably the competition between the main and associated crops, the growth of late season green manure crops, the accumulation and decomposition of the crop residues and their impacts on the soil organic matter.

Results and Discussion

Introducing cover crops in farmers rotations could reduce organic matter losses and, in some cases, slightly increase soil organic matter content (e.g. +1% over 30 years). This result is in line with several studies showing that the use of cover crops is an efficient way to maintain or increase soil organic matter content. Simulation results also showed that the use of cover crops can significantly reduce reactive nitrate losses, essentially through a reduction of nitrate leaching (e.g. - 22 kg N ha-1 on average per year). As observed in field experiments, the model showed that, as a result of a higher soil organic matter content, corn and soybean yields did not decrease with cover crops and that cereal yields even increased. Simulation results also suggest that in the rotation with cover crops, and after at least a full rotation with cover crops, a reduction in N fertilization can be envisaged without dramatically affecting yields (reduction < 5%) while mitigating increasingly N losses. The results were presented at a fourth workshop, and the presentations and discussions helped convince dairy and cash crop producers to test these agroecological systems on their farms. As a result, the participants decided to adopt the same approach to develop and implement improved crop rotations on 10 farms in the watershed and to monitor their effects on crop yields and the environment.

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Conclusions

In this study, we challenged the use of STICS for two main issues rarely addressed in simulation experiments: (1) the simulation of complex rotations, and (2) the simulation of their long term effects on critical processes for agroecological systems, such as organic matter evolution. The poverty of existing datasets highlighted the need for funding agencies to keep supporting field experiments that allow to acquire data, that can improve our understanding of these systems, and support model development and parameterisation.

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S2-O.08

Can legume crop residues contribute to sustainable intensification of rainfed rice production in Madagascar?

Ranaivoson Lalaina[1] (lalainabakotiana@yahoo.fr), Falconnier Gatien[2], Autfray Patrice[2], Muller Bertrand[3], Leroux Louise[2], Affholder François[2], Ripoche Aude[2]

[1] *FOFIFA, Antananarivo, Madagascar*; [2] *AIDA, CIRAD, Montpellier, France*; [3] *AGAP, CIRAD, Montpellier, France*

Rainfed agriculture on smallholder farms across the tropics is crucial for food security and livelihoods when availability of irrigated land is limited. Coarse-textured soils with low organic carbon and poor inherent fertility prevail in these systems (Tittonell and Giller, 2013). In the absence of sufficiently remunerative market, smallholders cannot afford mineral fertilizers so that nutrient inputs are generally limited to manure. Integrated soil fertility management, *e.g.* integration of legumes combined with additional supply of mineral fertilizers, is required to sustainably increase rainfed agriculture productivity (Vanlauwe et al. 2014). In Madagascar, most smallholders do not use mineral fertilizer under rainfed agriculture. Incorporation of Nitrogen (N) rich crop residues could increase nutrient supply and improve N use efficiency (Aggarwal et al., 1997). Nutrient supply from residues is a complex process related to decomposition rates of residue, which is impacted by residue type and climate variability, *e.g* increased temperatures can accelerate residue decomposition while intense rainfall can increase the loss of the precious mineralized N through leaching. The potential contribution of N rich crop residues to increase staple crop productivity is therefore complex to anticipate. Soil-crop models can account for such complexity. This study aims at (i) calibrating the STICS crop model for rice yield modeling in the smallholder context of cool humid uplands in Madagascar and (ii) use the model to explore the effect of incorporation of rice and legume residues for low (25 kg N ha-1) and high (160 kg N ha-1) fertilizer inputs with a variable climate.

The soil-crop model *STICS* (Brisson et al., 2003) was chosen for its capacity to account for soil water and nutrient dynamics during crop cycle for various climates and crop management. Rice experiments (cultivar NERICA 4) carried out in 2016-2017 and 2017-2018 cropping season in Ivory (19°33'S, 46°24'E, 950 m a.s.l) on Ferralsols were used for model calibration and testing. Two previous crops were compared: (i) rice and (ii) *Mucuna cochinchinensis* - *Crotalaria spectabilis* intercropping, combined with two levels of nutrient input, *i.e.* manure only (25 kg N ha-1) or manure and mineral fertilizer (160 kg N ha-1). Residues were incorporated at plowing. Measured data include rice phenology, above ground biomass and plant N, grain yield and in-season soil moisture and soil N.

The calibrated STICS model reproduced adequately rainfed rice emergence, flowering and maturity, with on average an error of less than four days. Simulated in-season soil N and rice biomass agreed with the observations with a relative Root Mean Square Error from 33% to 36% (see Figure 1 for rice residues with high N input treatment). The model could reproduce the additional mineral N supply and plant uptake associated with the incorporation of N rich legume residue for the two fertilizer treatments.

Calibration for grain yield and scenario analysis using historical climate (1980-2010) are on-going and will allow to determine the profitability and risk associated with the different simulated options. This study will contribute to gain new insights on the relevancy of legume residue for sustainable intensification of cropping systems in a tropical smallholder context.

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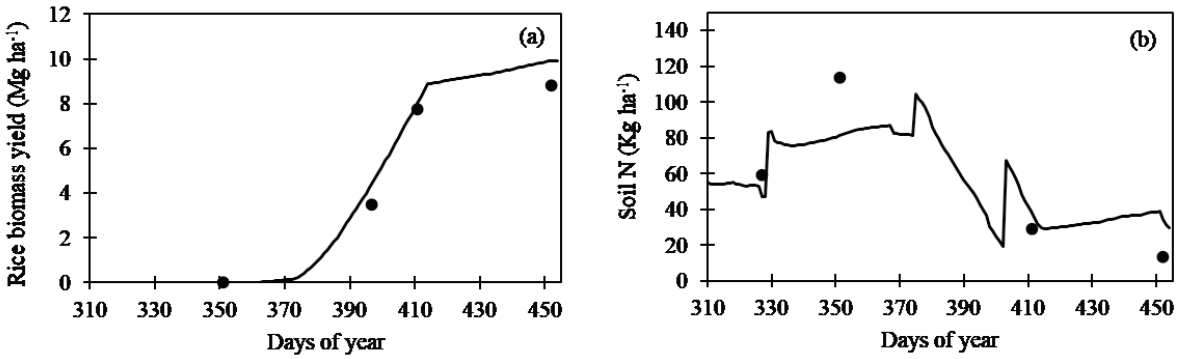

Figure 1: Comparison of observed and STICS simulated rice biomass (a) and soil N (b) dynamics during rice growing cycle for rice residues with manure and mineral fertilizer (160 kg N ha-1).

Keywords: upland rice, tropical climate, legume residue, soil nitrogen, low-input.

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S2-O.09

Effects of climate change on crop rotations and their management across the Federal state of Brandenburg/Germany

Kersebaum Kurt Christian (ckersebaum@zalf.de), Wallor Evelyn, Schulz Susanne

ZALF Müncheberg, Müncheberg, Germany

Introduction

The impact of climate change on crop production depends on one hand on the cultivated crop and their context within crop rotations and on the site conditions, e.g. soils and hydrology. We present a regional study across the federal state of Brandenburg/Germany based on gridded climate data and a digital soil map using the HERMES model, which aims to investigate common agricultural practices under current and future climate conditions regarding productivity and environmental effects.

Material and Methods

Within the study 5 different types of crop production are addressed by defining site dependent crop rotations over 4-5 years (Fig. 1). While one rotation is comprised by the most common crops, another rotation modifies the first one by introducing a legume followed by a more demanding crop. The third rotation intends to produce higher value crops, e.g. potatoes than the first one, while the fouth rotation has its focus on fodder grass and cereal production. Building on this the fifth rotation replaces the fodder grass by alfalfa. All rotations are simulated in shifted phases to ensure that each crop is simulated for each year.

We use an automatic management for sowing, harvest and nitrogen fertilization based on soil and climate information. The crop rotations are simulated with and without irrigation and with and without the implementation of cover crops to prevent winter fallow.

For soils we use the digital soil map 1:300.000 for Brandenburg. Soils are spatially aggregated in 99 soil map units. Within the soil map unit, up to three dominant soil types are considered to achieve at least 65% coverage. In total 276 soil types are defined by their soil profiles including soil organic matter and texture down to 2 meters. Groundwater levels are estimated using the depth of reduction horizons as constant values over the year, to consider capillary rise depending on soil texture and distance between the root zone and the groundwater table.

The soil map was intersected with gridded climate data at a resolution of 25x25 km for a baseline and climate scenarios (Webber et al. 2018) for the mid and the end of the 21 century. Two contrasting GCMs (HAD and MPI) are used to generate climate input for modelling for the RCPs 2.6, 4.5 and 8.5. Crop and soil variables and fluxes are analyzed.

Results and discussion

Results indicate that spring crops are more negatively affected by climate change than winter crop especially on soils with low water holding capacity, while a few areas with more loamy soils and potential contribution of capillary rise from a shallow groundwater may even benefit from climate change. Irrigation in most cases improved crop yield especially for spring crops. However, further analysis is required to assess if irrigation gains an economic benefit for all crop rotations. Nitrogen leaching can be reduced by implementing winter cover crops. However, increasing water scarcity during summer hampered cover crop establishment. Therefore, cover crops are increasingly skipped during simulation in the second half of the century according to the model defined sowing rules. Soil organic matter is assessed to decline for most sites and rotations. Only the rotations with multiyear grass or alfalfa can keep the level, but not on all sites.

Conclusions

Results show, that climate change impact varies strongly with site conditions. Therefore, adaptation measures have to be tailored site specifically.

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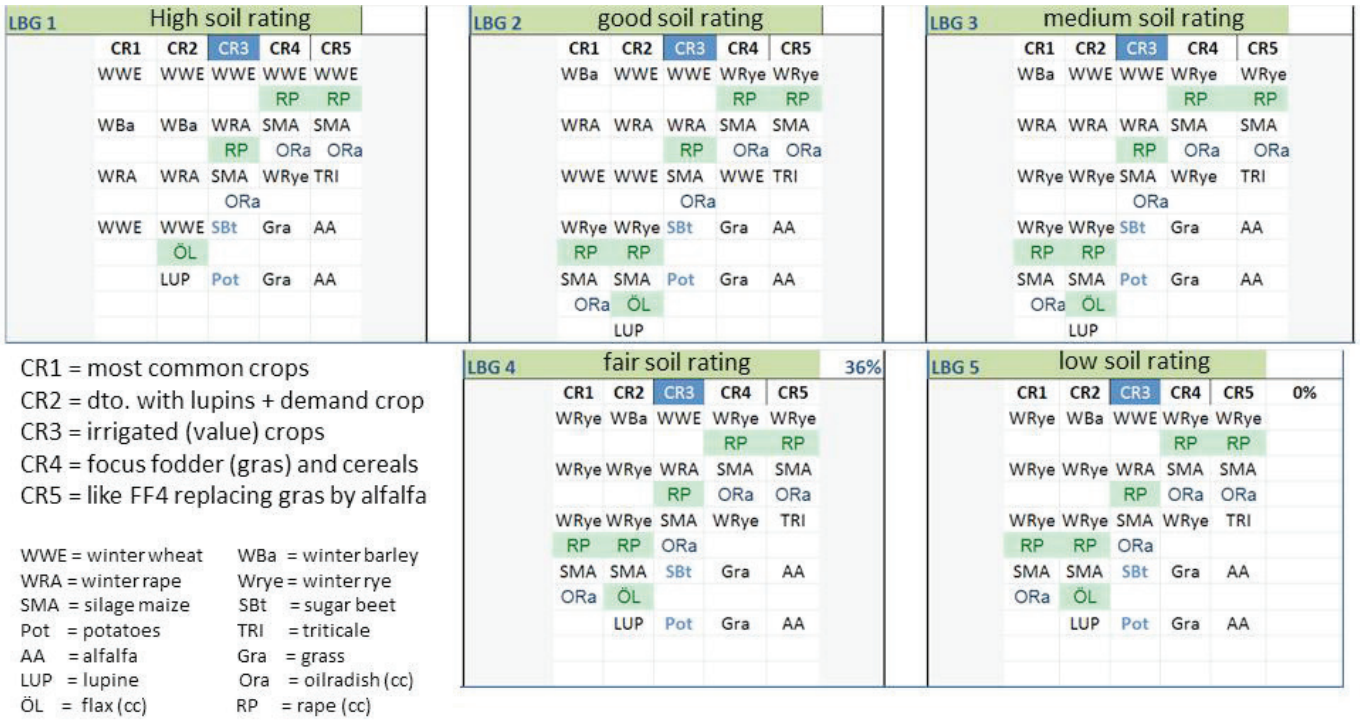

Figure 1: Crop rotation schemes and their soil specific realisation for simulation in Brandenburg

Keywords: Crop modelling, nitrogen, adaptation, irrigation, cover crops.

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S2-O.10

Uncertainties in simulating N uptake, net N mineralization, soil mineral N and N leaching in European crop rotations

Yin Xiaogang[1] (xiaogangyin@cau.edu.cn), Kersebaum Kurt-Christian[2], Beaudoin Nicolas[3], Constantin Julie[4], Chen Fu[1], Louarn Gaëtan[5], Kollas Chris[6], Manevski Kiril[7], Hoffmann Munir[2], Armas-Herrera Cecilia M.[3], Baby Sanmohan[7], Bindi Marco[8], Ferchaud Fabien[3], Ferrise Roberto[8], Garcia de Cortazar-Atauri Inaki[9], Launay Marie[9], Mary Bruno[3], Moriondo Marco[10], Öztürk Isik[7], Ruget Françoise[9], Sharif Behzad[7], Wachter-Ripoche Dominique[9], Olesen Jorgen E.[7]

[1] *China Agricultural University, Beijing, China*; [2] *ZALF, Müncheberg, Germany*; [3] *INRA, Barenton-Bugny, France*; [4] *INRA, Castanet-Tolosan, France*; [5] *INRA, Lusignan, France*; [6] *PIK, Potsdam, Germany*; [7] *Aarhus University, Tjele, Denmark*; [8] *University of Florence, Firenze, Italy*; [9] *INRA, Avignon, France*; [10] *CNR-IBIMET, Firenze, Italy*

Introduction

Modelling N transformations in soil and plant N uptake is crucial for N management optimization to increase N use efficiency and reduce N losses. However, it remains challenging because of the complexity of N cycling in soil-plant systems. Six commonly used process-based models (APSIM, CROPSYST, DAISY, FASSET, HERMES and STICS) were included in the study to simulate soil N mineralization and N fate in long-term crop rotations using the continuous simulation method after calibrations. The current study aims to assess the accuracy and uncertainty of both multi-model ensemble and individual models in simulating 1) plant N uptake variables, N mineralization and soil mineral N (SMN), N leaching, and 2) the effects of N managements (cover crops (CC) versus no CC and N rates) on N cycling in crop rotations.

Materials and Methods

The field experiment used for this study was located in Northern France (1991-2003). There were 12 treatments included in the study, with three experimental factors: crop rotation, the presence/absence of CC and N rate. Aboveground biomass, yield, N uptake, grain N were measured at harvest of each main crop during the experimental period. N leaching was measured based on the measurements from lysimeters and porous cups. The annual net N mineralization (M) were calculated using the gross N balance method based on the measured variables (more refers to Constantin et al., 2011). The performances of both individual models and multi-model ensemble were analyzed. The index of agreement (IA), mean bias error (MBE), root mean square error (RMSE) and mean absolute percent error (MAPE) were used to evaluate the model performance. The calculation of multi-model ensemble was the same as Yin et al. (2017).

Results and Discussion

Models reasonably well simulated the yield, aboveground biomass, N export and N uptake, except for sugar beet, which was generally less well parameterized. In addition, models provided more accurate simulations in terms of plant variables (i.e. N uptake and N exported) compared to soil variables (N mineralization and soil mineral N (SMN)) and environmental variables (N leaching). Multi-model ensemble significantly reduced the mean absolute percentage error (MAPE) between simulations and observations to less than 15% for yield, aboveground biomass, N exported and N uptake (Figure 1). Multi-model ensemble significantly reduced the MAPE between simulations and observations for net N mineralization, SMN and annual N leaching, while the MAPE was still large for SMN. In addition, models generally well simulated the CC effects on N fluxes, and all models correctly predicted the effects of the reduced N rate on all measured variables in the study. In conclusion, multi-model ensemble is a useful method for predicting yield, aboveground biomass, N exported and N uptake, which are mainly influenced by N availability and N inputs. The uncertainties of multi-model ensemble for N mineralization, SMN and N leaching are larger, mainly because these variables are influenced by plant-soil interactions and subject to cumulative long-term effects in crop rotations, which makes them more difficult to simulate (Yin et al., 2019).

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Conclusions

Multi-model ensemble is a useful method for predicting plant N variables rather than for soil N variables and environmental N variables. Better calibration for soil N variables is needed to improve the predictions of N cycling in order to optimize N management in crop rotations.

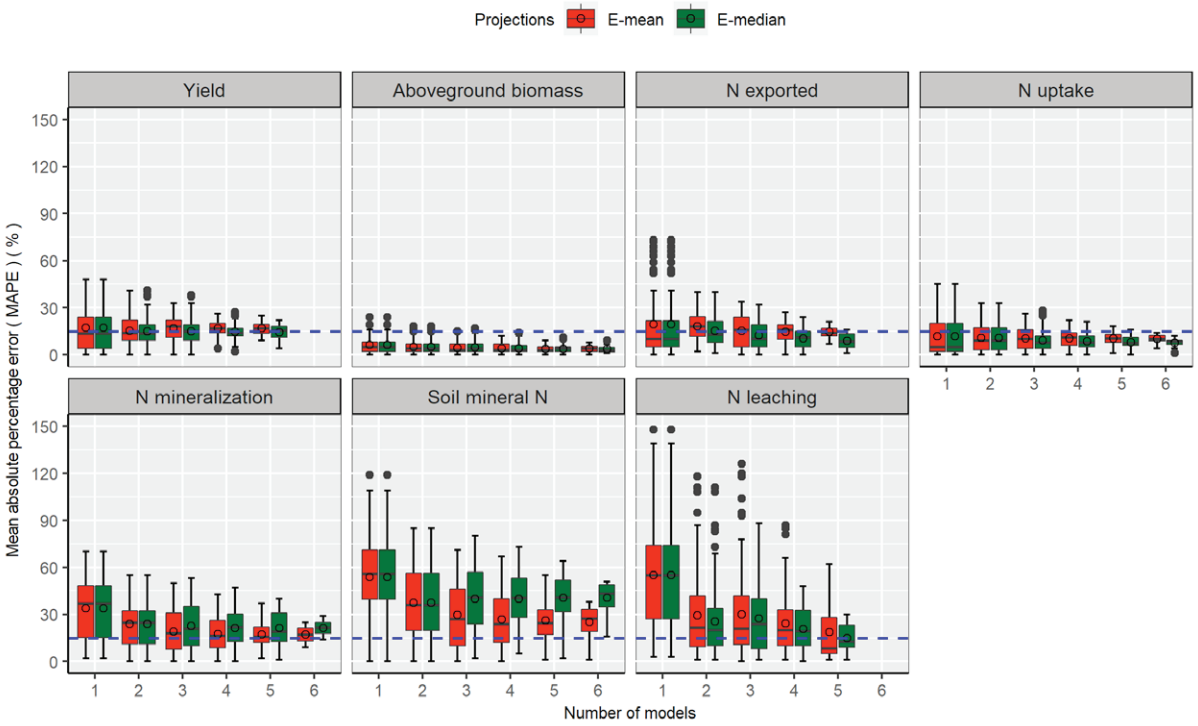

Figure 1 Mean absolute percentage error (MAPE) of the e-mean and e-median yield, aboveground biomass, N exported, N uptake, net N mineralization, soil mineral N and N leaching across all treatments at the rotation level as predicted by different number of models.

Keywords: Multi-model ensemble, N cycling, N exported, N mineralization, N leaching.

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S2-O.11

Long term modelling of crop biomass, N fate and GHG balance of organic cropping systems with a research version of STICS

Autret Benedicte[1] (benedicte.autret@inra.fr), Mary Bruno[2], Strullu Loïc[2], Chlébowski Florent[2], Mäder Paul[3], Mayer Jochen[4], Olesen Jørgen[5], Beaudoin Nicolas[1]

[1] *AgroIMpact, INRA, Barenton-Bugny, France*; [2] *AgroIMpact, INRA, 02000, France*; [3] *FIBL, Research Institute Organic Agriculture, Frick, Switzerland*; [4] *Institute for Sustainability Sciences, Agroscope, Zurich, Switzerland*; [5] *Department of Agroecology, Aarhus University, Tjele, Denmark*

Introduction

Although organic cropping systems are promoted for their environmental benefits, little is known about those due to their long term nitrogen (N) fate in the soil-plant-atmosphere system. Deterministic soil-crop models simulate the C-N cycles but applying them in such complex systems is a scientific and technical challenge. Our study relied on the hypothesis that formalisms successfully evaluated in conventional farming are valid in organic systems under good weed control (Autret et al., in press). With these assumptions, STICS soil-crop model represented a good candidate, to evaluate N fate and Greenhouse Gas balance (GHG) of organic systems (Brisson et al., 2003).

Material and Method

A research version of STICS was independently calibrated to simulate alfalfa (Strullu et al.; in press), as well as cereal cultivars grown in organic systems. It was applied then to simulate crop production, N surplus, nitrate leaching, gaseous N losses and changes in soil organic N (SON) in two long-term experiments: DOK in Switzerland (39-yr) and Foulum organic in Denmark (19-yr). Four treatments were considered in each experiment: two conventional ones with (CONFYM) or without manure (CONMIN), organic with manure (BIOORG) and unfertilized one (NOFERT) at DOK; conventional (CGL-CC+IF) and three organic treatments, one with cover crops only (OGL+CC-M) and two including cover crops and grass-clover with (OGC+CC+M) or without manure (OGC+CC-M), at Foulum. Some soil parameters were calibrated against the data of each respective conventional system. STICS predictions were then tested against the currently measured variables in organic systems. Finally, the model was used to predict the long-term N fate and the greenhouse gas balance (GHG) of all the systems.

Results and Discussion

The annual N surplus was satisfactorily predicted with a root mean square error (RMSE) of 28 and 33 kg N ha-1 yr-1 at DOK and Foulum, respectively, and a mean bias of -5 kg N ha-1 yr-1 in both experiments. The temporal evolution of SON was well captured by the model (Fig. 1). The long-term N surplus greatly differed between treatments at DOK, from -58 (NOFERT) to +21 kg N ha-1 yr-1 (CONFYM), but only from -9 (OGL+CC-M) to +21 kg N ha-1 yr-1 (OGC+CC+M) in Foulum. The simulated N leaching did not differ between treatments at DOK, while it was reduced by 41% in OGL+CC-M compared to CGL-CC+IF at Foulum, due to the combined effects of cover crops and absence of mineral N fertilizer. Simulated N volatilization was greatest in CONFYM and OGC+CC+M. Simulated denitrification was highest in BIOORG at DOK and 53% higher in fertilized treatments at Foulum. Predicted changes in soil N pools were always negative (from -18 to -78 kg N ha-1 yr-1), consistent with the measured N surpluses, depending on fertilization and crop rotation.

Conclusion

Simulations confirm the hypothesis that soil-crop model can predict C-N cycles of organic systems under caution of utilisation. They also show that arable organic systems do not systematically have lower N surplus and N losses than conventional ones, which represents a margin of progress.

Acknowledgements: French Ministry of Agriculture, PIREN Seine, ERA-NET UE project Climate-CAFE and FertilCrop for funds. FiBL, Agroscope and Aarhus University for sharing data.

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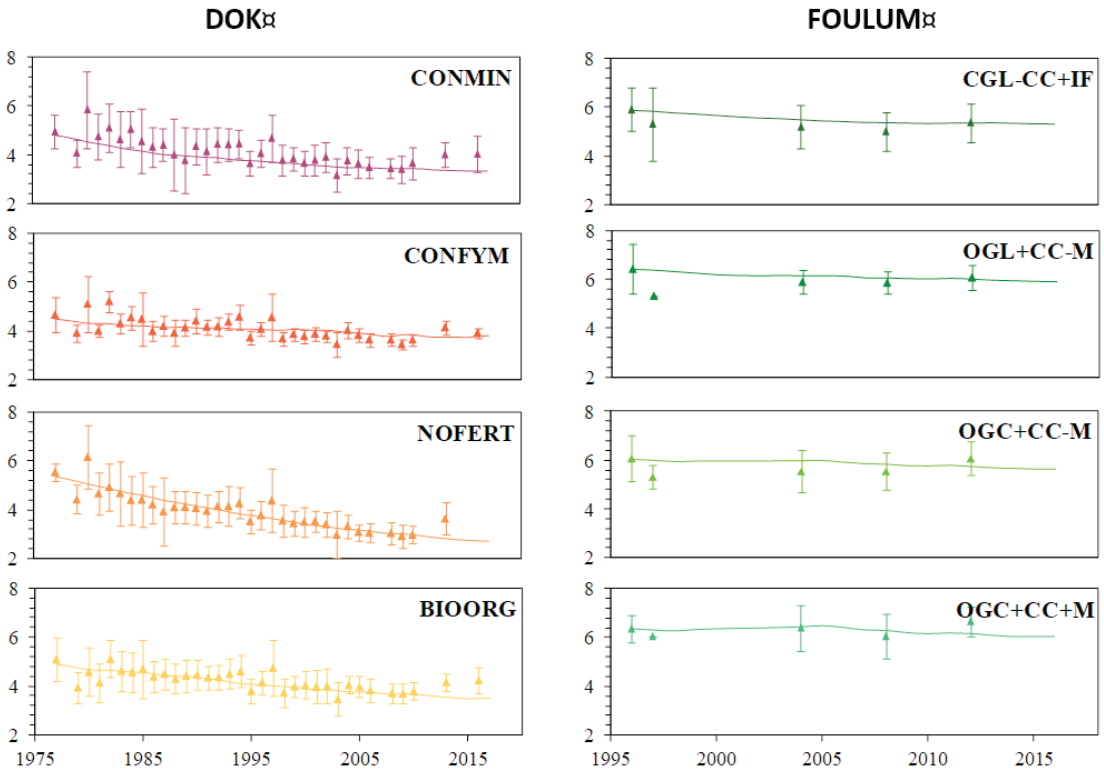

Figure 1. Evolution of SON stocks at DOK (0-20cm) and Foulum (0-25 cm). Lines display mean simulated values. Symbols (▲) display mean observed values ±SD (n = 3 at DOK, n = 4 at Foulum).

Keywords: STICS model, Greenhouse Gas Emission, SON storage, nitrate, Crop rotation.

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S2-O.12

Soybean fallows and nitrification inhibitors to reduce N_2O emission intensities in Australian sugarcane cropping systems

De Antoni Max[1] (max.deantoni@qut.edu.au), Parton William[2], Wang Weijin[3], Bell Michael[4], Grace Peter[1]

[1] *Queensland University of Technology, Brisbane, Queensland, Australia*; [2] *Colorado State University, Fort Collins, Colorado, United States*; [3] *Department of Environment and Science, Brisbane, Queensland, Australia*; [4] *The University of Queensland, Brisbane, Queensland, Australia*

Introduction

The Australian sugar industry is facing mounting pressure to reduce the use of N fertilisers and the nitrous oxide (N_2O) emissions associated with it (Bell et al., 2015). Research has shown that N_2O emissions from sugarcane cropping systems can be reduced with the use of fertilisers coated with nitrification inhibitors (Soares et al., 2015), or by sowing legume crops in the fallows between sugarcane crop cycles (Wang et al., 2015). However, the efficacy of these two N management strategies across different climatic zones is still unclear, as results from field studies have been contradictory. The objectives of this study were to use the DayCent model to assess the long-term effects of the two strategies (separately or in combination) on N_2O emissions, N losses and yields, and determine under what circumstances and in what climatic regions or soil textures these strategies are most effective.

Materials and Methods

The model was parameterised using data from eight field experiments (39 treatments) conducted across four of the five main districts of the Australian sugarcane industry. A series of long-term scenarios embracing a range of N fertiliser rates, climatic regions (Tropics and Subtropics), soil textures (fine- and coarse-textured soils) and N-loss risk scenarios (crop fertilised well before or close to the on-set of the wet season) were tested for both N management strategies.

Results and Discussion

Simulations identified that, in situations prone to elevated N losses (e.g. coarse-textured soils in the high N-loss risk scenario), the combined use of legume fallows and N fertiliser coated with a nitrification inhibitor was the most effective strategy to maintain or even increase current yields while significantly reducing N_2O and nitrate (NO_3^-) losses. When used alone, the soybean fallow strategy showed a limited capacity to reduce N_2O emissions over the entire cane crop cycle (median: -3% compared to farmer practice), or even increased them in scenarios at high-risk of N losses in the Tropics. Compared with farmer practice, the use of DMPP urea alone allowed fertiliser N rates to be reduced by 30% without any substantial yield penalty. In environments prone to high N losses, DMPP urea abated overall N losses and N_2O emissions by 41% and 30%, respectively.

In systems that already have limited N losses instead, the best strategy to maintain or even increase current yields would be the introduction of a legume fallow to reduce the fertiliser N rates only in the plant crop. Importantly, when used appropriately, all the strategies assessed in this study enabled substantial reductions of the N fertiliser rates currently used in the industry without incurring large yield penalties.

Conclusions

This study highlighted the potential to achieve large improvements in N use efficiency and reduction in N_2O emissions in the Australian sugar industry, without sacrificing productivity. Future experiments should strive to simultaneously assess plant N uptake and all N loss pathways (e.g. NO_3^- leaching and runoff, and N_2O and N_2 fluxes) to precisely determine N budgets and enable more accurate model parameterisations. As recommended by Galdos et al. (2017), these works should assess soil quality, nutrient cycling, greenhouse gas emissions, and crop production during the entire crop cycle (five years) using innovative techniques such as stable isotope labelling and intensive soil flux measurements with automatic chambers.

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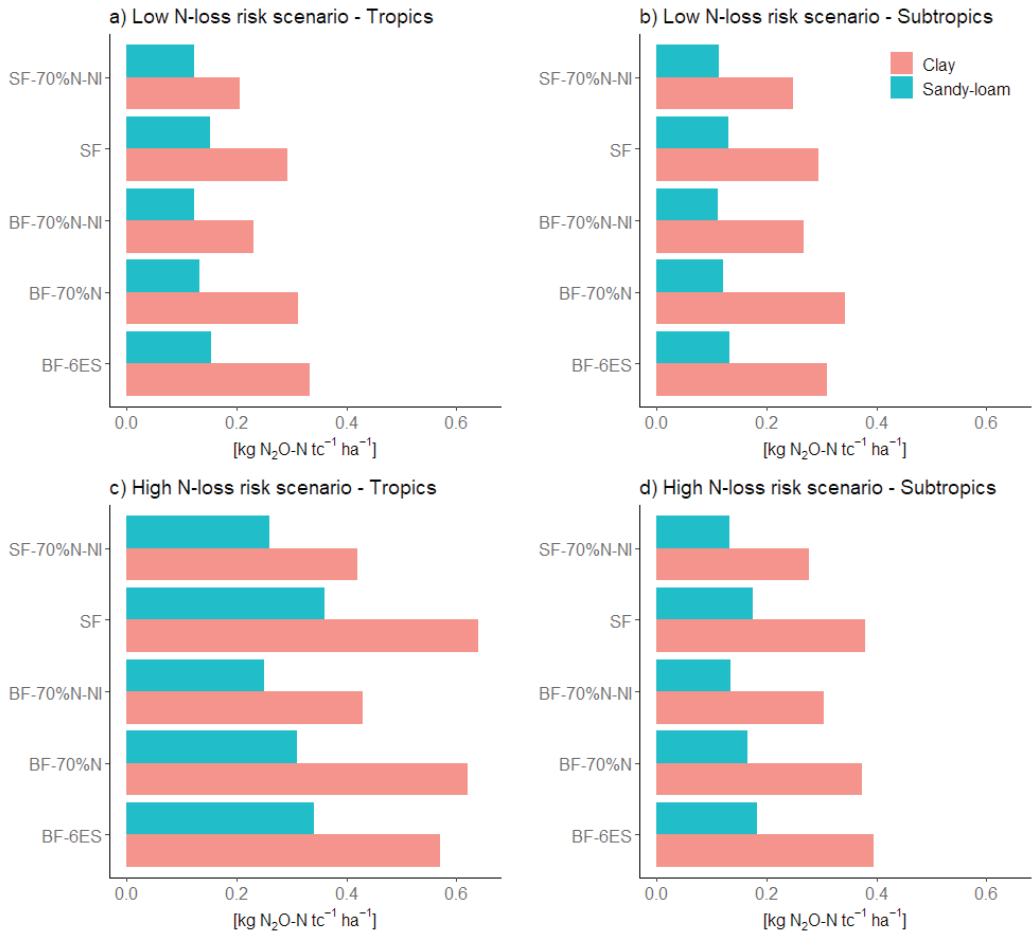

The combined use of legume fallows and N fertiliser coated with a nitrification inhibitor was the most effective strategy to maintain or even increase current yields while significantly reducing N_2O losses.
Here are shown the median N_2O emission intensities over the 6-year cycles of the five strategies across N-loss risk scenarios (High and Low), soil textures (Clay and Sandy-Loam) and climatic regions (Tropics and Subtropics).
BF-0N: Bare fallow followed by unfertilised sugarcane. BF-6ES: Bare fallow followed by sugarcane fertilised according to local recommendations using the Six Easy Step approach. BF-70%N: Bare fallow followed by all stages of the sugarcane cycle receiving 30% less N than with local recommendations using the Six Easy Step approach. SF: Soybean green manure crop grown during the fallow between crop cycles, after which the plant crop received 50% less N compared with the Six Easy Step approach. BF-70%N-NI: Bare fallow followed by all stages of the sugarcane cycle receiving 30% less fertiliser N (coated with DMPP) compared with local recommendations using the Six Easy Step approach.

Keywords: Sugarcane, N_2O emissions, Daycent, Nitrification inhibitors, Legumes.

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S2-O.13

Management of cover crops has to be climate and soil specific. A simulation approach

Meyer Nicolas[1] (nicolas.meyer@inra.fr), Constantin Julie[1], Bergez Jacques-Eric[1], Justes Eric[2]

[1] *UMR AGIR, INRA, Auzeville-Tolosane, France*; [2] *PERSYT Department, CIRAD, Montpellier, France*

Introduction

Cover crops provide multiple ecosystem services such as reducing nitrate leaching, providing "green manure" effect, improving soil physical properties, increasing carbon storage in the soil and controlling pests, diseases and weeds (Justes et al., 2017). Cover crops could also help mitigate and adapt to climate change (Kaye and Quemada, 2017) but modify soil water balance and fluxes.. They increase evapotranspiration by increasing cover transpiration and decrease soil evaporation, and then they reduce water drainage in temperate climates (Meyer et al., 2019). However, the equilibrium of these processes depends on cover crop management, climate and soil type. No consensus exists on the impact of cover crops on soil water availability for the next cash crop. Dynamic soil-crop models can be a powerful tool to estimate water fluxes that are difficult to measure in field experiments, such as drainage, evaporation, and transpiration. They can also be used over long climatic series. Such models can also simulate a wide range of cover crop management practices under diverse soil and climate conditions and then allow extrapolating results of field experiments that are expensive, time consuming and rare (Bergez et al. 2010). We hypothesis that the cover crop management must take into account soil and climate context to maximize the multiple ecosystem services and in the same times reduce the negative impact of cover crops on soil water balance and on the next cash crop. The goal of our study was to analyse by simulation the best cover crop managements according to soils and climates in the Adour-Garonne catchment.

Materials and Methods

We performed a multi-simulations approach with the STICS soil-crop model. The Adour-Garonne catchment (south-western France) soil and climate diversity was represented by an east west transect using five specific sites. We tested one bare soil management as control and three different cover crop species with several management: sowing (four dates), destruction (four dates), residues management (2 types), soil nitrogen initialization (2 types). We then tested two following cash crops for evaluating the following effect on sunflower (rainfed) and maize (irrigated).

Results and Discussion

Our results confirm that cover crops always reduce water drainage and increase evapotranspiration. However, the impact on the next cash crops depends on soil and climate, i.e. a yield reduction was simulated in dry sites and an increase in wet sites. On-going analysis of simulation outputs should enable us to determine whether these differences are due to a change in the water or nitrogen balance. A last step concerns the simulation of climate change, which would help to quantify the impacts on water fluxes in a near or a far future.

Conclusion

The study done after a double step of model calibration and validation shown that the variability of the soil and climatic context must be considered to identify the best cover crop managements; these are definitely site and climate-dependant. However, the potential of cover crop mulch to reduce soil evaporation before sowing the next cash crop was found a good compromise between improving cover crop services and decreasing negative impact on the water balance and its resulting consequences.

Keywords: STICS soil-crop model, Drainage, Water balance, Evapotranspiration, Climate Change.

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S2-O.14

A minimalist mixture model for cereal-legume intercropping

Berghuijs Herman[1] (herman.berghuijs@slu.se), Weih Martin[1], Van der Werf Wopke[2], Vico Giulia[1]

[1] *Department of Crop Production Ecology, Sveriges Lantbrukuniversitet, Uppsala, Sweden*; [2] *Centre for Crop System Analysis, Wageningen University and Research, Wageningen, The Netherlands*

Background

Cereals and legumes use different nitrogen pools to fulfill their nitrogen demand. While cereals take up nitrogen from the soil, legumes fix atmospheric nitrogen. Due to this niche differentiation, the cereal experiences less competition for nitrogen from a legume neighboring plant than from a neighboring plant of its own species, if the species are grown as an intercrop. In order to exploit the benefits in full, it is important that a farmer choses the adequate crop species and cultivar composition of such an intercrop. Yet, it is difficult to say a priori which combination of crop traits in an intercrop results in the highest yield, as this requires that the key interactions within and between species are considered simultaneously, together with local management practices, soil properties and climatic conditions. Models offer a powerful tool to explore a wide range of traits and trait combinations and pedo-climatic conditions. Existing crop models considering intercrops have often high parameter requirements, which hinders their application. In this study, we developed a Minimalist Mixture Model (M^3) to simulate cereal-legume system and identify suitable crop combinations for high yields.

Material and Methods

M3 simulates the daily biomass production and partitioning of one crop species (pure culture) or two crop species (intercrop) grown in either in row configurations or homogeneous mixed configurations. We calibrated the model on data of Dutch field trials of pure cultures of faba and spring wheat. Next, M^3 was applied to a fertilized wheat-fababean intercrop field grown in Uppsala, Sweden. Both crop species were sown and harvested at the same date. We run a sensitivity analysis for the thermal time from emergence to flowering using various combination of values for this parameter for wheat and faba bean. For each combination, we calculated the sum of yields of both species and the land equivalent ratio.

Results

The highest sum of yields can be obtained for intermediated thermal time for emergence until flowering (780 °C d for wheat and 500 °C d for faba bean). However, for this combination of values the land equivalent ratio is lower than 1. The land equivalent ratio increases if the thermal time of emergence to flowering for one species is considerably larger than of the other species.

Conclusion and Discussion

M^3 was used to find the combination of thermal times of both wheat and faba bean in an intercrop that results in the highest yield. We indeed found an optimal combination, but the land equivalent ratio for this combination was lower than 1. This means that growing the highest yielding crop species in a pure culture would result in a higher total yield than the intercrop. This is likely due to the fact that the system considered was well-fertilized, so that the wheat did not benefit from the lower competition for nitrogen due to the presence of the faba bean. In further research, we will apply the same type of sensitivity analysis for cereal-legume crops grown under lower nitrogen levels and for other plant traits to assess what combination of plant traits results in the highest total yields. We will then check whether this total yield is higher than the yield that can be obtained by growing the highest yielding species as a pure culture.

Acknowledgements

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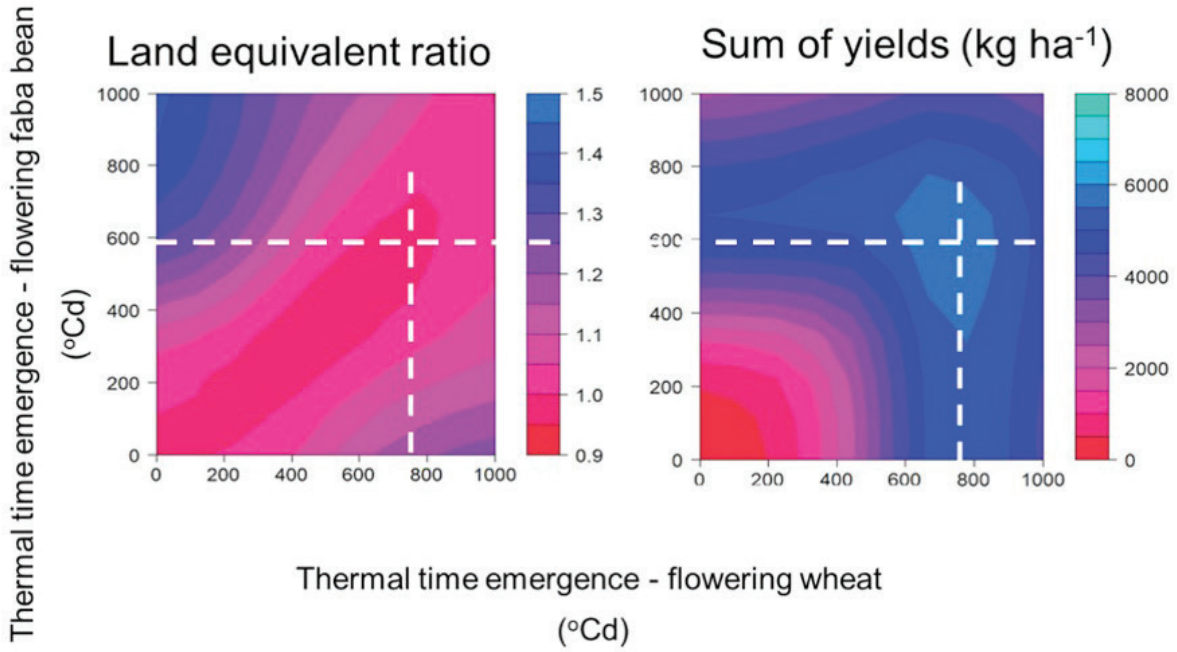

Figure 1: Land equivalent ration and sum of yields of both species in a faba bean - wheat intercrop.

Keywords: Intercropping, cereal-legume, land equivalent ratio, yield, crop model.

S2-O.15

Implementation of new formalisms in STICS for intercropping modeling

Vezy Rémi[1] (remi.vezy@cirad.fr), Munz Sebastian[2], Gaudio Noémie[3], Launay Marie[4], Paff Kirsten[5], Lecharpentier Patrice[4], Ripoche Dominique[4], Juste Eric[6]

[1] *UMR AMAP - BIOS, CIRAD, Montpellier Cedex 5, France*; [2] *Department of Agronomy, Institute of Crop Science, U. Hohenheim, Stuttgart, Germany*; [3] *AGIR, INRA, Toulouse, France*; [4] *US1116 Agroclim, INRA, Avignon, France*; [5] *UMR SYSTEM, INRA, Montpellier, France*; [6] *Persyst department, CIRAD, Montpellier, France*

Introduction

Intercropping, the mixture of species, is often proposed as an agroecological solution to meet several challenges, such as decreasing the use of chemical inputs and soil erosion, increasing crop productivity in low inputs conditions, and carbon sequestration. However, it is difficult and costly to evaluate the potential of all possible combinations of species and managements with field experiments. Crop models can be used instead to simulate scenarios for optimizing a specific objective considering given constraints (e.g. increase crop yield while reducing N inputs). The STICS soil-crop model was already adapted to simulate intercrops (Brisson et al., 2004; Launay et al., 2009), but the model failed to reproduce the competition for light, and particularly plant height (Corre-Hellou et al., 2009). Hence, our aim was to improve the current version of the STICS intercrop model to integrate (1) a computation of plant height linked to biomass, instead of leaf area, and (2) a revised computation of the equivalent density to better simulate the potential competition between plants. A second step was to evaluate the new intercrop model to verify the improvement in comparison to the previous version with simulations for various experiments taken from a comprehensive dataset.

Materials and Methods

The new version includes a new computation of plant height using an allometric relationship with the plant dry mass that can describe a large range of relationships while being robust and parameter scarce. It also includes some bug fixes and a new computation of the equivalent density, a concept first included by Brisson et al. (2004) to consider the interspecific competition between plants. After having implemented the new formalisms, they were evaluated using observations from durum wheat and pea grown either in sole crop or bi-specific mixed intercrop in Auzeville (France) for three years in 2007, 2010 and 2011. The parameters of the new formalism were calibrated using the sole crop data, except those only used for intercropping. Then, the simulated leaf area index (LAI), aboveground biomass and plant height were compared to measurements at different growth stages for each species, either in sole crop or in intercrop. The new version of STICS-intercrop was also compared to the previous.

Results and Discussion

The simulations for LAI, aboveground biomass and plant height were significantly closer to observations using the new version of STICS-intercrop compared to the previous version for the wheat-pea intercrop (Fig. 1). The new version decreased the error of simulation (RMSE) by 15.8 % on average for the two species and the three variables, and improved the average model efficiency from -0.27 to 0.53. These results show that the new formalisms included in STICS-intercrop are relevant. In order to define its validity domain, this version was also tested extensively using different N-treatments, species and pedoclimates in Paff et al. (2020). The sticRs (Vezy et al. 2019) package was used to perform simulations and analysis.

Conclusion

New formalisms were implemented in STICS-intercrop to model species mixtures with a higher accuracy while keeping a relatively simple approach (no plant architecture in 3D). The new version successfully simulated LAI, aboveground biomass and plant height for both wheat and pea grown in either sole or intercropping.

Acknowledgements

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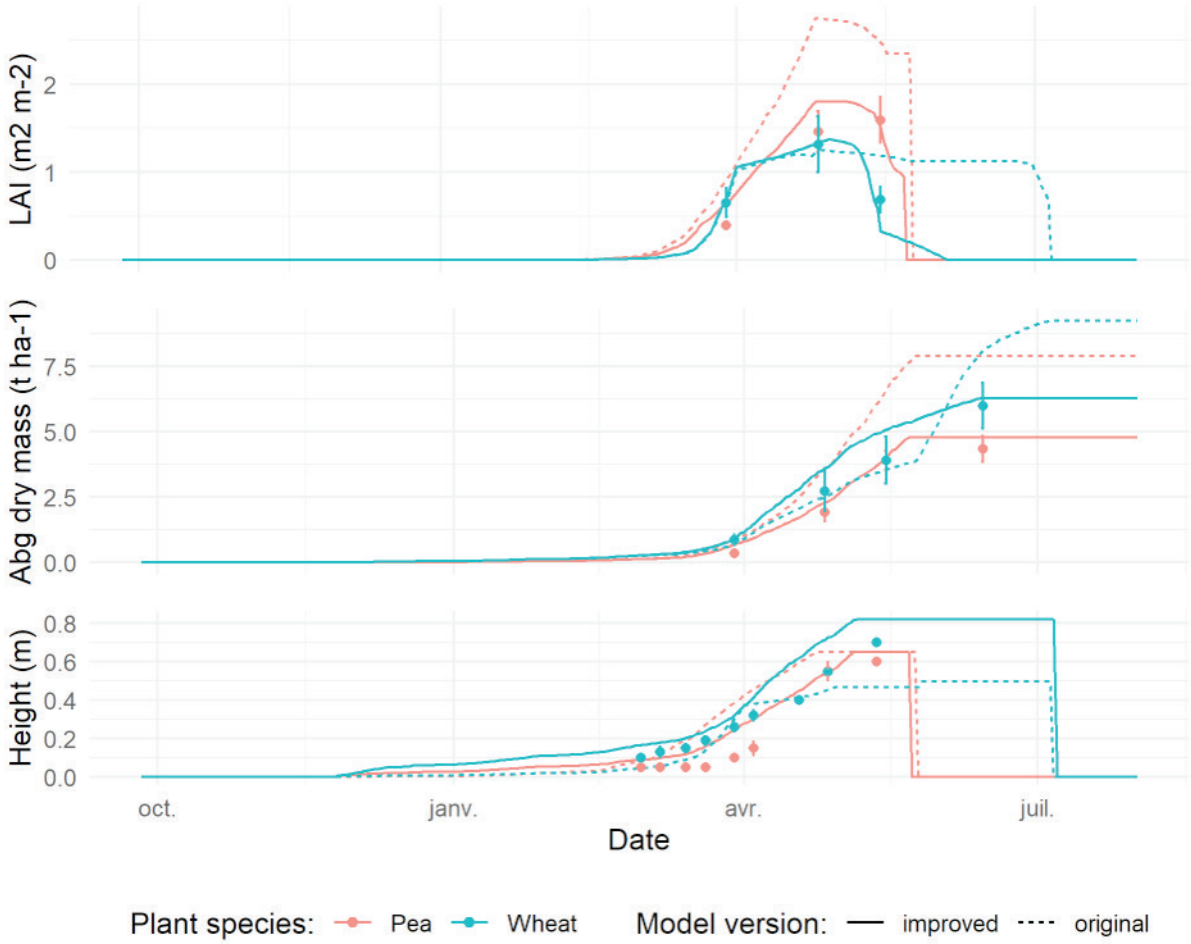

Figure 1. Simulated (lines) leaf area index (LAI), aboveground biomass, and plant height for each plant species for a wheat-pea mixture compared to observations (points).

Keywords: crop model, wheat, pea, ecological intensification.

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S2-O.16

Individual-based modelling as a tool to identify combinations of traits promoting overyielding in grass-legume mixtures

Louarn Gaëtan[1] (gaetan.louarn@inra.fr), Barillot Romain[2], Combes Didier[2], Escobar-Gutiérrez Abraham[2]

[1] *URP3F, INRA, Lusignan, France*; [2] *INRA, Lusignan, France*

The role of many plant traits involved in carbon (C) and nitrogen (N) economy on species balance and total above-ground biomass production of grass-legume mixtures is still to be determined. A modelling approach using the Virtual Grassland model [1, 2] was developed to explore key trait combinations favourable to overyielding and mixture persistence.

The model was previously calibrated for alfalfa-based mixtures [3]. Taking this calibration as a departure point, a first step consisted in running a sensitivity analysis. This allowed us to identify the model parameter (i.e. plant traits) most sensible to inter-specific competition among 30 candidate traits. A second step then consisted in testing the impact of sensible parameter combinations (selected to account for distinct physiological functions: light acquisition, mineral N acquisition, kinetics of growth and resource use efficiency) on virtual mixture performance. Each trait combination was assessed in a virtual experiment based on the de Wit's replacement design (Fig. 1A) that allowed us to assess density-dependent overyielding (Fig. 1B). Three pedo-climatic conditions, differing by their N fertility level (0N, 120N, 300N), were analysed.

Based on our simulations, maximal overyielding was achieved in cases where trait values were divergent for N acquisition (i.e. allowed complementarity in the use of different N pools) but convergent for light interception (i.e. limiting the asymmetric competition for light). The best combination of traits was not the same in all the pedo-climatic conditions tested and depended on the level of mineral N available into the soil. Random trait combinations could frequently lead to sub-optimal yields (i.e. less than a neutral situation of competition, Fig. 1C) and even to under-yielding situations (i.e. less than the average of monocultures). Such situations were frequent when non-legumes displayed late growth kinetics.

Overall, our study demonstrates how heuristic modelling can help to identify the most favorable combination of traits in a given pedoclimate [4].

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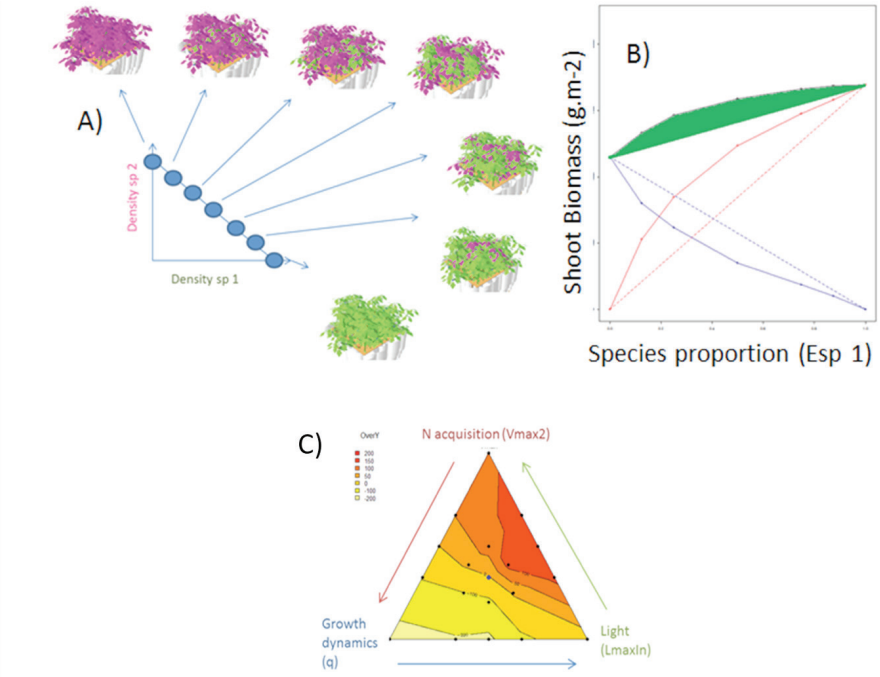

Figure 1. Virtual experiment design (A) and overyielding estimate (B, green area) used to asses a binary mixture – The example is for a neutral situation of competition where species differ by a single trait affecting N fixation C) Example of overyielding map for the 120N fetility level – The central blue point represents a neutral situation of completion; each corner indicates the maximal divergence for a single trait value in favor of grasses.

Keywords: Individual-based model, grass-legumes mixtures, overyielding, trait divergence, complementarity.

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S2-O.17

WALTer: modeling the impact of competition for light on the regulation of tillering in wheat cultivar mixtures

Blanc Emmanuelle[1] (emmanuelle.blanc@inra.fr), Thiaville Louise[1], Barbillon Pierre[2], Enjalbert Jérôme[1], Lecarpentier Christophe[1]

[1] *GQE - Le Moulon, INRA, Univ. Paris-Sud, Gif-sur-Yvette, France*; [2] *UMR MIA-Paris, AgroParisTech, INRA, Univ. Paris-Saclay, Paris, France*

Introduction

Increasing the within-field diversity is a key leverage of agroecology. For example, varietal mixtures could buffer environmental stochasticity, and improve the resilience of low-input cropping systems (Reiss and Drinkwater, 2017). However, many questions are raised by the complex interactions occurring in such variety mixtures, ranging from synergy to competition.

Wheat mixtures are a good model to study plant-to-plant interactions, as wheat is a strategic crop worldwide. Moreover, the use of wheat mixtures by French farmers has increased sharply in recent years, leading to a growing need for practical rules on how to design and manage such populations. Nevertheless, few studies have focused on reasoning the genetic composition of these mixtures in order to maximize complementarity and minimize competition between genotypes. In particular, how differences in traits of the aerial architecture can improve light interception and yield has been poorly studied, while mixing varieties with contrasted architectures has even been discouraged (Borg *et al.*, 2018) to avoid competition but discarding any potential beneficial role of such functional diversity.

Developing an ecophysiological modeling approach is particularly sound to understand the key mechanisms affecting light interception efficiency in mixtures, while offering an alternative to the complexity of experimental studies, due to almost infinite number of combinations of wheat cultivars that can be evaluated.

Materials and Methods

WALTer (Lecarpentier *et al.*, 2019) is a Functional Structural Plant model that simulates the development of wheat from sowing to flowering with a daily time step. The development of vegetative organs follows descriptive rules adapted from the ADEL-wheat model (Fournier *et al.*, 2003). The model simulates the plasticity of tillering in response to competition for light based on three simple rules: (I) tillers are emitted following a thermal time schedule and a fixed probability of emergence, (II) the emission of tillers stops due to an early neighbor perception and (III) tillers that don't intercept enough light due to shading regress.

Using this model, we simulated mixtures of 2 varieties differing only in height, with height differential varying from 0cm to 120cm. For each variety in mixture, we analysed the tillering dynamics, the Green Area Index dynamics and the amount of PAR (Photosynthetically Active Radiation) intercepted.

Results and Discussion

WALTer has shown its ability to reproduce accurately the plasticity of the tillering dynamics for contrasted sowing densities.

When used to simulate mixtures, WALTer showed that increased height differences led to more light interception that could lead to greater yield. Interestingly, the simulations have highlighted the non-additive properties of these mixtures, as the over-interception of PAR by the highest cultivar was always more important than the under-interception by the shortest.

Conclusions

WALTer, through an approximated but efficient modeling of tillering in wheat, allows for an exploratory approach of branching plasticity, and provides interesting insights on how competition for light functions in mixtures. It also paves the way for the optimization of the radiation interception efficiency in variety mixtures.

As the model is rather simple, it can be used in association with a population genetics model to study the evolution of wheat mixtures or segregating populations over generations of resowing.

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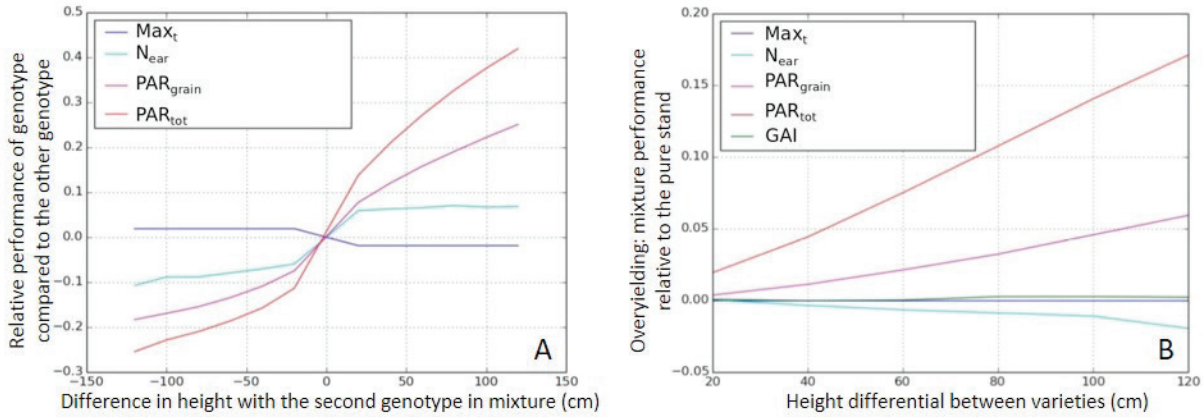

Figure 1: (A) Relative performance of genotype compared to the other genotype and (B) overyielding, as a function of the height differential between varieties (cm) for the maximum number of tillers emitted (Maxt), the final number of ears (Near), the maximum Green Area Index (GAI) and the cumulated amount of PAR (Photosynthetically Active Radiation) intercepted during the whole cycle (PARtot) and during the estimated period of grain formation (PARgrain).

Keywords: FSPM, plant-plant interaction, aerial architecture.

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ABSTRACTS PARALLEL SESSIONS

SESSION III

LINKING CROP/PLANT MODELS AND GENETICS

Following advances in genetics, genomics and phenotyping, plant breeding is limited by our ability to predict genotype x environment x management (GxExM) interactions. This session focuses on recent developments on prediction frameworks structured around crop/plant ecophysiology and modelling, and their application for crop improvement. This includes:

1. advances in GxExM modelling to guide research and breeding targets by characterising the target population of environments (TPE) and identifying traits most relevant to the TPE;
2. Approaches that link crop/plant models and genetics based on the dissection of complex traits into component physiological traits, and their application to evaluate the phenotypic performance of genomic regions underlying these adaptive traits. This includes methods linking crop/plant models with genomic prediction and/or breeding-system model;
3. Integration of crop/plant modelling and phenomics approaches to phenotype traits of interest in large number of genotypes.

This session will present studies working in these areas that enable linkage between crop/plant models and genetics, as well as their applications in predicting phenotypic performance and enhancing the rate of genetic gain. Studies on other related prospects such as GxExMxS (society) considering the end-users/farmer's demand are also welcome.

S3-Keynote

Utilization of crop modelling tools as a guiding principles in crop improvement programs; current status at CG-system

Kholova Jana (janakholova@yahoo.com)

GEMS, SACSAT, ICRISAT, Hyderabad, Telangana, India

Most of the crop improvement strategies in developing countries aim to produce few "broad-adapted genotypes" with superior performance across range of the agro-ecologies and mostly built-upon improvement of yield potential [1]. This approach payed off mainly in the regions with relatively stable environments, nevertheless, proved largely ineffective to accelerate production in context of extremely variable semi-arid tropical (SAT) agro-ecologies burdened with strong crop-management-environment (GxExM) interactions. One of the obvious obstacles to improve crop production in complex environments is that, breeding programs traditionally rely only on multi-location crop trials which evaluate the elite cultivars across limited number of sites and seasons and with limited management treatments which may not sufficiently represent the range of situations occurring within the main production agri-systems. Selections under such circumstances inevitably stagnates the crop production improvement. The on ground testing is also usually limited by availability of resources which one can use to optimize the management practices for any given cultivar at particular location. Therefore, it became very clear that major progress can be achieved only when the cultivar potential can be assessed across locations, representative sample of seasons and in combinations with various management options which is virtually impossible to test *in vivo* [2]. Accordingly, the most successful crop improvement programs operating in complex agro-ecologies pioneered the strategy of using the crop growth models in support of crop production improvement [3, 4]. Such approach requires welding together the traditional multi-location evaluations with models allowing extrapolation of crop testing across spatio-temporal scales. This approach multiplied the probability of selecting the plant material along with agricultural practices better suiting the particular geo-bio-physical context of given production system (concept of target population of environments [TPEs], [5]). In principle, the system modelling tool can be used to achieve the sufficient spatio-temporal scale needed in cropping system evaluations; (i) understanding the system production potential, the main limitations and identification of TPEs (ii) identification of the suitable GxExM interventions with high probability to maximize/stabilize the production within given region/TPE.

Generally, within the breeding programs there is at least minimum understanding of the main constraints limiting the crop production in the target agro-ecosystems (biotic and abiotic stress). However, very few programs pay attention to rigorous quantification of the stress severity, frequency and its effects on production across multiple locations and seasons which is the key to explain the yield losses. Crops simulation tools enable such analysis of the crop within the systems at relevant scale and so opens the possibility to identify the bio-geo-physical units with higher degree of similarities i.e. target population of environments; TPEs [5, 6, 7]. TPEs can then become the "geographically defined breeding unit" for which the particular GxM interventions could be developed to optimize the crop production. Importantly, the crop models enable the analyses of the future environments and so provide much needed insight into the strategy which needs to be adopted in order to adapt the cropping systems to the climatic changes. Furthermore, identification of TPE allows to optimize distribution of multi-location testing sites and/or avoid redundancies. TPEs analysis also helps interpreting the outcomes of multi-location trials within the TPEs and deploy appropriate statistical treatment. In short, the TPEs insight helps to avoid testing the crops in less relevant sites and selection of crops in abnormal years which do not sufficiently represent the most frequent environmental scenarios occurring at the particular TPE.

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The same simulation set-up used to define TPEs can be consequently used to identify the GxExM interventions with high probability to enhance the crop production/resilience within the system. The options identified in-silico can be specifically and non-redundantly targeted for in-vivo evaluation [8]; i.e. allows for testing specific plant types with specific management options in multi-location trials as opposed to conventional strategy of "testing everything everywhere". Therefore, models can be employed as decision making tool to quantitatively define some of the breeding targets which, in turn can be used to evaluate and optimize the economics of breeding programs, resource investments [resources/% genetic yield gain] and therefore improve efficiency of breeding programs.

Keywords: Crop growth model, CGIAR institutions, crop improvement programs.

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S3-O.01

Adaptive landscapes to explore genetics and environment

Truong Sandra[1] (sandra.huynhtruong@corteva.com), McCormick Ryan[1], Rotundo Jose[1], Boer Martin[2], Messina Charlie[1]

[1] *Predictive Agriculture, Corteva Agriscience, Johnston, Iowa, United States*; [2] *Biometris, Wageningen University and Research, Wageningen, Gelderland, Netherlands*

Introduction

While traditional breeding strategies select predominately for yield performance in a target population of environments, yield is a non-linear combination of constituent processes ranging from traits proximal to yield formation, to genes that determine how the plant integrates environmental information. The combination of these component traits and yield represent a high-dimension landscape over which breeding and agronomy programs explore to identify optimal performance. Here, we explore the theoretical performance landscape of yield from radiation use efficiency, phenology, and harvest index, and explore the trajectory by which a panel of elite soybean commercial releases explored the landscape. We also explore the theoretical performance landscape of yield based on precipitation. This characterization of the trait and environment space can inform and aid design of breeding and agronomy programs by suggesting optimal tradeoffs of exploration versus exploitation in optimization strategies.

Methods

Landscapes of multiple models were evaluated including a process-based model, a static model generated by dimensional analysis, and a dynamical systems model of ordinary differential equations (Sinclair, 1986; Montieth, 1977). These experimental and simulated yields of a panel of elite soybean commercial releases were projected and examined in the landscapes constructed (de Felipe et al., 2016).

Results

The yield landscapes of process-based or mechanistic crop models can be relatively simple despite the models' complexity, particularly when only considering one environment. These landscapes have the potential to be captured by simpler, more easily parameterized models. In the comparison of the process-based model to the static model derived from dimensional analysis, the landscapes captured the same relative trends for a given environment. However dynamic systems models are useful for capturing temporal variation. When examining temporal variation such as where the amount of water available to the plant is the same but the timing in which it is available is different, static models require different covariates or restructuring to capture this variation. Generally, a static model would be unable to capture the variation introduced by temporal dynamics, whereas the dynamic model more explicitly incorporates the timing of water availability leading to different landscapes. Trait projections of RUE, HI, and R7 into an embedded 2D space reveal distinct trajectories of genetic gain. When reducing the dimensions of 3 explanatory variables into 2 composite explanatory variables, distinct trajectories of genetic gain appear to be present.

Conclusions

The concept of adaptive landscapes has been considered for over a century starting with Armand Janet's phenotypic selective surface in 1895, Sewell Wright's genetic frequency landscape in 1932, Simpson's phenotypic evolutionary landscapes in 1930's, and the present-day molecular landscapes like the Kauffman's NK model (Dietrich and Skipper, 2015; Kauffman and Levin, 1987). When environments are sufficiently similar, simpler models can capture the topography of the landscape, reflecting the wide success of linear models and closed-breeding programs targeting specific TPEs in the modern seed industry. More complex combinations of environments and genetics require more complex models to explain variation and may favor exploration strategies over exploitation strategies.

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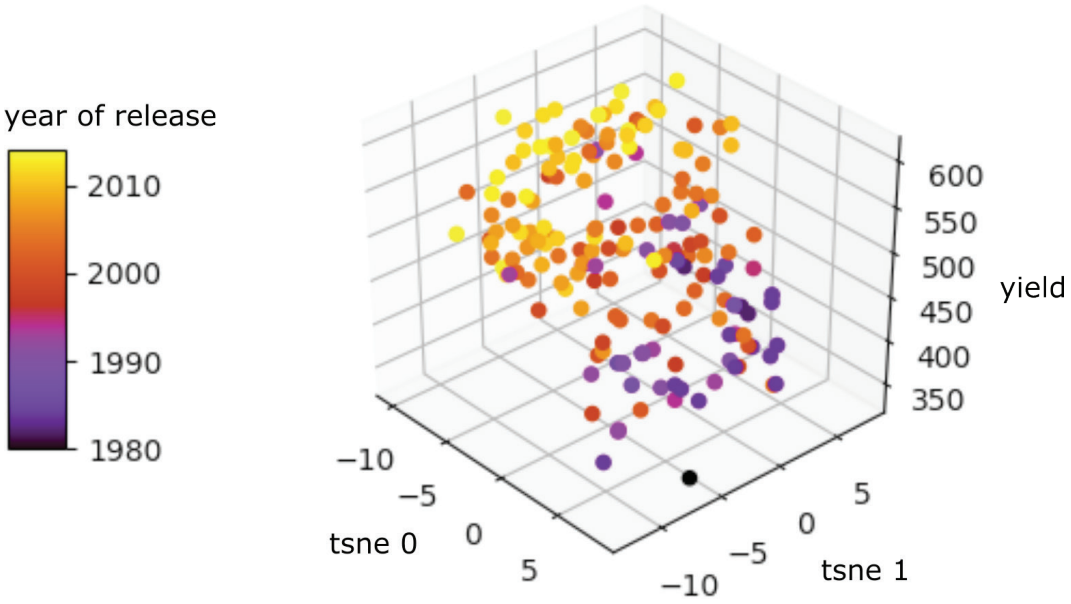

t-distributed Stochastic Neighbor Embedding (t-SNE) of physiological traits radiation use efficiency, harvest index, and days to physiological maturity versus yield of a panel of elite soybean commercial cultivars

Keywords: adaptive landscape, crop growth model, genetics, environment.

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S3-O.02

Optimized cultivar deployment improves the efficiency and stability of sunflower crop production at national scale.

Casadebaig Pierre[1] (pierre.casadebaig@inra.fr), Gauffreteau Arnaud[2], Langlade Nicolas[3], Mestries Emmanuelle[4], Sarron Julien[5], Trépos Ronan[6], Debaeke Philippe[1]

[1] *UMR AGIR, INRA, Castanet-Tolosan, France*; [2] *UMR Agronomie, INRA, Thiverval-Grignon, France*; [3] *UMR LIPM, INRA, Castanet-Tolosan, France*; [4] *Terres Inovia, Castanet-Tolosan, France*; [5] *UMR HortSys, CIRAD, Montpellier, France*; [6] *UR MIAT, INRA, Castanet-Tolosan, France*

Plant breeding programs design new crop varieties which, while adapted to distinct population of environments, are nevertheless grown over large areas during their commercial life.
Over this global farming area, the crop is exposed to highly diverse stress patterns caused by climatic uncertainty and various management options, that can often lead to decreased crop performance regarding to the expected level (yield gap).
Phenotypic plasticity is defined as the range of phenotypes a single genotype can express as a function of its environment (Nicotra et al., 2010). At the population level, this process underlies the relative variation in performance of varieties across environments. It is commonly referred as genotype x environment interactions in plant breeding and agronomy and can explain up to 20% of total yield variance observed in multi-environment trials.

In this study, our aim is to assess how a finer spatial management of genetic resources could reduce the genotype-phenotype mismatch in farming environments and ultimately improve the efficiency and stability of crop production. We used modeling and simulation to predict the crop performance resulting from the interaction between cultivar growth and development, climate and soil conditions, and management actions (Casadebaig et al., 2016). We designed a computational experiment that evaluated the performance of a collection of commercial sunflower cultivars in a realistic population of farming environments in France, built from agricultural surveys (Sarron et al., 2017). Distinct farming locations that shared similar simulated abiotic stress patterns were clustered together (Chenu et al., 2013) to specify environment types (figure 1). Optimization methods were then used to search for cultivars x environments combinations that lead to increased yield expectations.

Results showed that a single cultivar choice adapted to the most frequent cropping environments is a robust strategy. However, the relevance of cultivar recommendations to specific locations was gradually increasing with the knowledge of pedo-climatic conditions. At the national scale, tuning the choice of cultivar impacted crop performance the same magnitude as the effect of yearly genetic progress made by breeding.

We argue that this approach, while being operational on current genetic material could act synergistically with plant breeding as more diverse material could allow access to cultivars with distinctive traits that are more adapted to specific conditions.

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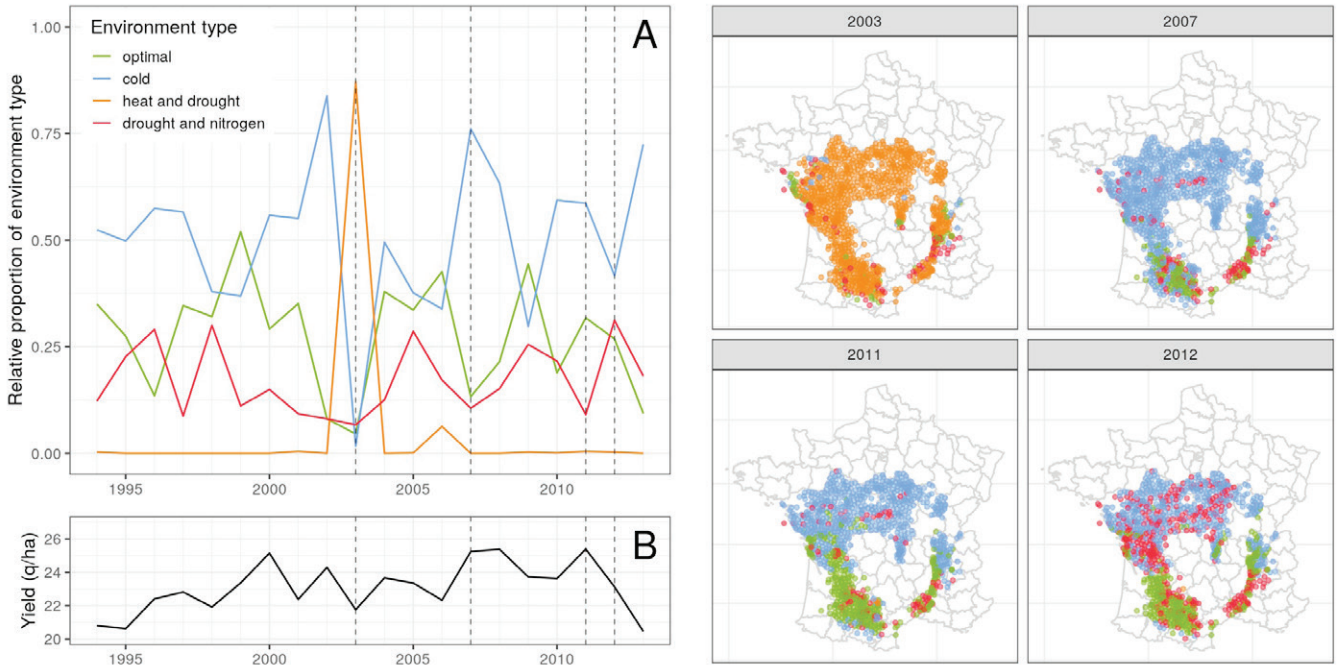

Figure 1. Temporal and spatial distribution of environment types. The panel A displays the evolution of the relative proportion of environment types over 20 years. For reference, panel B is the national sunflower yield. The right panels display the spatial distribution of environment types (colors) for each individual farming condition (dots) of the sampled cropping area, for a subset of four contrasted years.

Keywords: crop management, phenotypic plasticity, modeling, genotype-by-environment interactions, sunflower crop.

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S3-O.03

Integrating crop modelling, physiology and genetics to aid crop improvement in changing environments

Chenu Karine (karine.chenu@uq.edu.au), Harris Claire, Ababaei Behnam

QAAFI, The University of Queensland, Toowoomba, QLD, Australia

Introduction

Following advances in genetics, genomics and phenotyping, trait selection in breeding is limited by our ability to understand interactions within the plant and with the environment, and to identify traits of most relevance to the target production environments. Crop models provide a means to predict the potential value of traits across a wide range of environments (e.g. Chenu et al., 2017). When looking across traits, a recent study investigating the value of all traits from a crop model in Australian environments (Casadebaig et al., 2016) found that high-impact traits were related to water capture and usage (root system and transpiration efficiency), light capture and usage (above-ground architecture and photosynthesis), phenology and biomass partitioning. While most of those traits or processes have been studied to different extents, we focus here on transpiration efficiency (TE), i.e. the amount of biomass produced per unit of water transpired.

Component traits of TE that have shown genotypic differences include (1) the ability to limit transpiration rate per unit leaf area under high vapour pressure deficit (VPD; Schoppach and Sadok, 2012) and (2) photosynthetic capacity (Silva-Perez et al., 2018). Here, we dissected variation in TE for contrasted wheat genotypes and simulated the impact of such variability on wheat yield across the Australian production environments with an improved version of the APSIM crop model.

Materials and Methods

Six wheat genotypes with contrasted TE (Mace, Janz, Scout, Seri-M82, Drysdale and Suntop) were grown in a lysimetry platform (Chenu et al., 2018) under unrestricted water. Water use was measured automatically from sowing until harvest, around the flag-leaf stage. TE was calculated as the ratio of above-ground dry biomass produced per cumulative gram of water transpired from sowing. Photosynthetic capacity was measured with a LI-COR LI6400. Normalised transpiration rate (TR) of each pot was calculated as hourly TR divided by the TR recorded the same day at a VPD of 1.2 kPa.

A new transpiration module was implemented to an improved version of APSIM from Zheng et al. (2019) as described in Ababaei et al. (2019). The module calculates hourly TR as a function of VPD and soil-water status. Simulations were performed at 60 sites across Australia between 1988-2017 for five sowing dates, five initial soil moisture levels at sowing, and local N application rates (Chenu *et al.*, 2013). Cultivar Hartog (i.e. no TR restriction by VPD) and a virtual genotype with a TR reduced by 30% at VPD>1.3 kPa, as observed experimentally, were simulated.

Results and Discussion

Genotypic differences were observed withTE ranging from 4-4.5 (Mace and Janz) to ~5.5 g kg^{-1} (Drysdale and Suntop). Low-TE genotypes were found to have a normalised TR that increased linearly with VPD, while high-TE genotypes tended to conserve more water at high VPD. For VPD>1.3 kPa, high-TE genotypes Drysdale and Suntop had a normalised TR 28% lower than low-TE genotypes Mace and Janz. No significant differences were found in photosynthetic capacity except for Mace, which had a lower photosynthetic rate.

A new transpiration module was incorporated in APSIM to simulate the genotypic differences observed in response to VPD. When tested across five experiments including a wide range of management practices, the new model produced better estimates for in-season LAI and biomass, and yield at maturity (Ababaei et al., 2019).

Reduced TR at high VPD led to higher yield in most sites across the Australian Wheatbelt. The greatest benefits were simulated for the eastern part of the Wheatbelt, where crops heavily rely on water stored in the soil. In such environments, restricting water loss during the hot hours of the day allows crops to save water e.g. during early development so that they can use it later at more sensitive growth stages. Across Australia, reduced TR at high VPD increased yield in over 70% of the scenarios tested (year × site × management combinations) and only rarely had substantially adverse effects due to limited water loss restricting CO_2 uptake and hence photosynthesis.

Given the potential value of TE and limited TR at high VPD, a genetic study was conducted to identify underlying molecular markers and assist breeding for more crop per drop (Fletcher et al., 2019).

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Conclusion

TE was found as a valuable trait to increase productivity in previous modelling studies. Physiological dissection of TE highlighted that genotypic variations in TE were related to the level of normalised TR at high VPD. Crop modelling revealed that this trait is expected to increase wheat productivity most seasons across most of the Australian Wheatbelt. The greatest benefits were simulated for the eastern part of the wheatbelt, where crops rely on stored soil moisture. Based on these results, a genetic study was conducted to identify underlying molecular markers and further assist breeding programs.

Keywords: wheat, APSIM, breeding, water deficit, transpiration.

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S3-O.04

Yield prediction based on QTLs for component traits in yield dissection models

Tsutsumi-Morita Yutaka[1] (yutaka.tsutsumi@wur.nl), Khaleghi Sedighehsadat[1], Heuvelink Ep[1], Van Voorn George.A.K.[2], Marcelis Leo.F.M.[1], Van Eeuwijk Fred.A.[2]

[1] *Horticulture and Product Physiology, Wageningen University and Research, Wageningen, Netherlands*; [2] *Biometris, Wageningen University and Research, Wageningen, Netherlands*

Introduction

Yield is an important breeding target. Yield has been improved by selecting yield itself phenotypically and genotypically. Although yield has been increased for decades, yield trends seem not to be sufficient to keep pace with the increase in world population.

Yield has been selected for yield itself. However, selection for yield itself does not clarify the physiological reason why a genotype shows higher yield than others. One of the promising methods is to combine crop models with genetic information. A crop model helps to understand the underlying physiology of yield. Genetic information was integrated into crop models by estimating genetic coefficients from the effects of known genes (White and Hoogenboom, 1996); by predicting component traits or parameter values by using quantitative trait loci (QTLs) (Yin et al., 2002; Chenu et al., 2009); and by predicting parameters by whole genome prediction (Technow et al., 2015). The advantage of using crop models for breeding is that we understand the relationship among traits. This is important because a significant increase in one component may not necessarily result in an increase in crop yield (Yin and Struik, 2008). Although several studies were conducted by combining crop models and genetic information, more research is needed to make this knowledge applicable for breeding.

In this study, we used two yield dissection models, where we included QTLs for component traits. Component analysis often formulated yield as a product of grain number and grain weight (we call it sink dissection). Sink dissection is very useful to investigate the relationship between grain number and grain weight. However, sink dissection does not evaluate how much photoassimilate is produced (source strength), and how much ratio of photoassimilate is allocated to yield. To evaluate this, we need another dissection (we tentatively call it source dissection). Yield is dissected into the water content of harvested organs and the total dry weight of harvested organs, which are further dissected into total plant dry weight and harvest index. By using both sink dissection and source dissection, we understand how yield is physiologically formulated. The objective of this study is 1) to understand how yield is composed of component traits; 2) to investigate how yield QTLs were underpinned by QTLs for component traits; 3) to assess the possibility of yield prediction by using yield dissection models, where each component trait was predicted by own QTLs. If we can predict yield by QTLs for component traits, then we can breed the high-yield line by looking into the component traits.

Materials and Methods

We phenotyped an indeterminate tomato population of 700 hybrids that were crosses between 350 recombinant inbred lines (RILs) and two elite lines. The 350 RILs were originated from four parents: two elite lines and two wild ancestors. Yield and component traits were measured during a whole-season in a commercial tomato greenhouse in the Netherlands.

Component traits were selected based on yield dissection models. In sink dissection, yield was dissected into number of fruits and individual fruit fresh weight. In source dissection, yield was dissected into the reciprocal of fruit dry matter content and total fruit dry weight. Total fruit dry weight was further dissected into the fraction of partitioned to fruit and total plant dry weight.

QTLs were detected by a mixed model approach, where we used Identity by Descent probabilities between parents and offspring. After the single-QTL analysis at each marker position, the multi-QTL model was used to predict each trait. Yield was predicted in two ways: (1) from QTLs for yield itself; (2) from yield dissection models, where each component trait was predicted by own QTLs.

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Results and Discussion

Yield positively correlated with both number of fruits and individual fruit fresh weight in sink dissection; however, there was a negative correlation between these two component traits. This result indicated that the increase in number of fruits or individual fruit fresh weight does not necessary result in yield improvement. On the other hand, the source dissection showed that yield positively correlated with the reciprocal of fruit dry matter content and total fruit dry weight. Because these two component traits showed no correlation with each other, we can control these two component traits independently. The total fruit dry weight further correlated with total plant dry weight. We detected QTLs for yield and component traits. Most QTLs for yield colocalized with QTLs for component traits. Prediction abilities were similarly high between the yield prediction from QTLs for yield itself and the yield prediction from yield dissection models where each component trait was predicted by own QTLs.

Conclusions

Our results show that there is a possibility for making a breeding strategy for high yield by looking into component traits in yield dissection models.

Keywords: breeding, multi-parent population, sink-source, tomato.

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S3-O.05

A phenomics-based model to identify achievable ideotypes of leaf growth in the diversity of European environments

Parent Boris[1] (boris.parent@inra.fr), Lacube Sebastien[1], Hammer Graeme[2], Tardieu François[1]

[1] *LEPSE, INRA, Montpellier, France*; [2] *Centre for Crop Science, University of Queensland, Brisbane, Australia*

Introduction

Under soil water deficit, plants limit transpiration by decreasing leaf area to save water for the end of the crop cycle. However, a large trade-off exists between of saving water and its negative effect on cumulated photosynthesis. It is therefore essential to identify "where and when" a given combination of traits values (ideotype) related to leaf growth results in a comparative advantage on crop production.

Materials and Methods

For this purpose, (i) we developed a phenomic-based model of leaf development and expansion (elongation and widening) for which parameter values can be obtained in phenotyping platforms for hundreds of maize hybrids. (ii) We parametrised 254 maize hybrids maximising the maize genetic diversity (iii) we simulated the optimum crop cycle duration in current and future European environments and (iv) determined ideotypes of leaf growth adapted to the different environmental scenarios.

Results and Discussion

Results indicate that sensitive hybrids perform better in southern Europe under rainfed conditions while less-sensitive genotypes perform better in northern Europe or in irrigated fields. However, the best combinations of parameters determined in an unconstrained phenotypic space were not available in the observed genetic diversity. Overall, we provide elements on where and when a combination of trait values can give a comparative advantage on yield, together with the boundary of possibilities within the current genetic diversity.

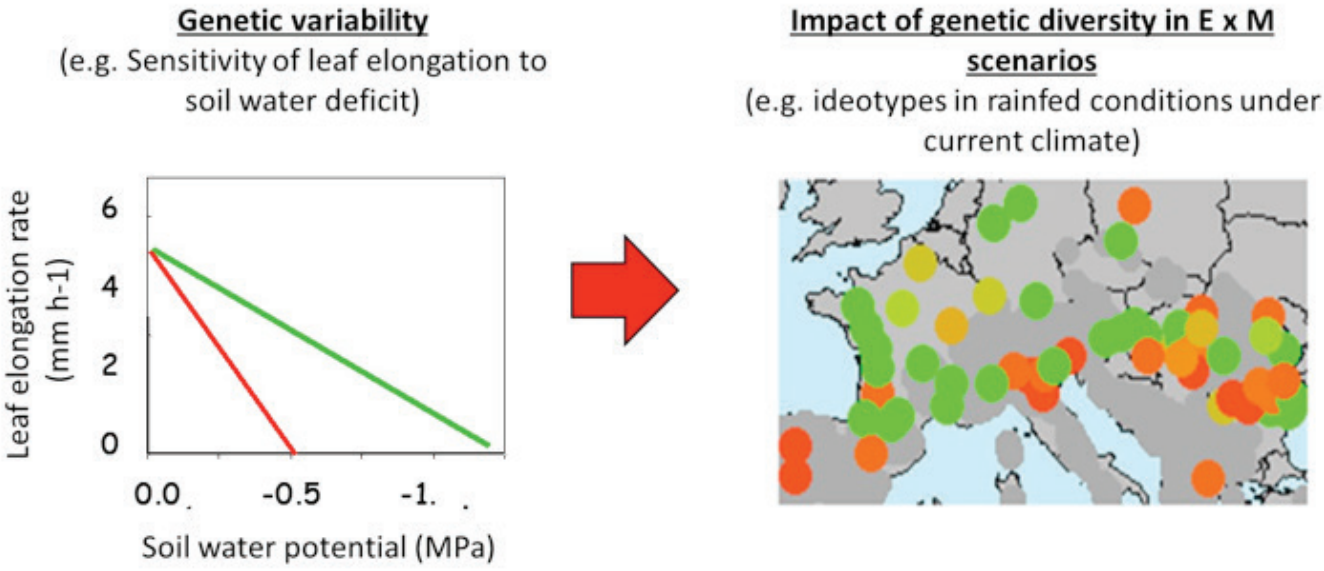

Figure 1. Impact of the genetic diversity of the sensitivity of leaf elongation to soil water deficit on maize yield under rainfed conditions in 59 european field sites. Colors indic ate which trait value (ideotype) provides a c omparative advantage on crop yield.

Keywords: genetic diversity, leaf growth, G x E x M, climate change, yield predictions.

S3-O.06

Crop model-aided genomic prediction: a multi-model study on rice phenology

Yang Yubin[1] (yyang@aesrg.tamu.edu), Wilson Lloyd T.[1], Li Tao[2], Paleari Livia[3], Confalonieri Roberto[3], Zhu Yan[4], Tang Liang[4], Tao Fulu[5], Chen Yi[6], Hoogenboom Gerrit[7], Boote Kenneth J.[7], Gao Yujing[7], Onogi Akio[8], Nakagawa Hiroshi[9], Yoshida Hiroe[9], Yabe Shiori[8], Dingkuhn Michael[10], Lafarge Tanguy[10], Wang Jing[1]

[1] *Texas A&M AgriLife Research Center, Beaumont, TX, United States*; [2] *DNDC Applications Research and Training, Durham, NH, United States*; [3] *Cassandra lab, ESP, University of Milan, Milan, Italy*; [4] *Nanjing Agricultural University, Nanjing, China*; [5] *Chinese Academy of Sciences, LUKE, Beijing, China*; [6] *Chinese Academy of Sciences, Beijing, China*; [7] *University of Florida, Gainesville, FL, United States*; [8] *Institute of Crop Science, NARO, Tsukuba, Japan*; [9] *Ins. for Agro-Environmental Science NARO, Tsukuba, Japan*; [10] *UMR AGAP, CIRAD, Montpellier, France*

Introduction

The ability of biophysical crop models to decompose complex traits and processes enables them to explicitly account for G×E×M interactions while integrating the contributions of multiple component traits. For this reason, crop model-aided genome-wide association study (GWAS) and genomic prediction (GP) are increasingly considered as a powerful technology to extend the potentiality of genomics research (Messina et al., 2018). The objective of this study was to evaluate the feasibility of integrating plant genomics with crop modeling to predict days to flowering, a complex plant phenotypic trait that is controlled by multiple interacting genes.

Materials and Methods

We used an ensemble of seven rice models from the AgMIP project differing in structure and parameters to investigate the possibility to increase the reliability of model-based GP through the use of multi-model approaches. The complex target trait was days to flowering recorded in a rice diversity panel with 169 accessions and 700K SNPs for 10 environments (location × year × sowing date) covering a wide range of conditions for temperature and photoperiod. The complex trait was decomposed into simpler component traits codified in parameters (e.g., daylength sensitivity, base temperature for thermal time accumulation) according to the algorithms used by the different models to reproduce phenology. Genotype-specific parameter values were first derived through optimization, and then estimated via GP based on the most significant SNPs from GWAS. A replicated 13-fold cross-validation scheme was used to evaluate the accuracy of the days to flowering simulated by crop models based on genomic-predicted model parameters. Relationships between parameters and markers at positions close to known major genes affecting heading date were also evaluated.

Results and Discussion

Pearson correlation coefficients between predicted and observed days to flowering among the seven models ranged from 0.35 to 0.97 for calibration and from 0.23 to 0.75 for evaluation (Figure 1 for two rice models). A large heterogeneity was observed among models both in terms of average performance and differences in accuracy between calibration and evaluation, suggesting that, besides model structure the number of model parameters used also plays a key role, with the worst performance for models that had many genetic parameters simultaneously optimized. Significant associations between parameters and markers close to known heading date genes (e.g., *Hd1*, Yano et al., 1997) were found, supporting the role of crop models in decomposing complex traits and linking phenotypic response with information at genome level.

Conclusions

This research demonstrates the usefulness of using multi-model ensembles in model-aided GP, opening new opportunities for the integration of genomics and crop modeling. The heterogeneity in model structures and the distinct approaches to decompose complex traits into simpler component traits could represent a solution to reduce the uncertainty due to the imperfect relationships between plant physiology and genetics as formalized in existing crop models.

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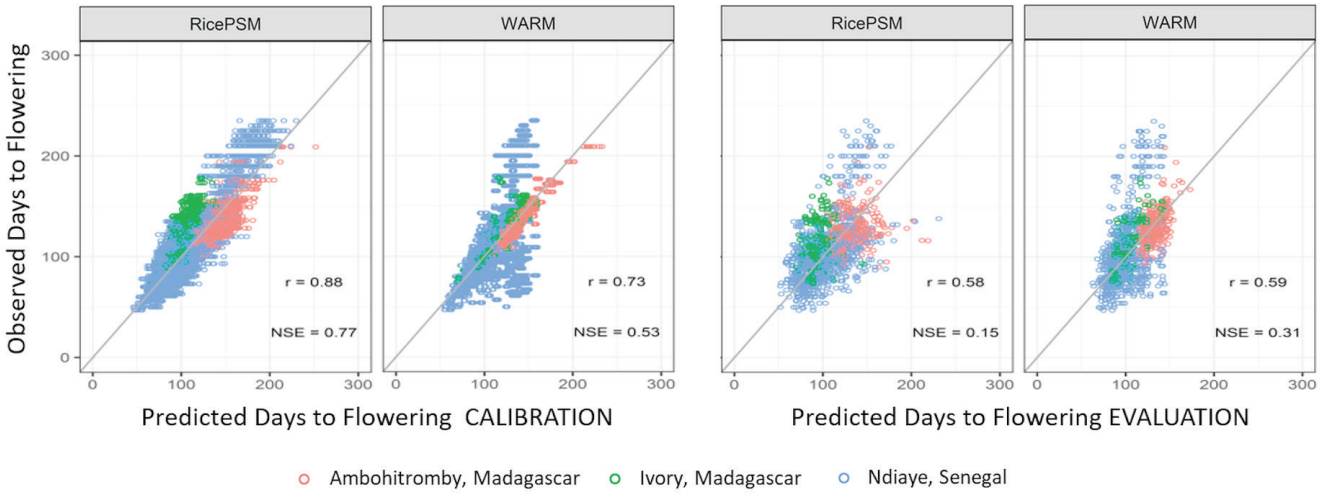

Agreement between observations and days to flowering simulated by using genomic-predicted model parameters for the rice models RicePSM (Wu and Wilson, 1998) and WARM (Confalonieri et al., 2009). NSE: Nash-Sutcliffe Efficiency.

Keywords: Gene-Based Modeling, GWAS, Genomic Prediction, Model Parameters.

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S3-O.07

Substantial increase in yield is predicted by designing wheat ideotypes for Europe under future climate

Senapati Nimai (nimai.senapati@rothamsted.ac.uk), Semenov Mikhail A.

Rothamsted Research, Harpenden, Herts, United Kingdom

Introduction

A considerable increase in food production is needed to underpin future global food security. Raising upper limits in crop yield potential is the key for increasing food production under future climates. Europe is the largest wheat producer delivering 20% wheat globally, but its genetic yield potential under future climate is yet unknown (Semenov et al., 2014). The study objective was to design in silico future wheat ideotypes based on state-of-the-art knowledge in crop physiology and availability of genetic variation, and to assess genetic yield potential of wheat in Europe under future climate.

Materials and Methods

Representative sites across Europe were selected, covering the major wheat growing regions in Europe, from Spain in the south to Denmark in the north, and Hungary in the east to the UK in the west. To estimate variation in wheat yield due to inter-annual variation in climate and climatic extremes, a 100 years of daily weather data at each site was generated by using a stochastic weather generator (LARS-WG 6.0) for baseline and future climates. The target 2050-climate was based on projection from a global climate model HadGEM2 from the CMIP5 ensemble for the RCP8.5 The Sirius wheat model was used to design wheat ideotypes. It includes a computational framework facilitating design of crop ideotypes and optimization of cultivar traits in a target environment (Semenov et al., 2013). An ideotype was defined as a set of Sirius cultivar parameters (traits) that would deliver high yield when optimised in a target environment, representing an ideal wheat plant. A total of seven Sirius cultivar parameters representing different wheat cultivar traits, e.g. canopy architecture, growth rates, phenological development, response to abiotic stresses (Senapati et al., 2019b), were selected for optimization due to their a) importance for crop yield improvement under climate change, b) large natural variations observed in wheat germplasms, c) potential for improvement through genetic adaptation. An evolutionary search algorithm with self-adaptation (EASA) was used in Sirius to optimize cultivar parameters in a high-dimensional parameter space with a complex fitness function for the best performance of wheat ideotypes.

Results and Discussion

Genetic yield potential was assessed by optimizing wheat ideotypes to maximize grain yield under 2050-climate. Two distinct types of wheat ideotype were designed viz. heat and drought sensitive (iS) or tolerant (iT) around flowering (Senapati et al., 2019a). A wheat yield potential of 9-16 t ha^{-1} was estimated for iS under rainfed conditions for the 2050-climate in Europe, while a yield potential of 12-17 t ha^{-1} was estimated for iT. The mean yields of iS (12.8 t ha^{-1}) and iT (14.4 t ha^{-1}) ideotypes represent 66% and 89% greater yield potential compared to current local cultivars under baseline climate, and 47% and 67% greater compared to current local cultivars under the 2050-climate. Wheat ideotypes, optimised for 2050-climate in Europe, show a substantially greater yield compared to current local cultivars. An optimal crop phenology (flowering, grain filling and maturity) under future climate was the main driving force for high yield potential of wheat ideotypes. Others key traits were identified as tolerance to heat and drought stresses around flowering, optimal canopy structure (leaf area and “stay green”) and root water uptake, and tolerance to drought stress. Thus, wheat ideotypes were able of making the maximum use of local environmental conditions and represent the best possible crop adaptation for the future climate, constrained by the available wheat genetic variation. Making the best use of the local climatic conditions, exploiting genetic diversity and plant adaptation are important for increasing crop genetic yield potential.

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Conclusions

Wheat ideotypes, optimised for local environments, predicted a substantial (66-89%) increase in wheat yields compared to current local cultivars in Europe under 2050-climate. Heat and drought tolerance around flowering, optimal phenology and canopy structure were identified as key traits to achieve such high wheat yields under future climatic conditions. Designing wheat ideotype and identifying key traits has the potential to accelerate crop improvement, genetic adaptation and breeding under future climates.

Acknowledgements

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Keywords: Genetic yield potential, in silico design, Sirius wheat model, LARS-WG weather generator, climate change.

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S3-O.08

Comparison of estimation methods to capture better the genetic variability within crop growth model parameters

Larue Florian (florian.larue@cirad.fr), Beurier Grégory, Rouan Lauriane, Luquet Delphine

AGAP, CIRAD, Montpellier, France

Introduction

Crop growth models (CGM) are expected to capture the biological processes at which genotype X environment interactions (GxE) are expressed in order to support the identification of optimal combinations of crop traits in targeted environments. They have indeed the potential to evaluate, *in silico*, the effect of elementary traits and related genetic factors on phenotype and yield elaborations. Thus, crop growth modelling is an interesting tool for crop selection. This requires making crop models more responsive to climate change variables and thereby increase the number of physiological parameters and the internal trade-offs / compensations among modelled processes making simulation response to genotypic parameters non-linear. This, combined with the fact that wider genetic diversity needs to be studied to seek for adaptive markers makes the process of parameter estimation tricky. When dealing with such studies, it is important to choose a method for estimating the parameters that best reflect the genetic variability.

Parameter estimation, i.e. looking for parameter values that allow to predict the most accurately the observed phenotypes, is widely used to calibrate crop growth models (Wallach, 2011). Different methods can be used to accomplish this task, ranging from the direct measures of parameters, brute-force strategies, to metaheuristics estimation or Bayesian computation. Furthermore, depending on available data, parameters can be estimated by considering replications and environments independently, or by considering genotypes and thus estimating parameters based on mean phenotypic values of replications for a given genotype in one or several treatments as a way to capture within the parameter values, the genotypic determinisms of observed / simulated phenotypes. Another strategy is to estimate the parameter values on the entire genetic diversity panel and then refine the parameter values for each genotype by working on the difference to the population mean.

Materials and Methods

The ecophysiological model Ecomeristem was used as a case study. This model relies on ca. 10-12 key genotypic parameters controlling C source - sink relationships and their impact on plant and crop phenotypic plasticity in response to the environment (water, light, temperature) (Larue et al., 2019). The model was applied to a data set consisting of 197 African sorghum genotypes phenotyped under two water conditions in the Phenoarch platform with four replications (Larue et al., 2018). Data related to plant leaf area development, biomass accumulation, leaf and tiller number and water use were daily or weekly estimated depending on the automation of measurements. Using these data and this model, parameter estimation methods were studied by comparing their ability to generate a set of parameters that best capture the genetic variability and heritability of these parameters and as far as possible to their molecular value (GWAS).

Results and Discussion

Preliminary results show that metaheuristics are best suited to deal with the parameter estimation process of complex, non-differentiable crop growth models with dynamic instantiation and non-linear processes.

Conclusions

In this study, we propose a comparison of different parameter estimation methods and strategies for their application with the objective of selecting the approach that allows the best capture of the genetic variability within CGM parameter values, in a context where numerous parameters have to be estimated conjointly. Differential evolution, a metaheuristic method, allows for quick and efficient parameter estimation while being less prone to local minima than other methods.

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Acknowledgements
This work was supported by the projects Sorghum Genomics Toolbox (funded by Bill & Melinda Gates Foundation) and Biomass for the Future (ANR-11-BTBR-0006-BFF, funded by the French National Research Agency (ANR).

Keywords: Parameter estimation, Optimization, Metaheuristics, Sorghum.

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S3-O.09

Cool beans: modelling leaf temperature and breeding for heat avoidance.

Deva Chetan[1] (eecd@leeds.ac.uk), Urban Milan[2], Challinor Andrew[1], Falloon Pete[3]

[1] *University of Leeds, Leeds, United Kingdom*; [2] *CIAT, Palmira, Colombia*; [3] *UK Met Office, Exeter, United Kingdom*

Introduction

Transpirational cooling is an important mechanism for heat avoidance in plants (Blonder and Michaletz, 2018). The magnitude of transpirational cooling has been shown to vary by genotype. Breeders have used the difference between the temperature of the air and the temperature of the leaf to breed for heat tolerant varieties (Porch and Hall, 2013). Accurate modelling of leaf temperature by genotype would help breeders to assess the value of breeding for cooler plants in different target population of environments. We test whether leaf cooling in common bean varies with heat tolerance and build a model capable of simulating leaf temperature by genotype.

Method

We used data from two field experiments conducted at CIAT headquarters in Palmira, Colombia. Both experiments were conducted in fully irrigated conditions. In the first experiment, we used the MultispeQ v1 instrument to measure relative humidity and daytime air and leaf temperatures. We took measurements in both ambient field conditions, and greenhouse conditions with higher relative humidity. In the second experiment, we used the same instrument to measure relative humidity and daytime air and leaf temperatures in hot field conditions and hot greenhouse conditions. We used t-tests and permutation sampling to test for differences in mean transpirational cooling between heat tolerant and heat sensitive genotypes. We combined data from these two experiments and used a combination of regression and machine learning techniques to create a genotype dependent model of leaf temperature.

Results and Discussion

Heat tolerant common beans exhibit stronger transpirational cooling than heat sensitive common beans. This difference is larger in hotter and dryer conditions. We demonstrate that it is possible to accurately simulate leaf temperature by genotype across a range of temperature and relative humidity. Using only air temperature, relative humidity and genotype as inputs, our model explains 86 percent of variation in leaf temperature (Figure 1).

Conclusion

Our work suggests that the difference between leaf and air temperatures may be an effective way for breeders to screen for heat tolerance in common bean. Breeders can use the empirical model we have developed to help them assess the impact of breeding for cooler beans in different target population of environments. Future work will need to repeat this analysis for a wide range of genotypes and environments in order to explore the robustness of genotypic variation in leaf cooling and the trade-offs between water use and heat avoidance. The MultispeQ device allows low cost rapid phenotyping of transpirational cooling across environments. In the future, empirical models based on big data sets with low data input requirements may substantially improve canopy temperature simulation in process based crop models.

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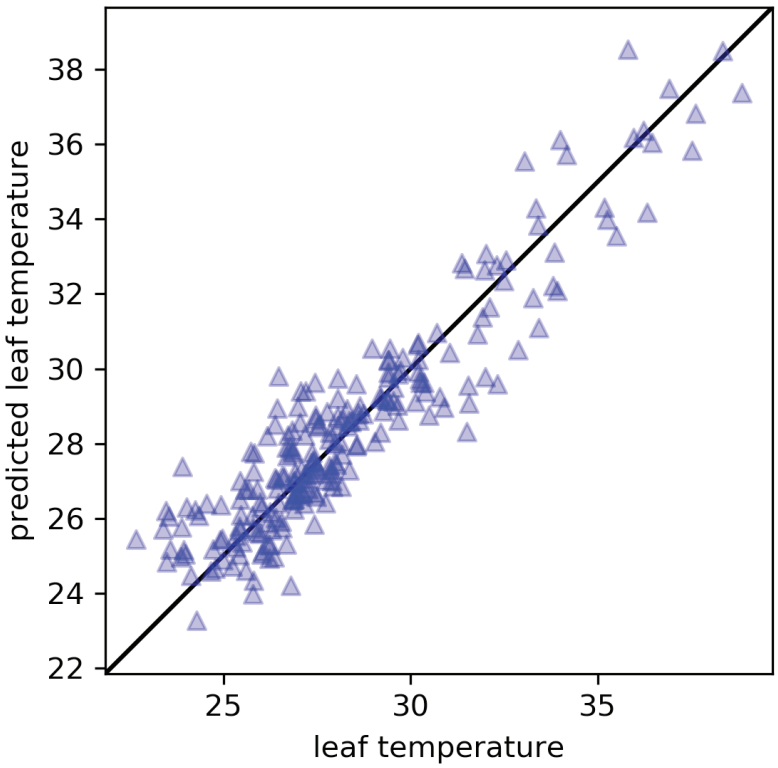

Source: Deva et al (2019) manuscript submitted for publication

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S3-O.10

Cross-scale modelling connecting photosynthesis with crop models to support yield improvement

Wu Alex[1] (c.wu1@uq.edu.au), Hammer Graeme[1], Doherty Al[1], Susanne Von Caemmerer[2], Farquhar Graham[2]

[1] *Centre for Crop Science, QAAFI, The University of Queensland, Brisbane, Australia*; [2] *Research School of Biology, Australian National University, Canberra, Australia*

Introduction

Improvement in staple crop yield is urgently needed to meet growing food demands globally (Ray *et al.,* 2013). This will likely need to come from improving crops' resource (e.g. light, water and N) conversion efficiencies, which are linked with photosynthesis. Assessing yield consequences of photosynthetic enhancement would help to maximise impact (Wu *et al.,* 2016). However, assessment of photosynthetic enhancement is confounded by complex interactions with crop growth, development dynamics and the prevailing environment. Here, we present a cross-scale modelling capability that connects leaf photosynthesis with crop yield in a manner that addresses the confounding factors.

Model Overview

The cross-scale modelling framework highlights "two-way" interactions between photosynthesis and crop models (Wu *et al.,* 2016; Wu *et al.,* 2019). Here, applied for connecting biochemical models of (C_3 or C_4) photosynthesis (von Caemmerer 2000) with APSIM (v7.8) crop models (Hammer *et al.,* 2010). Briefly (also see figure), daily biomass growth in the crop models was simulated by partitioning canopy leaf area index into sunlit and shaded fractions and calculating their CO_2 assimilation rates (A) and transpiration hourly (using combined A and gas diffusion model) over the diurnal period. A of the leaf fractions was calculated using the amount of available sunlight and leaf N (from canopy/crop scales); A also drove transpiration demand. Crop water supply was used to modulate A and reduced it when supply was limited. Daily canopy photosynthesis and actual transpiration were used to generate the consequent state of the crop, which regulated the subsequent diurnal calculations – closing the "two-way" loop.

Results and Discussion

Multi-year crop simulations were conducted for C_3 wheat and C_4 sorghum crops to assess the likely yield impact of three major photosynthetic manipulation targets: Rubisco carboxylation rate, electron transport rate and mesophyll conductance, and their combinations. The predicted yield response to 20% enhancement of the targets ranged markedly from −1.9 to +12.1%, depending on the photosynthetic manipulation, crop type and environment. The positive responses occurred mostly when water was non-limiting; however, the responses declined progressively as water became more limiting. Negative values were predicted for sorghum in low-yielding seasons because more rapid growth in early season used more stored soil water and increased late season water stress. However, when stomatal conductance (g_s) was decoupled from enhanced A, responses improved in drier seasons and reversed the negative yield impacts due to saving of water and mitigation of water stress.

The cross-scale modelling framework developed here bridges the modelling gap between leaf photosynthesis and crop growth, development and yield. The "two-way" modelling was vital in connecting crop growth and development processes across the biological scales of organisation and with environment. The model identifies the need to increase understanding and modelling of the A–g_s link to improve yield gains.

Conclusions

This modelling framework provides a capability to assess and compare yield consequences of different photosynthetic enhancement targets. The model also revealed critical issues associated with water-limited cropping situations, and identified the importance of the A–g_s link.

Acknowledgements

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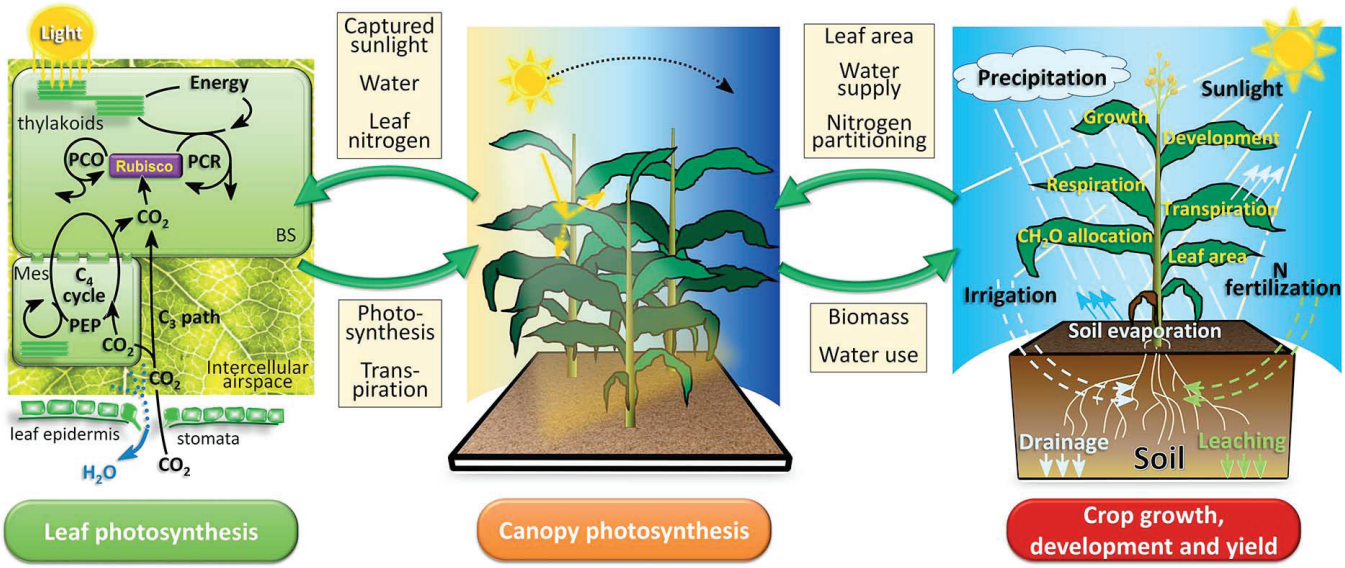

Figure: Cross-scale modelling framework that highlights the connections between crop growth and development models with the detailed biochemical model of photosynthesis via a sunlit-shaded canopy model.

Keywords: APSIM, photosynthetic enhancement, canopy model, water stress, stomatal conductance.

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S3-O.11

Extending the phenotype - combining proximal sensing with crop models to characterise radiation use efficiency

Chapman Scott[1] (scott.chapman@uq.edu.au), Potgieter Andries[2], George-Jaegli Barbara[3], Hammer Graeme[4], Jordan David[4], Yang Kai-wei[5], Tuinstra Mitch[5]

[1] *School of Agriculture and Food Sciences, The University of Queensland, St Lucia, QLD, Australia*; [2] *QAAFI, The U, Toowoomba, QLD, Australia*; [3] *QAAFI, Th, Warwick, Q, Australia*; [4] *QAAFI, The University of Queensland, St Lucia, QLD, Australia*; [5] *Department of Agronomy, Purdue University, West Lafayette, IN, United States*

Introduction

In both high-input and dryland crop production systems, breeders have an interest in increasing the biomass production of the crop, in addition to increasing grain yield. In the case of sorghum, biomass can often be the product of direct interest due to the use of the crop as fodder and energy sources. This research reports on projects in Australia on grain sorghum and in the USA on bio-energy sorghum. In both research programs, our objective is to understand how genotypes differ in their development of leaf area (including tillering in grain sorghum) and consequent light interception (Potgieter et al., 2017), and in their radiation use efficiency (RUE).

Proximal sensing in field trials can continuously describe the state and physical characteristics of a given genotype growing in a single plot (e.g. Chapman et al., 2014). One approach to using this type of data is to predict biomass directly (Masjedi et al., 2019). Here, we use UAVs/drones to characterise changes in light interception and to compute RUE. We can then utilise parameters in the APSIM cropping systems model (Holzworth et al., 2014) to compare the potential performance of different genotypes in diverse environments (Hammer et al., 2015).

Materials and Methods

Different germplasm sets were studied in contrasting environments in Queensland, Australia and Indiana, USA. In both studies, large sets of lines (>400) were grown for grain and/or biomass yield in experiments together with 'calibration' plots on which more detailed data on light interception and biomass production were collected via hand-sampling. Methods developed on calibration plots were extended to the larger sets to estimate RUE of diverse genotypes.

Results and Discussion

In the Australian dataset, measurements of biomass (dry mass per unit area) and light interception (using a light meter) on different dates in the calibration plots were used to develop prediction models using partial least squares regression. The independent variables in the prediction models were canopy cover and vegetation indices computed from aerial imagery. The sum of light interception was interpolated over time to calculate the sum of intercepted radiation and divided into the change in biomass between dates to calculate RUE.

In Purdue experiments, a different approach was used. We monitored leaf counts over time, final leaf size profile distribution and leaf angle of the calibration plots. Combined with estimates of plant population (derived from UAV) and derivation of light extinction coefficient, leaf area functions in APSIM were used to estimate LAI and light interception changes over time and computation of RUE. The model worked well over time (Fig 1) and was used to estimate genotype performance across mid-west environments.

The method used in the Australian can be calibrated for any situation using only the remotely-sensed data. Complementary research is comparing variation in field RUE with variation in leaf photosynthetic rate. The USA analysis allows for leaf parameters to be derived in a glasshouse and extrapolated to field situations Further research is aiming to predict RUE and other base parameters using genetic data to complement direct or remote sensing measurements.

Acknowledgements

The Australian research has been supported by the ARC CoE on Translational Photosynthesis, while the USA research is part of the DoE TERRA research program to develop improved bioenergy sorghum.

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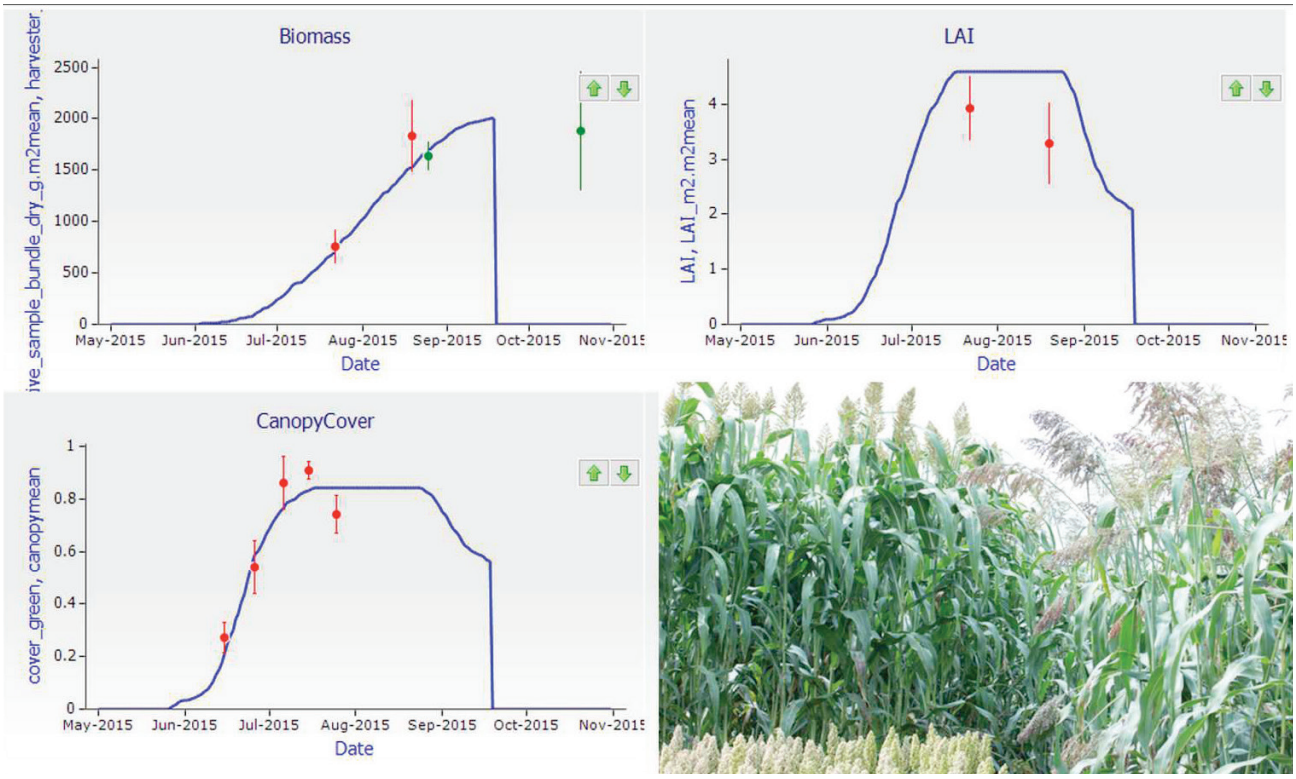

Fig. 1 Observed and simulated biomass, light interception and LAI for RS 374x66 Forage Sorghum, Lafayette 2015.

Keywords: sorghum, RUE, phenotyping, UAV.

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S3-O.12

Drought tolerance screening of soybean genotypes using UAV imagery and Functional-Structural Plant Modelling

De Swaef Tom (tom.deswaef@ilvo.vlaanderen.be), Borra-Serrano Irene, Saleem Aamir, Aper Jonas, Roldán-Ruiz Isabel, Lootens Peter

Plant Sciences Unit, ILVO, Melle, Belgium

Introduction

For North Western Europe, summer droughts are expected to increase in frequency and intensity. Given that yield losses due to drought stress in soybean can exceed 40%, breeding drought tolerant varieties is an important climate change adaptation strategy. Consequently, phenotypic traits related to drought tolerance are under great attention. A major challenge in phenotyping remains in the interpretation and transferability of observations, as these are to a large extent influenced by the environment and management. Moreover, plant water potential is generally considered as one of the best plant water status indicators, but its measurement currently relies on destructive sampling and is not fit for high throughput phenotyping.

Therefore, we present an approach that uses drone based plant height observations in combination with a simplified soybean functional structural model. This model is based on the model of Tuzet et al. (2003), which provides a whole plant water transport description including drought induced stomatal closure. Moreover, this model enables continuous simulation of the plant water potential. We further extended this model with a model of plant growth driven by turgor pressure, to enable linkage between plant water status and plant growth in variable growth conditions (Coussement et al. 2018) (Fig. 1 Left).

Material and Methods

In the context of the EU project EUCLEG (www.eucleg.eu), an experiment with 360 accessions of 4 maturity groups (MGI, MG0, MG00, MG000) was installed using mini-plots in Melle, Belgium, in 2018 according to a randomized row-column-block augmented design in two neighbouring fields. On one of the fields a mild drought treatment was imposed at flowering (R2 stage) using rain-out shelters (Fig. 1 Right), while in the other field irrigation was applied to keep the soil up to field capacity (control). Soil moisture was monitored using TDR sensors and weather information was recorded by a mobile weather station.

The growth and development of the plants were monitored from germination to harvest on a weekly basis using drone based imagery. More specifically, a time series of plant height and canopy cover was extracted from RGB images and canopy temperature was measured with a thermal camera six times during the experiment (Figure 1. Right).

The model was implemented as a system of ordinary differential equations in R using the RxODE package (Fidler et al. 2018), and parameters related to whole-plant hydraulic resistance, tissue extensibility and stomatal conductance sensitivity to drought were estimated specifically for each genotype via calibration on the drone based measurements of the control and drought stress treatments.

Results and Discussion

This approach enables to unravel different water use strategies (hydraulic functioning, stomatal closure,…) among the different genotypes. Furthermore, it provides new model-derived phenotypes that can be used for selection in the breeding process. Finally, these genotype specific parameters can then be used as more environmentally independent phenotypes, and will be linked to the genotypic information to improve marker development.

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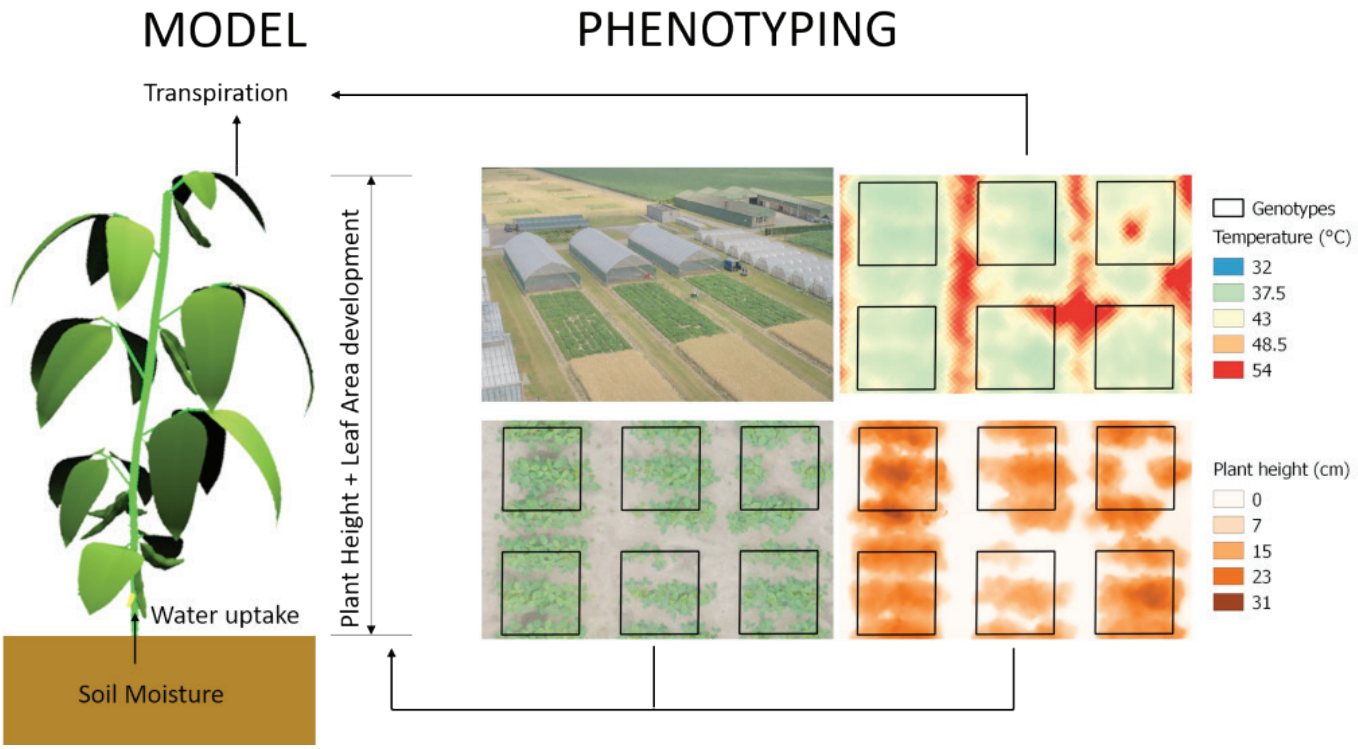

Figure 1. Plant growth model with UAV data incorporation (canopy temperature and plant height) for each genotype present in the field.

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Predicting flowering time of wheat genotypes across diverse environments in Australia

Zhao Zhigan[1] (Zhigan.Zhao@csiro.au), Bloomfield Maxwell T[2], Zheng Bangyou[3], Brown Hamish E.[4], Huth Neil I.[5], Hunt James R.[2], Celestina Corinne[2], Harris Felicity[6], Porker Kenton[7], Biddulph Ben[8], Wang Enli[1]

[1] *CSIRO Agriculture & Food, Canberra, ACT, Australia*; [2] *La Trobe University, Department of Animal, Plant&Soil science, Bundoora, Vic, Australia*; [3] *CSIRO Agriculture & Food, St Lucia, QLD, Australia*; [4] *The NewZealand Institute for Plant&Food, Christchurch, New Zealand*; [5] *CSIRO Agriculture & Food, Toowoomba, QLD, Australia*; [6] *Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga, NSW, Australia*; [7] *South Australian Research&Development, Urrbrae, SA, Australia*; [8] *Primary Industry & Regional development, Perth, WA, Australia*

Introduction

Optimal flowering time is critical for wheat in Australia to avoid frost, terminal drought and heat risks, and to maximise grain yields (Bloomfield et al., 2018; Zheng et al., 2013). For new released (or prior to be released) cultivars, data from field experiments across environments or from multiple sowing dates are needed for calibration of crop models to predict flowering time. In addition, current process-based crop models often perform poorly in predicting flowering time across contrasting environments due to the inability to separate effects of vernalization and photoperiod on development (Brown et al., 2013), thus leading to parameter equifinality and inaccurate characterization of cultivars (Wang et al., 2019). Recent progress in modelling wheat phenology (Brown et al., 2013) has enabled better qualifications of vernalisation and photoperiod processes through linking their impact to the number of leaves to be emerged before flowering and to the major Vrn and Ppd genes. In this model framework, parameters related to flowering time can be quickly determined from controlled environment (CE) experiments. In this paper, we report the first results on performance of the model to use parameters derived from controlled environments and to predict flowering time of multiple wheat cultivars grown in field experiments across a wide range of environments.

Materials and Methods

The Plant Modelling Framework (PMF) (Brown et al., 2014) implemented in APSIM Next Generation (Holzworth et al., 2014) was used for the initial model validation. Wheat phenology is simulated as development progress from sowing to harvest ripe with 10 sequential phases: (i) germinating, (ii) emerging, (iii) vegetative, (iv) stem elongation, (v) early reproductive, (vi) grain development, (vii) grain filling, (viii) maturing, (ix) ripening, and (x) ready for harvesting. Phenological development of wheat from emergence towards terminal spikelet is determined by requirement of vernalization and sensitivity to photoperiod of the cultivar, which also determines the final main-stem leaf number (FLN) and leaf phyllochron (°Cd) (the thermal time between the emergence of leaf tips). The duration from terminal spikelet to flag leaf stage is linked to leaf phyllochron and the number of leaves left to appear at terminal spikelet. The duration from flag leaf to flowering is 2.5 phyllochrons plus a cultivar-specific photoperiod response in terms of phyllochrons (Brown et al., 2018).

Observed data on main stem leaf emergence and total number of leaves of 69 cultivars from four treatments in the CE experiments were used to derive the seven phenology parameters in the new phenology model. The four treatments were:

1) SV – short day (8 h photoperiod), vernalised;
2) SN– short day (8 h photoperiod), not vernalised;
3) LV- long day (17 h photoperiod), vernalised;
4) LN - long day (17 h photoperiod), not vernalised;

Data from previous 158 field experiments were used to test the model. The experiments were conducted from 1992 to 2018 with 3-5 sowing dates ranging from 14 Mar to 12 Aug at 46 sites across Australia. Forty Seven of the 69 cultivars in the CE experiment were used in the field experiments. In total, 1431 field observed heading or flowering dates were used to test the model.

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Results and Discussion

In general, model performance was reasonably good compared to observed flowering and heading dates (DAS – days after sowing), with a tendency to overestimate time to flowering or heading. With the derived parameters from CE experiments, the new phenology model in APSIM Next Gen explained 72% of the variation in heading or flowering time observed in the field trials. The slope of the regression line (for heading and flowering time data together) was 0.94 (close to 1.0), but the root mean square error (RMSE) was relatively large, 19.88 days. The poor performance was largely cultivar-related, rather than site-specific.

Conclusions

This is the first attempt to derive model parameters of APSIM Next Generation using data from CE experiments and to validate the model against field data across diverse environments in Australia. The primary results for model performance was encouraging. Further work is continuing to look at the details of the model performances for each of the 47 cultivars to inform model improvement.

Acknowledgements

This research is funded by the Grains Research and Development Corporation (GRDC) through the research project 'National Phenology Initiative (Project No. 9175445)'.

Keywords: APSIM, crop modelling, heading time, phenology, genotype-phenotype prediction.

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ABSTRACTS PARALLEL SESSIONS

SESSION IV

LINKING CROP MODELS TO DATA STREAM SYSTEMS IN THE DIGITAL AGE

The majority of one-dimensional crop models are designed to simulate soil-crop-atmosphere processes over relatively uniform spatial conditions; however, accurate field and regional predictions need to account for the inherent spatial variability within and between fields by defining homogeneous field sub-units. The recent advances in proximal and remote sensing of soil and landscape properties, management practices and crop status provide opportunities to better capture the spatial and temporal variations when running crop models over spatial domains. This session will address current and novel approaches enabling crop models to be spatially explicit using different data assimilation techniques.

The session will also address the relative relevance of the various sources of geospatially referenced data streams and their optimal temporal and spatial scale in relation to the simulation objectives. The successful coupling of data streams to the crop models will provide support to various topics such as in-season adaptive management, yield forecasting, assessment of environmental impacts and sustainability of crop production.

S4-Keynote

Managing agricultural fields: from observation to prediction

Vereecken Harry (h.vereecken@fz-juelich.de), Schnepf Andrea, Hendricks-Franssen Harrie-Jan, Vanderborght Jan, Kollet Stefan, Montzka Carsten, Jonard Francois, Weihermüller Lutz, Herbst Michael, Brüggemann Nicolas

Agrosphere Institute, Forschungszentrum Jülich GmbH, Jülich, NRW, Germany

Climate change and especially hydro-meteorological extremes, such as droughts, are affecting the land surface of the Earth and socioeconomic well-being. Current analyses and projections indicate that the frequency of extremes will increase in the next decades, and that drought events in Europe will occur more regularly and might be more disruptive. Heat waves in combination with longer drought periods caused a loss in agricultural productivity but also impacted the availability of water resources (e.g. low water levels in rivers) and led to a decrease of the storage capacity of grass- and agricultural lands for carbon storage (e.g., Ciais et al., 2005). In addition, we observed a worldwide increase in risk of forest fires and pest outbreaks. At present, we face the challenge of quantifying and predicting the resilience and adaptiveness of our terrestrial ecosystems, both natural and managed, in view of the expected increase in extreme events. In Central Europe, the 2018 extreme drought affected agricultural production and forests leading to damages on the order of billions of Euro. Similar losses occurred during the drought 2003. The consequences of these damages motivated the EU to upgrade its civil defense mechanism by launching a risk data hub to enhance EU resilience.

Forecasting methodologies based on the combination of observations and integrated models provide a unique opportunity to inform farmers and stakeholders in order to better adapt to extreme drought events. New sensor technologies such as cosmic ray sensors for measuring soil moisture, Unmanned Aerial Systems (UAS) equipped with multispectral and thermal infrared cameras, Lidar systems and smart sensors to determine greenhouse gas emissions and soil and water quality offer a unique opportunity to provide such information. In addition, new developments such as remotely sensed solar-induced fluorescence (SIF) and new satellite missions will allow to better inform land surface and crop growth models in order to adjust irrigation management before crops are being severely damaged by droughts.

In this presentation, we will highlight the current capabilities of predicting the future state of the land surface from groundwater into the atmosphere and address the value of continuous observations in constraining predictions of hydrological states and fluxes as well as vegetation parameters. We will show how the Terrestrial Systems Modeling Platform, TerrSysMP, (Gasper et al., 2014) is able to forecast the soil moisture status and evapotranspiration of the European land surface at the 12 km scale for several days and up to one week. We will show how predictions of soil moisture and runoff can be improved at the 3 km scale across Europe using remotely sensed soil moisture leading to a new reanalysis product for monitoring surface soil moisture and hydrologic fluxes. Using TerrSysMP, we demonstrated that at catchment scale assimilating soil moisture measurements using cosmic rays sensors showed a great potential to improve predictions of soil moisture. Space-borne and UAS observations were used to retrieve small-scale evapotranspiration patterns to detect plant stress. We are studying the value of using SIF measurements to better constrain crop growth predictions under water stress conditions. This is done by forward simulation of the SIF signal based on AgroC (Klosterhalfen, 2017) and SCOPE (van der Tol et al., 2009) and using inverse methods to estimate parameters of the root water uptake function. The effect of specifically adapted root architectures on mitigating drought stress can be included in such simulations by parameterizing the root water uptake function using explicit 3D root architecture as obtained from models (CRootBox, Schnepf et al., 2018) or experiments.

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Digital avatars are currently under development that allow integrating UAS technologies to inform robots performing interventions at the field scale using a multi-scale simulation platform. In this multi-scale platform functional-structural plant models operating at the plant-stand level can be linked to functional structural plant models to better quantify the sensitivity of crops to the environment. In addition, very good knowledge of the subsurface properties at field scale is essential to obtain realistic predictions of crop growth. Hydrogeophysical measurement techniques like Electro-Magnetic Induction (EMI) and Ground Penetrating Rader (GPR) offer unique possibilities to characterize within field heterogeneities of soil properties and soil moisture status and to relate this to agronomic variables. We are convinced that an integration of smart sensor technologies in combination with State-of-the-Art terrestrial and crop growth models will contribute to secure agricultural production under a changing climate

Keywords: Sensing, prediction, crop models, UAS, landsurface.

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S4-O.01

A cybernetic precision sugarcane irrigation system informed by the IrrigWeb crop model

Everingham Yvette[1] (yvette.everingham@jcu.edu.au), Wang Eric[2], Steve Attard[3], McGlinchey Mark[4], Linton Aaron[5], Xiang Wei[2], Philippa Bronson[2], Inman-Bamber Geoff[1]

[1] *James Cook University, Townsville, Queensland, Australia*; [2] *James Cook University, Cairns, Queensland, Australia*; [3] *AgriTech Solutins, Ayr, Queensland, Australia*; [4] *SQR Software, Cascades Pietermaritzburg, Kwa-Zulu Natal, South Africa*; [5] *Think Pink Hire, Home Hill, Queensland, Australia*

Introduction

The digital revolution promises many advances in agricultural practices. Given that irrigated agriculture delivers 40% of the worlds food supply (Garces-Restrepo et al., 2007) and there are surmounting economic, and environmental pressures on water resources, it is imperative that agricultural enterprises look at new ways inspired by the digital revolution to save water, reduce runoff and increase yields at the same time. The first step in this process requires understanding crop evapotranspiration so the irrigation amount (mm) can be determined.

Crop evapotranspiration is dependent on many factors, one of which is climate - past, present and future. Other factors include crop type, location, farm management, irrigation inputs and soil characteristics. Crop models synthesize this information and estimate crop evapotranspiration and the irrigation required to meet crop water demand. Barriers to adoption of crop models are considerable and well documented (Hochman and Carberry, 2011, Thorburn et al., 2011). One reason for their low uptake is the time investment required by end-users to gain benefits from the information processed by the crop model. This is especially the case with irrigation, where irrigation events must be managed for multiple fields and at multiple times throughout the crop cycle. This means frequent data inputting processes are needed to continuously update the crop model so irrigation schedules can be generated throughout the irrigation season.

Much more popular amongst growers is automation. This is due to the many conveniences that automated irrigation offers. However, automation alone is not a solution for delivering improved irrigation use efficiency. Expert systems like crop models, are needed to deduce how much water should be applied to a paddock and when this should occur. For reasons outlined above there are many constaints which limit farmer engagement with crop models.

In this paper, the development of an integrated modelling approach involving the coupling of an automated irrigation system (WiSA) with an irrigation decision support tool (IrrigWeb, www.irrigweb.com) to improve irrigation management on a commercial sugarcane farm in north eastern Australia, adjacent to the Great Barrier Reef, is described.

Materials and Methods

An Uplink program was designed to connect the automated irrigation system (WiSA) to the irrigation support tool (IrrigWeb). Uplink allows seamless and effortless irrigation record keeping and data importing. To stream the irrigation schedule computed by IrrigWeb to WiSA, a Downlink program was created. The Downlink program adjusts the IrrigWeb generated irrigation schedule and allows the farmer to configure irrigation management rules to overcome practical constraints like pumping capacity, tariffs and crop priority. The Uplink and Downlink programs were connected via the Internet of Things. The Internet of Things uses technologies like sensors, actuators and communication devices to connect systems and *things*, like a crop model and an irrigation pump. A real-farm trial on furrow and drip irrigation was undertaken for a period of six months in the Burdekin sugarcane growing district of northern eastern Australia.

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Results and Discussion

During the farm trial, the Uplink program saved the farmer a significant amount of time. Instead of the farmer manually entering records, Uplink uploaded irrigation and rainfall data directly into IrrigWeb. The Downlink program calculated and applied irrigation schedules automatically. This irrigation schedule was inclusive of practical real world constraints that sit outside the capability of the crop model. The farm trial results demonstrated the closed-loop system offers a number of advantages over more traditional irrigation approaches. Although the system could reliably manage the irrigation schedule during the trial, more testing is required to move the system to a state that is scalable and transferable.

Conclusion

The cybernetic closed-loop system outlined herein presented a unified framework for coupling an irrigation decision support tool with an automated irrigation system in a way that can help farmers save time, money, water, energy and reduce runoff to improve unique environmental systems like the Great Barrier Reef. Whilst still in an experimental phase, the system offers a platform to fuse multiple data streams like extra sensor data and downscaled climate forecasts into the system to improve the precision of the irrigation system. Science based systems that offer advantages to growers can deliver practical, profitable and environmental benefits to irrigated agricultural systems worldwide.

Acknowledgements

This research was funded by the Australian Government's National Environmental Science Program - Tropical Water Quality Hub. Special thanks is extended to the Burdekin sugarcane farmers in our consultative group, Burdekin Productivity Services, Sugar Research Australia, NQ Dry Tropics and WiSA for their support.

Keywords: Internet of Things, Automation, Closed-loop, IrrigWeb, Agtech.

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S4-O.02

Fitting a dynamic structural maize model on thousands of plants imaged in a high throughput phenotyping platform

Fournier Christian[1] (christian.fournier@inra.fr), Artzet Simon[1], Tardieu François[1], Pradal Christophe[2]

[1] *LEPSE, INRA, Montpellier, France*; [2] *INRIA-CIRAD, Montpellier, France*

Introduction

High throughput phenotyping allows screening a large number of plants in control conditions. It has been used to extract traits relative to plant development and functioning, and identify genetic region controlling them or find ideotypes for different conditions (Tardieu et al, 2017). However, such traits are often seen as independent variables, and concern only a small part of the information available on images. We propose here a more comprehensive approach, by fitting an architectural model of development to the data.

Materials and Methods

Multi-view images from a complete phenotyping experiment (1600 plants, 40 days) performed on the PhenoArch platform (https://www6.montpellier.inra.fr/lepse/M3P/PHENOARCH) was processed with the phenomenal pipeline (Artzet et al., 2018). The pipeline allows for the 3D reconstruction of the plant (as a set of voxels), together with a segmentation of the set of voxels into plant organs (Figure 1). These data were first fitted with the parametric leaf shape model of Fournier et al. (2012), and assembled with ADEL-maize (Fournier et al., 1998) to obtain a virtual plant (Figure 1). For each individual, the reconstruction of the different timepoints were then merged into a single dynamical object, by fitting ADEL development scheme to the data.

Result and discussion

The first step of the fitting merely correspond to a simplification of the plant volume, using a geometrical model for leaves and stems. We evaluate, for the first time at the individual plant level, the impact of this simplification, by comparing the interception efficiency of the two reconstructed objects. The analysis points two important differences: one linked to the representation of leaves as flat object (versus undulated surface) and one linked to the simplification of the representation of the whorl. Data allowed to propose improved model on both aspects. The second step was to find a model-consistent pattern of plant development over time, by linking the different timepoints. It first allows to denoise the data, by separating plausible actual leaves from segmented artifacts. It also allows to track object over time, hence extracting dynamical features and obtain more robust measurement on stable objects. From the modeling point of view, this allows to test and improve ADEL parameterisation on hundreds of different genotypes.

Conclusions

Fitting a structural plant model to elaborated phenotyping data acquired in a platform was beneficial both for model improvement and data analysis. The improved model more closely match the interception efficiency of observations and has more robust parameterisations. Data analysis was enriched with dynamical features and benefits from averaging of repeated measurements. As a result, we obtain a fully parameterised structural model for hundreds of genotypes. Foreseen application of such a model range from multi-genotype analysis of plant development , use in interpretation of phenotyping data in the field (Liu, 2017) and ideotyping.

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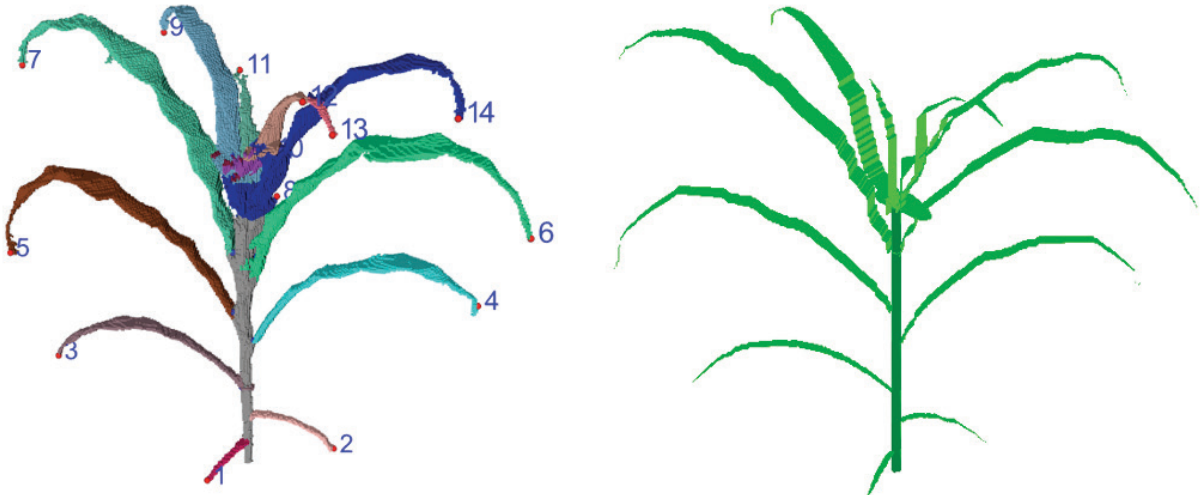

Fitting a structural plant model to high throughput phenotyping data. On the left, a 3D plant reconstructed as a set of voxels, and segmented with the Phenomenal pipeline (Artzet et al. 2018) . The stem has been identified, together with individual leaves. On the right, a fit of the structural plant model ADEL to the data (Fournier et al 1998).

Keywords: Model assisted phenotyping, maize, architecture, development.

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S4-O.03

UNIFI.GrapeML: new capabilities for the simulation of vineyard systems

Leolini Luisa[1] (luisa.leolini@unifi.it), Bregaglio Simone[2], Ginaldi Fabrizio[2], Costafreda-Aumedes Sergi[1], Di Gennaro Salvatore Filippo[3], Matese Alessandro[3], Bindi Marco[1], Moriondo Marco[3]

[1] *DAGRI, University of Florence, Florence, Italy*; [2] *CREA, Bologna, Italy*; [3] *CNR-IBE, Florence, Italy*

Introduction

The production of high quality wines is determined by environmental and agronomic factors contributing to the definition of the Terroir of the different wine regions. Despite five countries represent around 50% of the global vineyard surface (OIV, 2018), the finest wines are often a prerogative of narrow geographical areas with specific agro-environmental conditions. Nowadays, most of these areas are risk-prone due to climate change and extreme events, which affect the climate niches of the traditional wine regions determining a shift of grapevine cultivation towards new suitable areas (Leolini et al., 2018a). Process-based crop models are a viable mean to assess grapevine growth and production, as well as to forecast future performances of vineyard systems. This study aims at presenting an application of a grapevine simulation model (UNIFI.GrapeML, Leolini et al. 2018b, Leolini et al. *in press*) which use remote sensing data for estimating grape yield.

Materials and Methods

UNIFI.GrapeML is a model library of the BioMA software environment (http://www.biomamodelling.org/), collecting the main modelling approaches for reproducing grapevine physiological processes. The UNIFI.GrapeML interface is composed by input-output variables grouped into domain classes according to system analysis (Leffelaar, 1993), while the modelling approaches to reproduce grapevine physiological processes are implemented as strategies (Fig. 1). This software infrastructure allows to select at run-time different phenological models, and currently implements the simulation of aboveground and fruit biomass accumulation, also presenting a new approach for estimating sugar and acidity content in grapes. The model library was also applied in a case-study of precision viticulture in which remote sensing information was used as input to refine grape yield simulation at sub-plot level.

Results and Discussion

UNIFI.GrapeML has already been tested with experimental field data collected in Northeastern Spain, and a sensitivity analysis was carried out showing the strong contribution of leaf growth and crop partitioning on fruit biomass at harvest. The model accuracy in reproducing phenological development (average Pearson $\bar{r}$ =0.57), soil water content ($\bar{r}$ =0.70) and yield (r = 0.59) was evaluated in a multi-year experiments in the same area. The grape quality model was calibrated and validated in Montalcino, Italy (sugar: RMSE=1.45; acidity: RMSE=0.68), and then projected on future climate conditions evidencing an increasing trend on sugar and an opposite one for acidity. The application of the model with remotely-sensed leaf area index data increased model performance in simulating grape yield.

Conclusions

UNIFI.GrapeML is a ready-to-use library of models to in-season yield and quality forecast, as well as a tool to inspect the future suitability of vineyards in light of the ongoing climate changes. The BioMA environment allows an easier maintenance and use of the model code comparing to the monolithic structure of traditional models. This favours the further implementation of UNIFI.GrapeML such as with the integration of remote-sensed derived data in the model for improving the grape yield accuracy.

Acknowledgements

This study was partially supported by “Climate change impact mitigation for European viticulture: knowledge transfer for an integrated approach”, funded by European Union’s Horizon 2020 Research and Innovation Programme, under grant agreement nº 810176.

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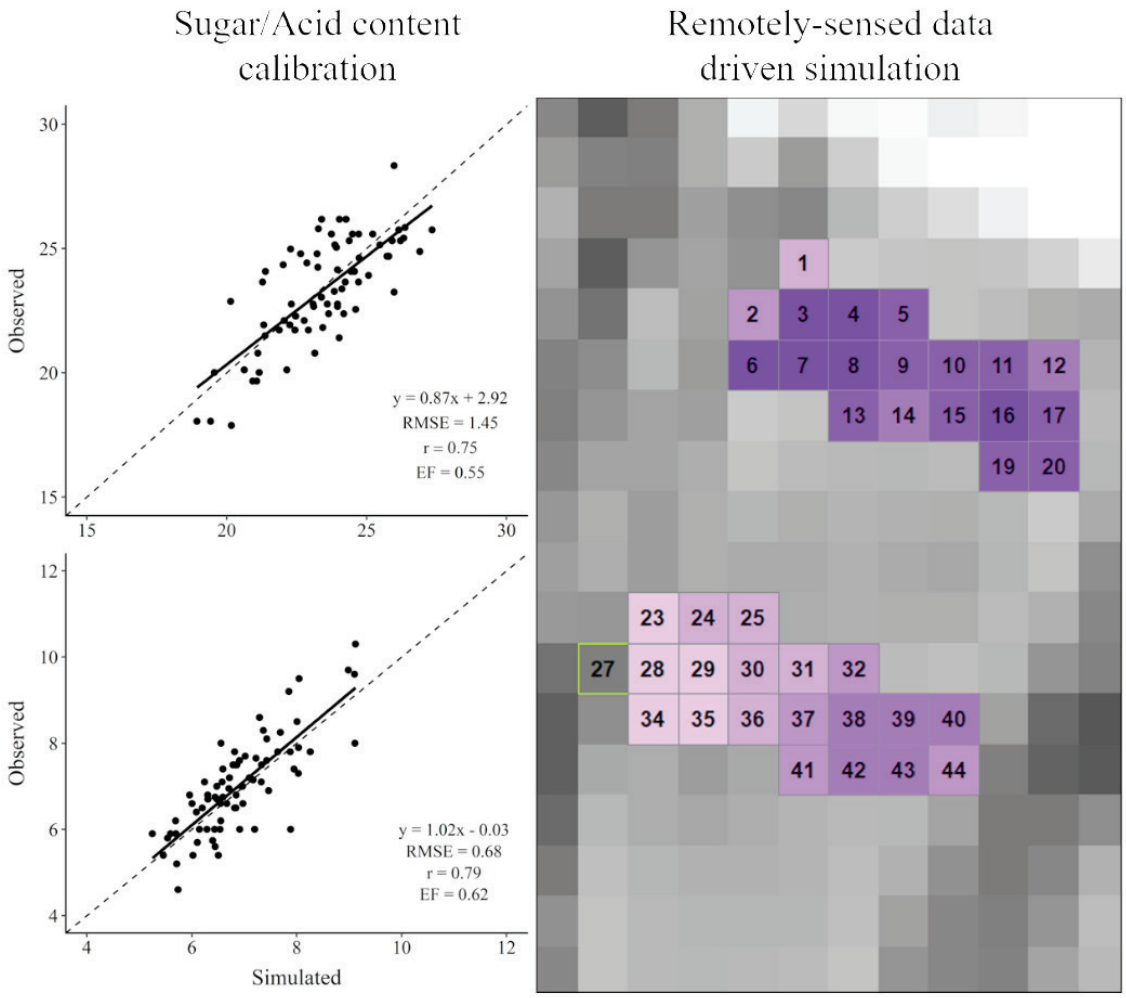

Figure 1. UNIFI.GrapeML new implementations

Keywords: Viticulture, Climate change, Crop modelling, Precision Agriculture.

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S4-O.04

Coupling of cropping system models with the AEGIS platform

Auzoux Sandrine[1] (sandrine.auzoux@cirad.fr), Christina Mathias[1], Ripoche Aude[2], Soulié Jean-Christophe[3]

[1] *AIDA, CIRAD, Saint Denis, Réunion*; [2] *AIDA, CIRAD, Antsirabe, Madagascar*; [3] *Recycling and Risk, CIRAD, Saint Denis, Réunion*

Introduction

Agroecological studies dealing with genotype by environment by management interactions generate heterogeneous datasets difficult to gather, store, share and analyse. Modelling is an essential tool for designing and evaluating innovative sustainable cropping systems. Data integration, sharing and reusing for crop modelling need a good data management. CIRAD has developed the AEGIS (AgroEcological Global Information System) platform, which aims to sustain the data value chain (Curry, 2015) for agroecological studies. This paper present the platform overall organisation and the approach used to ensure the data–model continuum.

Materials and Methods

Good data management is based on two key principles. The first is Data Lifecycle Management (DLM), which consists of managing data throughout its life cycle from production to use. The second is the FAIR data principles that aim to make data findable, freely accessible, interoperable and increase data reuse. Compliant with these standards, the AEGIS platform is organized into four pilars that focus on the steps of data acquisition, processing, sharing and enhancement. Data acquisition is a process of gathering, describing and harmonizing data. AEGIS integrates a generic ®ECOFI database (Auzoux *et al.*, 2017) using metadata technology that allows any type of data to be easily imported according to a collection process and uses a variable dictionary to facilitate the annotation of data making them understandable to all. Data processing is about making the raw data acquired easily usable for analysis and modelling. Through integrated dashboards, AEGIS offers a real-time overview of all stored data, ranging from raw data to indicators for assessing the sustainability and performance of agroecosystems. It provides homogeneous datasets for crops models simulations and capitalizes processed data, which can be simulation parameters and outputs, analysis results and performance indicators. AEGIS proposes data visualisation tools that highlight patterns and correlations inaccessible from the raw data. In the context of open data, AEGIS ensures data sharing increasing the impact and visibility of agroecological studies, promoting potential data reuse for modelling. Interoperability is considered as a necessity for data sharing and involves four levels of data exchange: system, syntactic, structural and semantic. AEGIS uses ontologies dedicated to the plant, pest, environment and cultural practices to ensure compatibility with data from other platforms that comply with these ontologies. Datasets provided comply with metadata standards such as Darwin Core, MIAPPE and EML. AEGIS is able to export data using the standard open Breeding Application Programming Interface (BrAPI). By ensuring data standardization, optimization and curation, AEGIS enhance data in term of publishing quality, accuracy in decision-making and financial value creation.

Results and Discussion

Such coupling of cropping system models allows performing three kinds of fundamental works in the present agroecological studies: (i) model validation, (ii) parameters estimation, and (iii) cropping system models comparison. In the first work (Chaput et. al 2019), that aims to test the ability of a crop growth model (STICS) to simulate the sugarcane growth response to different climates, soils and nitrogen management. The STICS model was calibrated using the observed data provided by AEGIS that illustrates more than 10 years of sugarcane trials in Réunion. In the second work (Christina et. al, 2019) that aims to model the annual variability of sugar cane yield in Reunion Island, AEGIS is the scheduler of the estimation process until the RMSE error is minimized. It asks to a simulated annealing algorithm to generate a new set of input parameters. These parameters are used to set up simulations of cane growth MOSICAS model thanks to the generic ®ECOFI database and output variables are compared to observed values stored within AEGIS. In the third work, that aims to study on sugarcane dealing with genotype, environment and management interactions as part of the "International Consortium for Sugarcane Modelling" (ICSM), AEGIS has been used to setup, launch simulations of STICS, MOSICAS, and DSSAT models, and compare simulations regarding observed values stored within AEGIS.

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Conclusions

AEGIS is a platform that participates in the construction of a data repository characterizing agroecosystems for integrated multi-scale analysis and ensures data consistency through harmonized reference systems and procedures. It provides all the features of the data value chain paradigm. It ensures a formal coupling (parametrization and output analyse) with the most well-known and ad hoc cropping systems models. It has been used in European and international projects involved in the agro-ecological transition as a steering and decision-making tool.

Keywords: Data integration, Data value chain, Interoperability, Crop modelling, Database.

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S4-O.05

Transcontinental prediction of soybean phenology via hybrid ensemble of knowledge-based and data-driven models

McCormick Ryan[1] (ryan.mccormick@corteva.com), Truong Sandra[1], Rotundo Jose[1], Gaspar Adam[2], Kyle Don[3], Messina Charlie[1]

[1] *Predictive Agriculture, Corteva Agriscience, Johnston, IA, United States*; [2] *Integrated Field Sciences, Corteva Agriscience, Jainesville, WI, United States*; [3] *Breeding, Corteva Agriscience, Princeton, IL, United States*

Introduction

Growers today face unprecedented levels of uncertainty and change as economic, climatic, and societal trends disrupt the productivity of traditional approaches. Adapting to such a dynamic environment requires exploration of an intractably large search space of crop, genotype, environment, and management, where much of that space has never been observed. To prescribe solutions in a changing environment, we leverage both prior biological knowledge in the form of explicit dynamical systems models as well data-driven, machine-learned models. The key challenges in modeling biological systems include incomplete knowledge of system behavior, insufficient data, over-parameterized knowledge-based models, and model selection. To address these issues, we apply data-driven approaches when the system is largely unknown, we employ knowledge-based models with improved interpretability and performance in data-poor environments, and finally we leverage an ensemble approach that increases prediction accuracy. These new approaches for fitting complex growth models, their hybridization with machine-learned models, and their application in capturing genetic by environment interactions will be discussed. Ultimately, improvements in the interpretability and predictive accuracy of crop models will improve the utility of prescriptive analytics for designing optimal agricultural systems.

Materials and Methods

A transcontinental soybean phenology dataset spanning North America and South America was collected from public and private sources, containing > 13,000 observations across > 180 unique combinations of locations and planting dates with relative maturity groups ranging from < 0 to > 9. These data were partitioned into folds of training, tuning, and testing sets by holding out environments. The training set was used to fit base models that included knowledge-based crop phenology from CROPGRO and SOYDEV (Jones et al., 2003; Setiyono et al. 2007) and data-driven recurrent neural network models (RNN); the tuning set was used to fit a super-learner; and the testing set was used to evaluate accuracy of the super-learner in out-of-sample data. The knowledge-based models were fit using a highly-parallelizable, multi-modal optimization strategy.

Results and Discussion

Multiple recurrent neural network architectures were able to learn to transform daily weather and environmental inputs to soybean developmental stages, achieving high out-of-sample accuracy. Re-trained knowledge-based models also achieved good generalization accuracy, and their inclusion as features when training data-driven models improved generalization performance. Ensemble prediction via stacking of posterior predictive distributions (related to Bayesian model averaging; Yao et al. 2018) demonstrated improved accuracy relative to any base learner or the simple ensemble average while providing the ability to remove redundant or non-performant models from the pool of ensembled models.

Conclusions

Given sufficient data, data-driven models can learn an accurate representation of soybean phenology across a transcontinental range of environments. While knowledge-based models lack the same degree of predictive skill, they are capable of generalizing well when trained, and when knowledge-based models are provided as features to data-driven models, they improve the machine-learning process by assisting the identification of better and more generalizable model fits.

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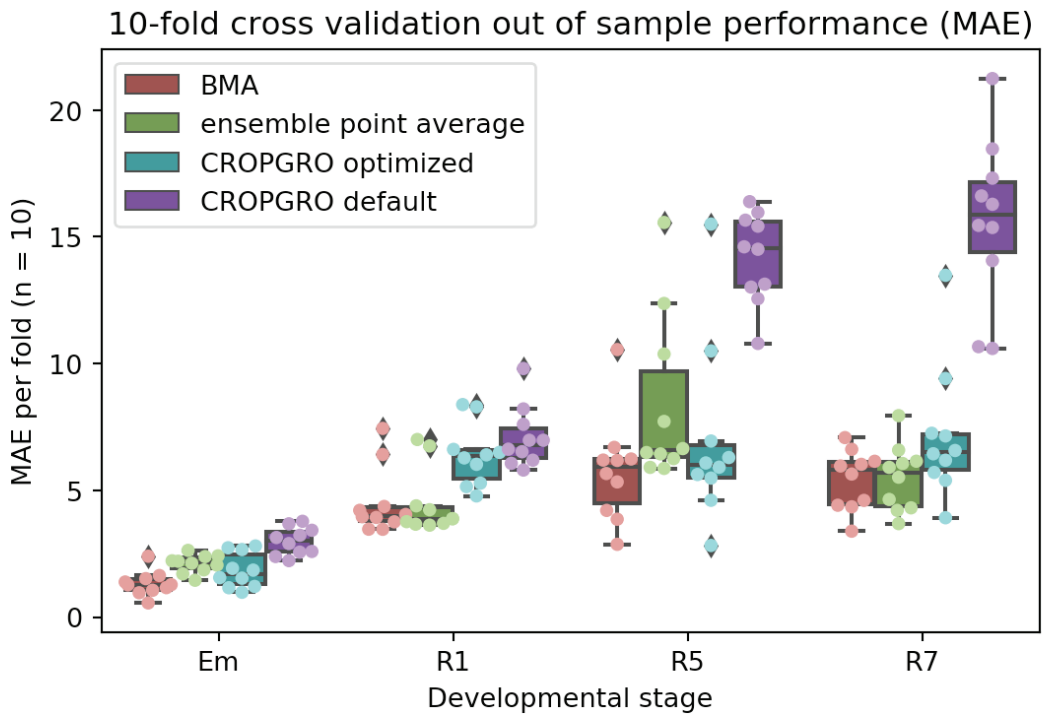

Comparison of out-of-sample performance across folds for Bayesian model averaging (BMA; via stacking of predictive distributions, Yao et al. 2018), the ensemble point average (all models weighted equally), CROPGRO with optimized parameters, and CROPGRO with default parameters. Ensemble models for emergence (Em) and R5 only contain the optimized and default CROPGRO, whereas ensemble models for R1 and R7 additionally contain 18 neural network models. In this case, the out-of-sample performance is evaluated only on the Testing set of each fold.

Keywords: soybean, phenology, optimization, ensembling.

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S4-O.06

Impact of pedotransfer functions on simulated crop growth in SW Germany with ExpertN-GECROS

Weber Tobias Karl David[1] (tobias.weber@uni-hohenheim.de), Bajracharya Rajina[1], Streck Thilo[1], Diamantopoulos Efstathios[2], Gayler Sebastian[1]

[1] *Biogeophysics, University of Hohenheim, Stuttgart, Germany*; [2] *Agrohydrology and Biophysical Modelling, University of Copenhagen, Copenhagen, Denmark*

Introduction

Winter wheat is the primary cereal crop in most regions around the world. Its productivity in the face of changing climate patterns in future is of major concern for worldwide food security. Climate impact modelling studies on site-specific crop growth dynamics provide insights into predicting and improving crop quantity and quality. Such studies require appropriate description of soil hydraulic properties to enable the simulation of water fluxes. One method is to adopt the Richards equation which in turn requires parametric soil hydraulic property function. One commonly adopted method is to use pedotransfer functions (PTF) to derive model parameters from readily available information on soil properties (van Looy et al., 2017) commonly contained in soil maps (Hengl et al., 2017). The choice of soil map and PTF has a considerable influence on simulated state variables. For the most commonly adopted model, the van Genuchten-Mualem model (VGM; van Genuchten, 1980), many different PTF have been derived. Also, many different soil maps with different level of detail exist, too.

Materials and Methods

In this study, the impact of soil PTFs on simulated winter wheat yield and protein content a region in southwestern Germany was studied. A wide range of PTFs were used from the literature and different sets of predicted VGM model parameters for the different a) soil maps and b) PTF were used in modelling the various state variables of interest in the agroecosystem model Expert-N 5.0 (XN5) with deterministic GECROS model parameterizations. Winter wheat growth dynamics were simulated over a 21-year period (2006 to 2028) in the Kraichgau region in Southwest Germany.

The prediction performance of the different PTFs are assessed by comparing the average and standard deviation of yearly yield and protein output. Time-series assessment as well as spatial map comparisons are made to enunciate the yield and protein characteristics.

Results and Discussion

Figure 1 shows the winter wheat yield simulation results of 2007 for one of the soil maps (BK50; the finest scale digital soil map from the local authorities). A regional average of around 7 t ha-1 were simulated. Visibly, the choice of PTF has an impact on simulated crop yield, as demonstrated by the standard deviation over the PTF simulation results. This is linked to the coupled processes in ExpertN, where because of the different PTF and the differences in predicted soil hydraulic properties, the water supply is simulated differently resulting in a sensitivity on crop yield. Quite clearly, the yield is influenced by the underlying soil information, too, which can be seen within a given grid cell in Figure 1. These results coincide with results from other state variables such as nitrate leaching, wheat protein content and evapotranspiration, too. The difference in the standard deviation is also a function of the grid cell of the regional climate simulation; thus, the model reacts sensitively to soil units, pedo-transfer functions as well as the gridding in the driving climate information.

Conclusions

Choice of soil map and the choice of PTF (Figure 1) reveal a considerable impact on simulated winter wheat yield. This is remarkable, as there is not only an uncertainty which stems from the crop models (Martre et al., 2015) but quite clearly also from the soil hydraulic property models and the information content in the soil maps.

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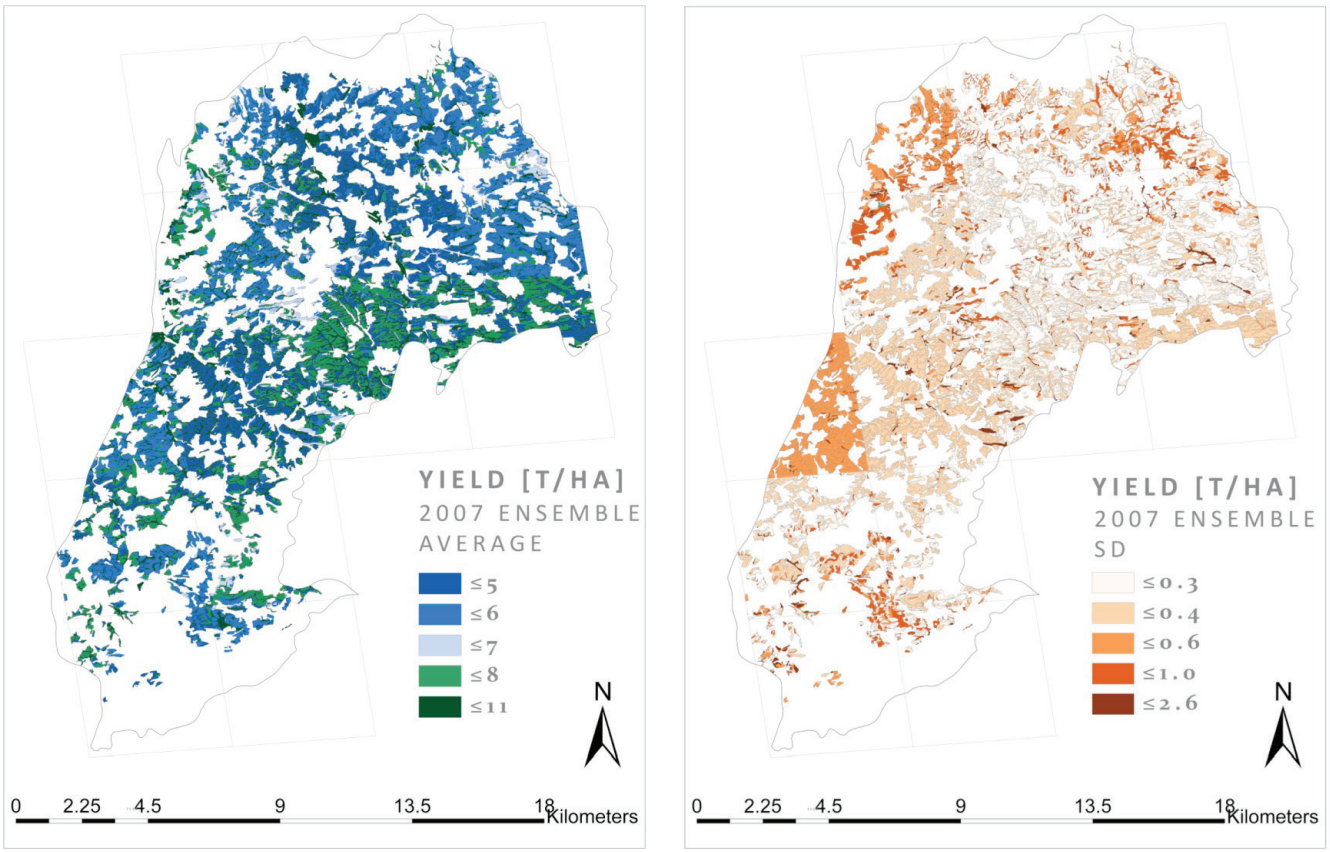

Figure 1: Winter wheat yields (left) averages and (right) standard deviations of the ensemble simulation with three results. The light grey boxes mark the simulation grid size of the regional climate simulations, the results of which were used to drive ExpertN-GECROS.

Keywords: crop modelling, soil hydraulic properties, ensemble modelling, impact assessment.

References:

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S4-O.07

Process-based crop modelling enables inverse prediction of plant available water holding capacity across farm with yield

He Di[1] (di.he@csiro.au), Yvette Oliver[2], Wang Enli[1]

[1] *Agriculture and Food, CSIRO, Canberra, ACT, Australia*; [2] *Agriculture and Food, CSIRO, Perth, WA, Australia*

Introduction

Plant available water holding capacity (PAWC) interacts with pre-season and in-season rainfall and other climatic variables to determine crop yield potential in dryland cropping systems. Spatial distribution of PAWC is one of the key factors impacting on the variations in crop yield across a farm. PAWC map helps improve yield forecast and inform spatially variable management practices like adjusting fertilizer and water inputs. However, high spatial resolution PAWC maps are not available due to difficulties to characterise PAWC using traditional methods that are costly and labour intensive. We explore a new approach to estimate PAWC from crop measurements, e.g. widely recorded crop yield, through combing process-based modelling together with an inverse modelling approach.

Materials and Methods

Five sites are selected in this study to cover a wide range of climatic conditions. More details about the climate sites are in He and Wang (2019). We used APSIM model to simulate wheat crop growth and yield with real field management details in response to 48 synthetic soil profiles that cover a wide range of PAWCs. Then we used the simulation results to develop a negative exponential model to quantify the relationship between PAWC and simulate yield. This model is then used to predict PAWC with measured crop yield.

Results and Discussion

Our results indicate that with an average yield of three consecutive years or more, we can get useful skill for PAWC predictions (prediction error < 37mm) for common range of PAWC across contrasting climate regions in Australia (Fig 1). For the summer rainfall dominant and wet sites, the skills are higher than the winter rainfall dominated and dry sites.

This method was tested with measured crop yield at three paddocks in Western Australia and successfully predicted the PAWC variables in the field. This study implies high potential of mapping soil PAWC across a farm with yield map data stream.

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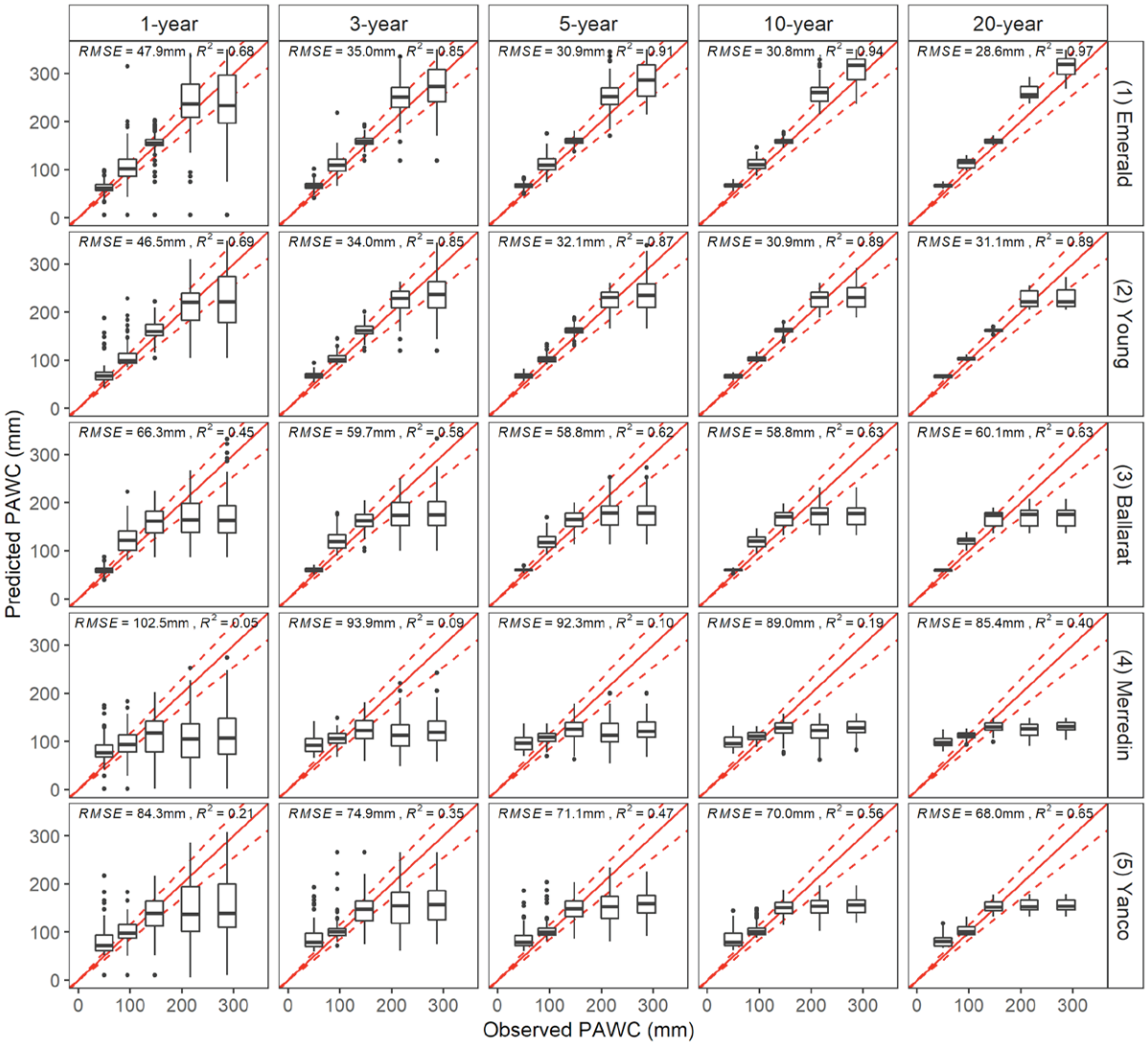

Figure 1. The maximum skill of PAWC prediction at five sites with contrasting climate conditions in Australia. PAWC Prediction error (RMSE) and coefficient of determination (R2) are labelled in each panel

Keywords: Inverse modelling, PAWC, Soil-crop modelling, APSIM, Yield map.

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S4-O.08

Coupling Sentinel-2 images and STICS crop model to map soil hydraulic properties

Lammoglia Karen[1] (karen.lammoglia@cirad.fr), Chanzy André[2], Guérif Martine[2]

[1] *UMR SYSTEM, CIRAD, Montpellier, France*; [2] *UMR EMMAH, INRA/Université d'Avignon, Avignon, France*

Introduction

The characterization of soil hydraulic properties such as the soil water storage capacity (SWC) is essential in hydrology or agronomy to establish the soil water balance and thus represent the hydrological functioning of a territory and/or the dynamics of a crop. SWC spatial variability is often strong resulting from heterogeneity in texture and structure as well as soil depth. *In situ* measurement of SWC is expensive, destructive and cannot be considered over a large area as it requires very large sampling plans. This study aims to develop a method to characterize SWC based on sentinel 2 images, yield map and the STICS model. The challenge is then to analyze how a model such as STICS, which involves a very large number of parameters, can be used in an operational context. This leads to define an inversion strategy that takes the main factors of variation into account.

Material and Methods

The study was conducted on durum wheat crops in the Avignon region (South-Eastern France). A set of 7 plots was monitored, 6 of which were cultivated by a farmer equipped with a yield monitoring device and 1 on the INRA research centre. Remote sensing data were acquired by sentinel 2 satellites. The LAI and FAPAR were calculated using a neural network applied to the 2, 4 and 8 bands at the resolution of 10 m. Field observations were made in pits (3 to 5 pits per plot) where soil depth and texture were systematically observed. The parameterization of the soil moisture initialization in STICS model was set up at the beginning of September depending on the previous crop. Prior to the inversion method design, a sensitivity analysis was made using the Morris method considering soil thickness, SWC in unit layer, sowing depth, sowing density, soil initialization (water and nitrogen) and organic nitrogen content. The inversion was done using the GLUE method a Bayesian approach, which allows exploring the parameter field within an *a priori* distribution.

Results

The influence of each investigated factor on foliar development varies over time. The crop establishment parameters are more influential at the beginning of the crop cycle. The influence of parameters related to SWC is mainly expressed at the end of the crop cycle with a difference in the rate of LAI senescence and the crop yield. Over the rest of the cycle, all the parameters have an influence with nevertheless a relative importance of each parameter that change according to the climatic years. All the investigated parameters had a significant effect on the annual yield. It is therefore important to have an inversion method that can separate the effects of the different parameters. The value of the SWC is the main factor influencing the calculation of yield and leaf development, while the way in which the SWC is established is less important. Thus, we can limit the number of parameters to be calibrated by focusing either on the soil thickness or the SWC per unit horizon, according to the a priori knowledge we have on the soil. Concerning the parameter used for the crop installation parameters, even if the effects of the two parameters are strongly correlated, there is an adding value in maintaining the estimation of both parameters. Finally, for the soil nitrogen effect, the determination of the two parameters, the initial soil nitrogen and the soil organic nitrogen, is not necessary. The initial nitrogen content of the soil is sufficient to represent the influence of the soil with regard to nitrogen nutrition. Comparing the inverted SWC to field measurements, we showed that the SWC was well characterized, in particular, when the soil has strong heterogeneities. Some spatial structures that do not coincide with the reality in the ground. This might be because STICS model do not simulate crop diseases or deficiencies in fertilizing elements. To limit the detection of those erroneous spatial structures, we simulated crop development in a different climatic year using the determined SWC.

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Conclusions

This study showed that the inverse use of the STICS model with time series of Leaf Area Index (LAI) retrieved from remote sensing enable mapping the soil water storage capacity (SWC), in particular in water stress conditions. However, other factors might affect foliar dynamic and yield that led to artefacts in SWC determination. Crop models offer a mean to consider part of those factors and the STICS model is particularly able to represent the quality of the crop installation and the nitrogen supply together with constraints on water supply. This was possible in an operational context, where most of the model parameters were set to default parameters. Multi-year analysis might be a mean to limit residual artefacts generated by pest and plant diseases. The study also underlines the importance of having high frequency Sentinel-2 images, as it allows capturing short feature as the senescence rate, which appears as an important proxy of the availability of water in the soil.

Keywords: crop model, remote sensing, soil water storage capacity, Sentinel-2.

S4-O.09

Processing chain for parcel and regional crop monitoring (PROCCY): Open Data, Sentinel-2, AquaCrop and sugar cane

Wellens Joost[1] (joost.wellens@uliege.be), Sall Mor Talla[2], Ville Anouk[3]

[1] *Environmental Sciences and Management, University of Liège, Arlon, Belgium*; [2] *Compagnie Sucrière Sénégal, Richard Toll, Senegal*; [3] *Spacebel, Liège, Belgium*

Introduction

FAO's crop growth model, AquaCrop, helps the "Compagnie Sucrière Sénégalaise" (CSS) monitor and manage its +/- 13.000 ha of irrigated sugar cane. Field, satellite and open data are linked to a crop growth model. A processing chain with dashboard was developed to asses irrigation calendars and estimate final biomass.

Materials and Methods

To facilitate the batch-processing of 1.000s of fields, the AquaCrop stand-alone version (Raes et al., 2012) has been integrated in an R environment (Figure 1). The resulting software tool has been baptized '*PROCCY*'; for '*Processing Chain for Regional & Parcel Crop Yield modelling*'. Soil physical characteristics for the region are automatically retrieved from SoilGrids and soil-hydraulic properties calculated using Saxton pedo-transfer functions. Meteorological data are downloaded from NASA's POWER project. Time series of median satellite fractional green vegetation cover (fCover) values are calculated for each field. A double sigmoidal function is fitted through the fCover data and phenological key data are assimilated into AquaCrop. Irrigation calendars are read from CSS' data base. A dashboard assists the graphical assessment of the simulation results.

Results and Discussion

AquaCrop's most important crop parameters were adjusted until a minimal error was obtained between observed and simulated biomass (R^2 0,6; nRMSE 9,1 %). Some detailed simulation results are presented in Figure 1. Figure 1.A represents simulated (black line) and satellite fCover (grey dots). Soil water depletion rates are depicted in Figure 1.B in black. Dashed grey lines represent field capacity and permanent wilting point. Irrigation events are in blue. If depletion rates drop below certain thresholds, water stresses affect: canopy development (green), stomatal closure (orange) and early senescence (red). Figure 1.C also shows eventual water stresses negatively impacting biomass production. Relative (green area), cumulative (blue line) and observed (red point) biomass are given in Figure 1.D. The observed biomass is only depicted for calibration and validation purposes.

The dashboard considerably enhances calibration and validation, and forms the core of the decision support tool. A straightforward overview is given of the interconnected simulation processes. An example of under- and over-irrigation are given in Figure 1. Observed vs simulated fCover values in Figure 1.A function as a sort of indicator light that simulations correspond to observed realities. The water balance (column B) of field one shows few irrigation events (bleu lines) and severe water stresses; field two intensive irrigation and a soil water content continuously above saturation. More details on these stresses are explained in column C: canopy expansion stress for the upper case and stomatal closure due to anaerobia for the lower case. Both type of stresses results in reduced biomass (column D). The dashboard serves to monitor actual irrigation calendars, but can also be used to develop and test new schedules.

Conclusions

The main strength of PROCCY is its generic approach combining free data and software. Presently show-cased for sugar-cane in Senegal, PROCCY is also being implemented for other crops in other regions (e.g. Mohammed Sallah *et al*., 2019).

Acknowledgments

The authors thank CSS for the field data and NADiRA (EU H2020 grant No 776309) for the scientific assistance.

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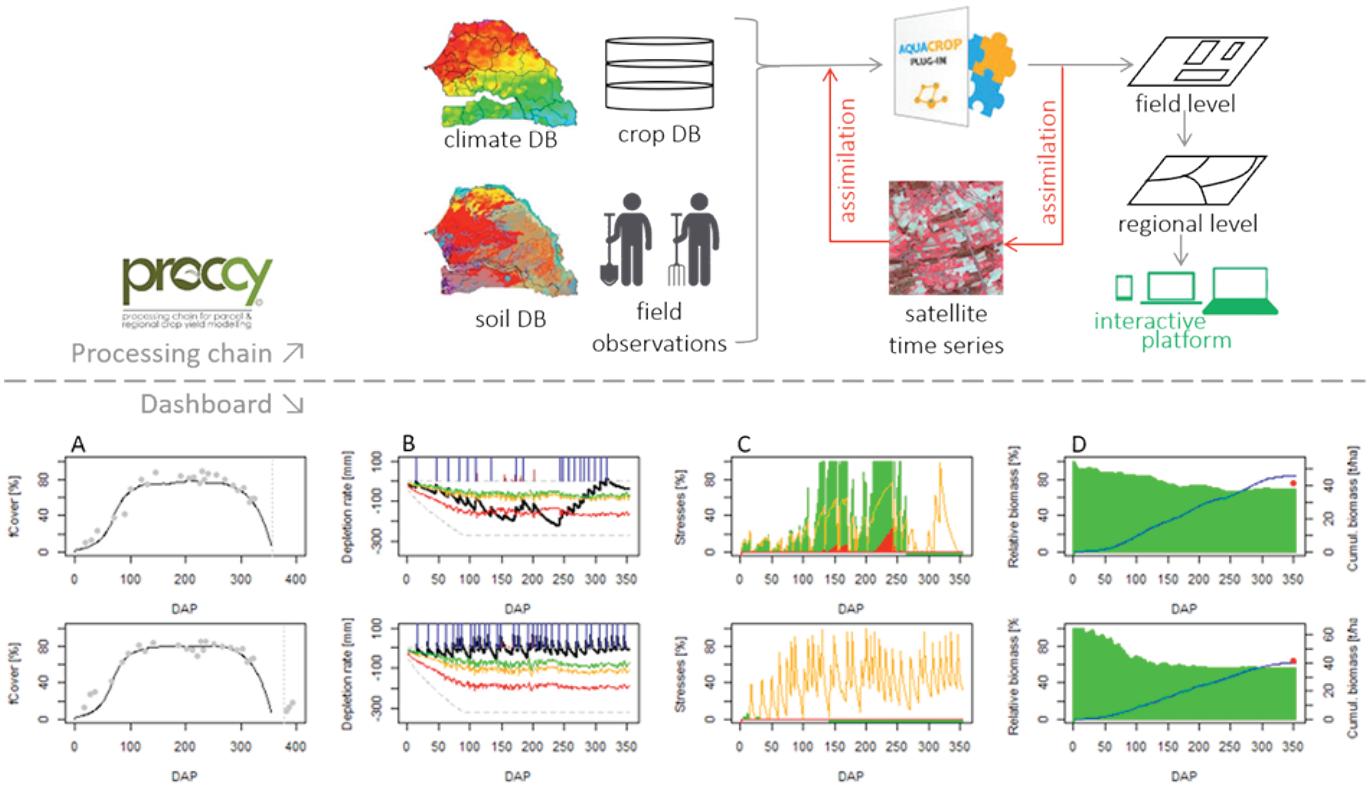

PROCCY workflow and dashboard (based on Wellens et al., 2017).

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S4-O.10

Remote sensing contributions to crop-yield simulation: bias and scarcity VS scale and predictive capacity issues

Baron Christian[1] (christian.baron@cirad.fr), Leroux Louise[2], Pellarin Thierry[3], Castets Mathieu[1]

[1] *Tetis/ES, Cirad, Montpellier Cedex 5, France*; [2] *AIDA/Persyst, Cirad, Dakar, Senegal*; [3] *Grenoble INP, IGE, Univ. Grenoble, CNRS, IRD, Grenoble, France*

Introduction

Easy access of Earth Observation data and the availability of a myriad of biophysical products strengthen the monitoring of the vegetation cover over large areas opening unprecedented opportunities for the spatialization of crop models. In West Africa, as in many parts of Africa, the heterogeneity of agricultural landscape, the scarcity of in-situ data and the quality of inputs data for crop models remains a challenge for yields forecasting across spatial scales. Using the SARRA-O crop model as an entry point, this study presents three ways to deal with environmental and data constraints using remote sensing data.

Results and Discussion

The first case study presents a direct application of the spatialized crop model SARRA-O, developed under the Ocelet Environment allowing it to use precipitation and weather data estimated from satellite images at different temporal or spatial resolutions. From territorial to regional scale, SARRA-O is dedicated to: crop monitoring, yield forecasting and provides climate services. Recently, ideal properties of models have been reframed as a list of criteria that should be considered when assessing crop yield and production forecast (FAO, 2016): i) timeliness; ii) statistical accuracy and sensitivity to extreme events and iii) simplicity in model structure and data requirements. These criteria in turn set constraints on the design of the SARRA-O model which has to integrate also spatial and near real time constraints. SARRA-O was applied in the Tuy province of Burkina Faso, characterized by high variability of environmental and management constraints. There, a farmer-based monitoring was carried out over three years in 6 villages with 30 plots and 3 rain gauge per village. Observed maize and sorghum yield are yields ranging from 0.5 to 5 t/ha and 0.2 to 3 t/ha respectively. To catch this variability, 4 level of intensification were defined to run the SARRA-O using rainfall estimation at 3km resolution and other meteorological estimation to estimate farmers yield over a territory of 5600km²; observed yield were of 2.3 compare to 2.8 t/ha for the simulated one.

In the second case study, the sensitivity of SARRA-O crop model was investigated through the use of several satellite precipitation products. Particularly, real-time precipitation products (i.e. 3 hours to 1 day) are interesting to enable real-time crop production estimates but are known to suffer from quantitative uncertainties and bias. Alternatively, adjusted precipitation products exploit ground precipitation measurements to correct bias but with a long latency (1 to 2 month). To correct bias and uncertainties in real-time, new precipitation algorithms were recently developed using satellite soil moisture data (SMOS, SMAP). Both spatial variability and mean value of crop yield are affected (Fig.)

Lastly, a timely and robust maize grain yield model based on remote sensing, SARRA-O and statistical approaches was developed in a context where *in-situ* data are scare. We adopted an “uncalibrated approach” where the output of the SARRA-O crop model was used as pseudo-ground data to estimate vegetative biomass at the flowering stage and crop water stress. The final remote sensing based model was able to explain 59% of the observed maize grain yield variability over the Tuy province (relative error of 7.2%).

Conclusion

In an environment of scarcity, the one-eyed man is king. Models are wrong, if their trends are correct they may be useful.

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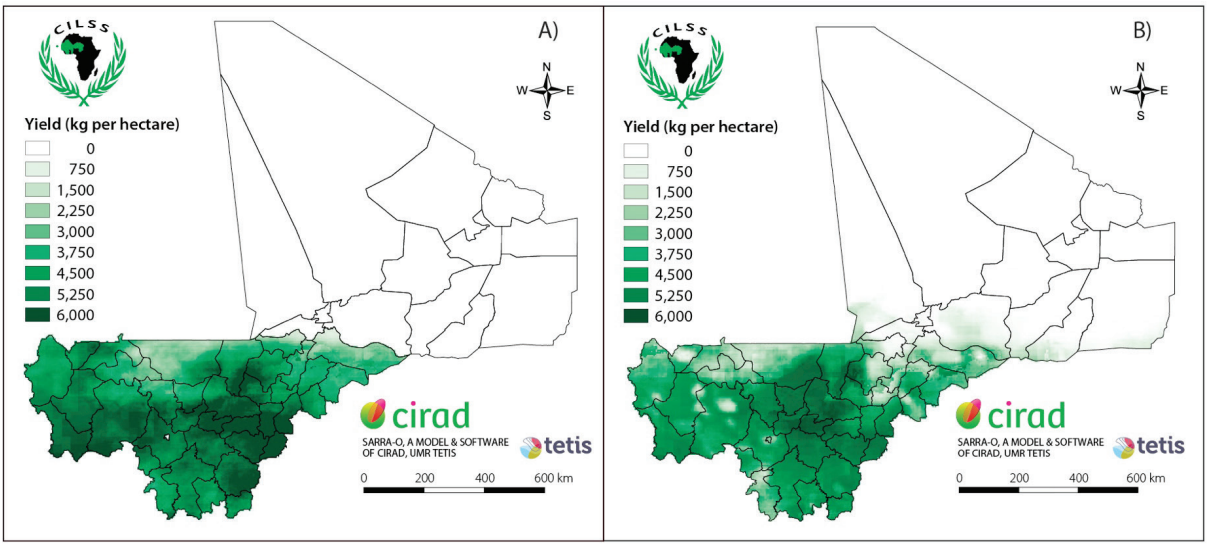

Fig.: Simulation of maize yield in optimum condition, Mali 2012, A) forced by TAMSAT rainfall estimation, B) same as A) with TAMSAT corrected by SMOS satellite data.

Keywords: crop model spatialization, food security, scale issues, climat impact, yield forecast.

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S4-O.11

Data assimilation of crop models and drone images based on an iterative sensitivity analysis for precision fertilization

Haumont Jérémie[1] (jeremie.haumont@kuleuven.be), De Swaef Tom[2], Cool Simon[2], Diels Jan[3], Lootens Peter[2], Schrevens Eddie[1], Saeys Wouter[1]

[1] *Biosystems, MeBios division, KU Leuven, Leuven, Belgium*; [2] *ILVO, Merelbeke, Belgium*; [3] *Earth and Environmental sciences, KU Leuven, Leuven, Belgium*

Open air vegetable farming is influenced by many external factors like weather, soil conditions and pests. To ensure high yields farmers incorporate large safety margins. This involves using excessive amounts of resources leading to detrimental effects on the environment like nitrogen leaching to ground and surface water. Today, in Flanders, Belgium, nitrogen fertilization in open air vegetable farming is typically based on the KNS-expert system, which involves nitrogen analysis in soil samples (Vlaamse Landmaatschappij, 2014). However, this approach assumes a constant nitrogen uptake, thus ignoring the actual crop development and the corresponding nitrogen uptake. Furthermore, the fertilization recommendations are provided at field scale, even though large variation within a field is observed regarding soil conditions and yield in vegetable production.

To deal with the former problem, mechanistic crop models can be used to optimize farm management through simulation of the crop development. However, these models are typically used in decision support systems at field, regional or country scales, and thus cannot cope with the observed field variations. Novel crop monitoring techniques using UAV's and field robots allow to measure key crop parameters like LAI, biomass, green crop cover and nitrogen content at high resolution. This makes them very useful to adapt crop simulation models to capture within field variation. Based on the discrepancy between observed and simulated values the model can be updated using data assimilation to improve the accuracy for further simulation (Jin et al., 2018). However, the large number of parameters in mechanistic crop simulation models for describing the underlying biological processes make this challenging. Therefore, the aim of this study is to ease data assimilation using an iterative sensitivity analysis of a crop simulation model for application in a variable rate fertilization decision support system for open field vegetable production.

The developed crop model combines a crop module which simulates biomass accumulation and respiration on an hourly basis with a quasi-2D extension of the WAVE model to account for heterogeneous root development in vegetable cropping (Van Loon, Vansteenkiste, Diels, & Schrevens, 2011; Vanclooster, Viaene, Diels, & Christiaens, 1994). The model was calibrated at field scale using experimental data over three consecutive years.

Prior to any measurements, the Sobol sensitivity indices of the model parameters and the initial conditions were calculated as a function of time based on Monte Carlo samples within the full parameter space using weather data of five historic years. Subsequently, the identifiable parameters were determined using the method of De Swaef et al. (2019), limiting the number of parameters which can be updated from measurements and fixing the values of the others based on previous knowledge. Thereafter, the model was updated using an iterative sensitivity analysis and data assimilation for application at sub field scale. Once a measurement has been performed, the sensitivity analysis was repeated using only the identifiable parameters and the weather data until measurement. Next, the model was updated to better represent the current situation, capture zone specific crop development and reduce the parameter space. Because the sensitivity of the parameters varies over time, only those with a significant effect on the measured variable should be considered. Subsequently this method was repeated with every measurement using the parameter space which has been reduced iteratively. In this way, data assimilation is facilitated by limiting the considered parameters to those which are identifiable and active at the moment of new measurements.

Acknowledgement
This research is funded by VLAIO, HBC.2017.0819. Furthermore, the research is supported by Inagro, ILVO, Vito, PSKW and PCG (BE).

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Keywords: data assimilation, sensitivity analysis, crop models, drone imaging.

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S4-O.12

Calibration of the Tipstar potato model using remote sensing data

van Oort P.A.J. (pepijn.vanoort@wur.nl), van Evert F.K., Kempenaar C.

Agrosystems Research, Wageningen University & Research Centre, Wageningen, The Netherlands

Introduction

Dynamic simulation models may enable for farmers the evaluation of crop and soil management strategies, or may trigger tactical crop and soil management interventions if they are used as warning systems, e.g. for drought risks and for nutrients shortage. For either type of use, simulation models must be calibrated to the conditions of each specific field. The objective of this study was to improve simulation results by integrating a range of (mostly online) observations during the growing season to calibrate model parameters.

Material and methods

The Tipstar potato model (Jansen 2008) was embedded in a modular infrastructure handling data import and export. All necessary environmental input data are retrieved from online sources, while variety specific parameters were obtained through model calibration. Sentinel satellite data were of a sufficiently high spatial and temporal resolution to allow for model calibration. Geometry and yield data were compiled from 40 fields in the Netherlands in the years 2014-2018, all with the same cultivar Fontane. For 21 of the fields in-season samples of aboveground biomass taken by a commercial farmer. Water-limited production was only simulated for fields where irrigation data were available. All fields received ample fertiliser. Previous studies showed late emergence can cause severe yield penalties (van Oort et al 2011). A method was developed to estimate emergence date and early growth rate from satellite derived LAI data (Bouman et al 1992).

Results and discussion

Emergence date and early (exponential) growth rate could be accurately estimated from satellite data (R2=0.90). Other parameters such as peakLAI and maximum leaf cohort age (oCd) could be estimated from LAI derived from satellite data. Aboveground biomass was significantly ($p<0.05$) correlated with WDVI vegetation index yet with relatively large random noise (R2 = 0.51). Accuracy was higher for parcels without drought stress (Figure 1, black symbols, R2 0.62-0.87 for 4 variables). Accuracy was lower for parcels with drought stress (Figure 1, red symbols). Accuracy was less for aboveground biomass than for LAI or yield (Figure 1), which may be due to the lower correlation between WDVI and biomass. In a next step, we will link these simulations to online decision support tools available in the online akkerweb platform (www.akkerweb.eu).

Conclusions

Considering the paucity of input data and their lower spatial resolution, we consider the model accuracies acceptable. Apart from the science of crop growth modelling, our work shows that it is slowly but steadily becoming possible to simulate potato growth for any field in the Netherlands.

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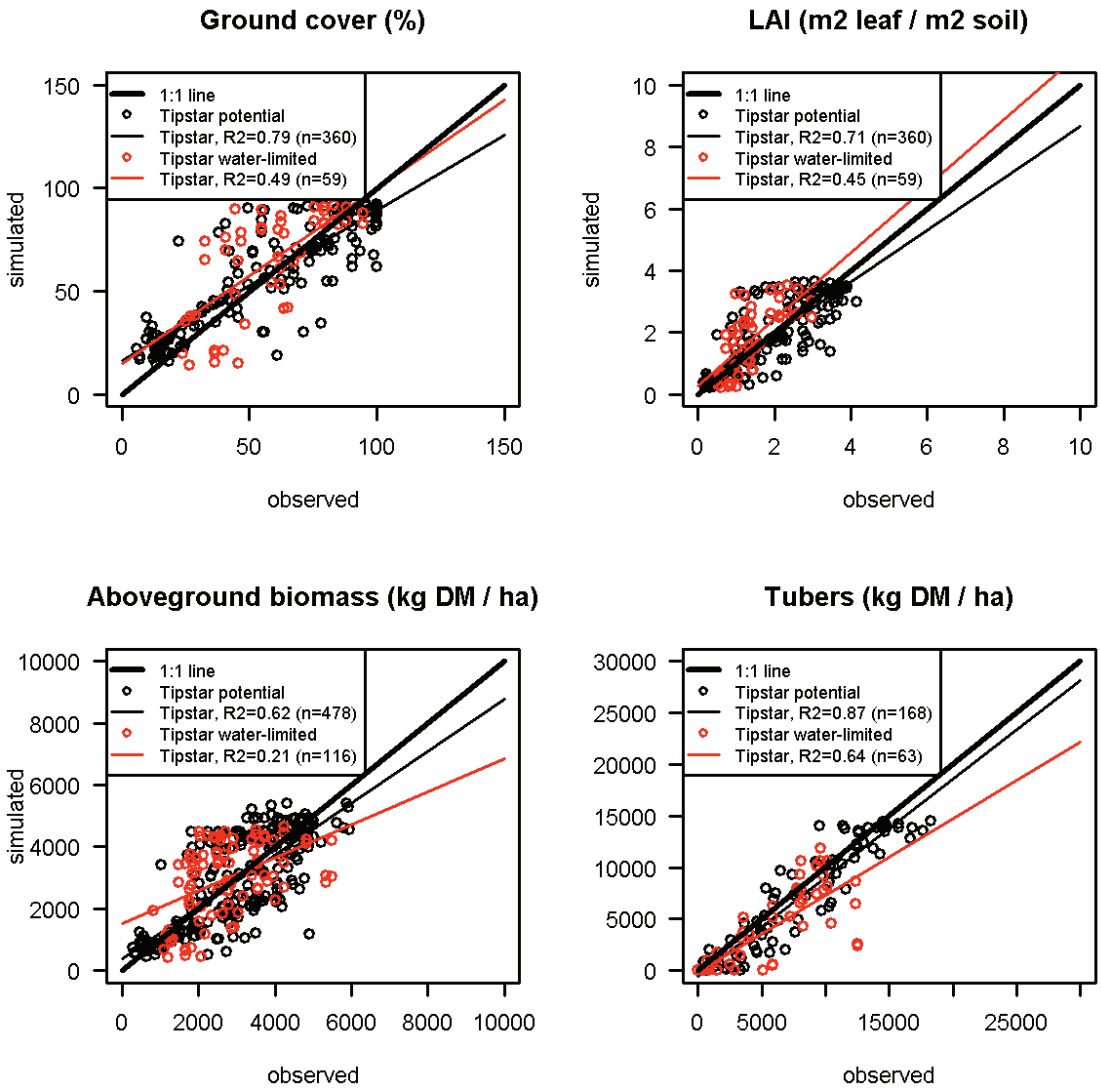

Figure 1. Tipstar model accuracy for four crop variables. Groundcover, LAI and aboveground biomass derived from satelite data plus in-season samples. Observed yield data are as reported by farmers.

Keywords: Tipstar, potato, sentinel, API.

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S4-O.13

Data assimilation and sensor fusion in the CHN crop model for integrated monitoring of nitrogen fertilization in cereals

Piquemal Benoît[1] (b.piquemal@arvalis.fr), Leroux Gaétan[1], Bonnefoy Michel[2], Braun Philippe[3], Jézéquel Stéphane[4], de Solan Benoît[5], Andrianasolo Fety[1], Gendre Sophie[6], Soenen Baptiste[6]

[1] *Information systems and methodology dpt., ARVALIS - Institut du végétal, Boigneville, France*; [2] *Regional actions dpt., ARVALIS - Institut du végétal, Beauce la Romaine, France*; [3] *Regional actions dpt., ARVALIS - Institut du végétal, Nîmes, France*; [4] *Regional actions dpt., ARVALIS - Institut du végétal, Gréoux-Les-Bains, France*; [5] *UMT CAPTE, ARVALIS - Institut du végétal, Avignon, France*; [6] *Agronomy, economy and environment dpt., ARVALIS - Institut du végétal, Baziège, France*

Introduction

Nitrogen management poses a major challenge for winter wheat producers in France. The amount of nitrogen input is currently computed with a balance approach, which is estimated at an early stage in the crop season. This approach has been revisited to propose a method based on real-time monitoring of nitrogen nutrition index (NNI) thus triggering the application of fertilizer according to predefined paths of NNI and soil nitrogen content (SNC) with promising results (Ravier et al., 2017). Besides, we used a dynamic crop model, CHN (Soenen et al., 2016), to provide real-time estimation and projection of NNI and SNC at plot scale in order to assess this new approach of nitrogen management.

The development of information technologies associated with the availability of satellite data like Sentinel-2 allows a spatial monitoring of crop with a weekly acquisition frequency. Other acquisition systems such as field sensors (Bosch smart crops ™) are now available and provide the same state variables as satellites, such as green leaf area index (GLAI) and chlorophyll content (Cab), at a daily time step. The combination of these different types of sensors offers both high spatial and temporal resolution of information about crop status at the field scale.

The objective of this study was to choose and assess a multi-sensor data assimilation method for the CHN model in order to estimate accurately real-time NNI and SNC on cereals for the purpose of nitrogen input management.

Materials and Methods

A state of art about data assimilation for dynamic models led us to distinguish (i) methods using calibration which consist in adjusting parameters and (ii) those based on filtering and forcing state variables. We conducted an opinion survey of product and project managers that made us choose the group of methods based on filtering and forcing state variables. Finally, methodological and cost constraints related to decision making allowed us to identify the Kalman filter applied to a dynamic regression model (KFDRM) (Wallach et al., 2019) as the most adapted method, because of its cheap computational cost and its simplicity of implementation.

In order to assess the KFDRM, we used an historical database regrouping high pedo-climatic and agronomic diversity of maize plot trials in France. With the KFDRM and the CHN model, we assimilated GLAI and/or plant nitrogen content (%N) measurements obtained from emergence to flowering stages.

Results and discussion

We compared the model predictions of above ground dry matter (AGDM) and absorbed nitrogen (Nabs) at flowering with and without data assimilation. Results are presented in Table 1. As NNI was computed from AGDM and Nabs estimations, we needed to increase the model performances for both variables. This could be done by assimilating GLAI and %N measurements, as assimilating GLAI measurements without %N permitted to increase the model accuracy on AGDM only.

Conclusion

For short to mid-term perspectives, new field trials were conducted on winter wheat in 2019 will allow us to assess data assimilation efficiency for nitrogen input management. Those were conducted at a large scale in France and measurements were obtained from Sentinel-2 and field sensors. A sensor fusion method allows estimating LAI and Cab at a daily time step and 20m x 20m resolution. Assimilating these data into CHN should help to establish real conditions results, a necessary step before bringing a new advisory service to producers.

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	AGDM (t / ha)		Absorbed Nitrogen (Kg N/ ha)	
	RMSE	Bias	RMSE	Bias
No data assimilation	2.47	0.84	38.3	-20.1
LAI data assimilation	1.34	0.41	35.6	-18
LAI and %N assimilation	1.41	0.49	21.8	2.8

Table 1. Model goodness of fit for AGDM and absorbed nitrogen at flowering, with or without data assimilation of measurements acquired since emergence. N=57

Keywords: Dynamic model, Kalman filter, Remote sensing, Nitrogen management, Nitrogen nutrition index.

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ABSTRACTS PARALLEL SESSIONS

SESSION V

CROP MODELLING FOR RISK AND IMPACT ASSESSMENT

Food insecurity, climate change, critical biodiversity losses and water scarcity are among the largest challenges facing humanity. Crop production, as the primary activity in provisioning human food, is both impacted by and contributes to these problems. Achieving food security in a globalized world under climate change requires a substantial increase in agricultural production. At the same time, agriculture is expected to minimize its environmental impacts, including greenhouse gas emissions, nutrient losses, water use, habitat loss and other forms of environmental degradation. Crop modelling can aid in identifying options by assessing trade-offs between production and water use, nitrogen losses and land requirements, as well as to quantify their associated risks in the face of climate change from local to global scales.

This session explores the role of crop modelling for risk and impact assessments of cropping systems. Contributions deal with advances in methods for risk, impact and tradeoff analysis, including scenario design and model output analyses; advances in data aggregation and model upscaling methods; yield forecasting systems; and integrated assessment modelling. Contributions that address knowledge transfer from crop modelling to policy makers and other stakeholders are particularly welcome.

S5-Keynote

Risks and opportunities for the European agricultural sector under 2050 climate change conditions

Dentener Frank (frank.dentener@ec.europa.eu)

Directorate Sustainable Resources, EC Joint Research Centre, Ispra, Italy

Assessing the risks, impacts, adaptation needs and opportunities of the European agricultural sector to produce sufficient crops under climate change conditions, involves a complex evaluation of climate scenarios in their socio-economic context, data analysis and coupling of crop and economic models, within Europe and the globe.
The Joint Research Centre provides scientific support to policy makers to evaluate the impacts of weather and climate on agricultural production covering seasonal to climatic timescales. Agro-climatic analysis shows that over the past 40-year climate zones have been migrating northward by 50-100 km per decade, lengthening the overall growing season, but also introducing new climate risks, and changing the suitability to grow specific crops. During the last years Europe has been suffering from unusual extreme heat and drought events in extensive regions of Northern Europe, events that may become the norm as early as 2040.
Using a set of high-resolution downscaled and bias-corrected climate scenarios we show how such climate risks (extremes and other factors) are represented in biophysical and statistical modelling frameworks, and what additional information can be obtained by combining these analyses. Coupled agro-economic analysis shows that in some cases Europe's agro-economic sector may benefit from climate change. We assess what improvement in crop models, coupled with other Earth system aspects, is needed to understand the physical limitations to such scenarios and assess realistic adaptation potentials.



The drought in central and northern Europe's 2018 spring/summer growing season could become the norm within 25 years

Keywords: Agriculture, Risk, Climate Change.

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S5-O.01

Crop modelling for sustainable nutrition security: lessons from UK Climate Change Risk Assessment and Africa projects

Challinor Andy[1] (a.j.challinor@leeds.ac.uk), Benton Tim[2], Adger Neil[3], Jennings Stewart[4], Rojas Maisa[5], Lambert Fabrice[5], Ramirez-Villegas Julian[6]

[1] *School of Earth and Environment, University of Leeds, Leeds, West Yorkshire, United Kingdom*; [2] *Chatham House, London, United Kingdom*; [3] *University of Exeter, Exeter, United Kingdom*; [4] *University of Leeds, Leeds, United Kingdom*; [5] *Universidad de Chile, Santiago, Chile*; [6] *CIAT, Cali, Colombia*

The complexity of the inter-related set of climate change and food security risks and responses means that crop models can be used in various different ways in assessing risk and nutrition security. These range from global and fully integrated assessment models to national risk assessments and to place-based research. This talk draws on involvement in a range of assessment in order to review the role of crop models and develop some overarching challenges within two areas:

1. Modelling impacts, adaptation and risk

Crop growth models are used to assess impacts on crop productivity and adaptation. Use of crop models for the UK Climate Change Impact Assessments (CCRA; 2017 and the current report, due in 2022) varied across chapters. For the assessment of UK productivity under climate change, the authors noted that "quantification of yield changes using multivariate crop models is complicated because of the difficulties of generalising from the site-specific conditions (for which the model is developed) to national-scale estimates" (Brown et al., 2016). Crop models played more of a role in assessing the transmission of risks to the UK from abroad (Challinor et al., 2016), since here aggregation error is less of a problem than for a relatively small country like the UK. However, even in this case, the relatively broad range of future yields predictions, and the complex interrelationships with supply chains, policy and economics, meant that crop models did not feature prominently in the main text.

In their review, Challinor et al. (2017) suggested ways to improve the use of crop models for risk assessment and adaptation. Taken together with the review of the use of crop models for UK CCRA (Challinor et al., 2016, 2018) and for the African projects, the following focal areas emerge and are presented in some detail: documenting and adhering to good practice; working with stakeholders to identify the timing of risks; use of multiple methods that critically assess the use of climate model output; increasing transparency and inter-comparability in risk assessments.

2. Assessing climate risk cascades across sectors and international borders

Systemic climate risks result from cascading impacts through inter-related systems. This is a particular challenge to risk assessment, especially when risks are transmitted across sectors and international boundaries. Work for UK CCRA suggests that a clear understanding of, and separation between, the different sources of risk (e.g. climate, agricultural management, policy, etc) is critical if risk interaction and transmission are to be assessed.

There are a range of modelling and qualitative and systems-based methods of assessing risk and risk transmission. We review these methods in the talk and provide two specific examples: i. the assessment of risks from weather-related shocks to international food production and trade, which was the most urgent risk identified by CCRA2017 (Fig. 1); and ii. a new platform that is being used to combine co-produced policy-relevant land use scenarios, crop productivity and emissions modelling, and trade and nutrition analyses, in order to address questions identified by engagement with African regional stakeholders.

Recommendations emerging from this part of the review overlap to a large extent with those of part 1. In particular, there is a need for risk cascade methodologies with transparent assumptions that uses both quantitative and qualitative methods.

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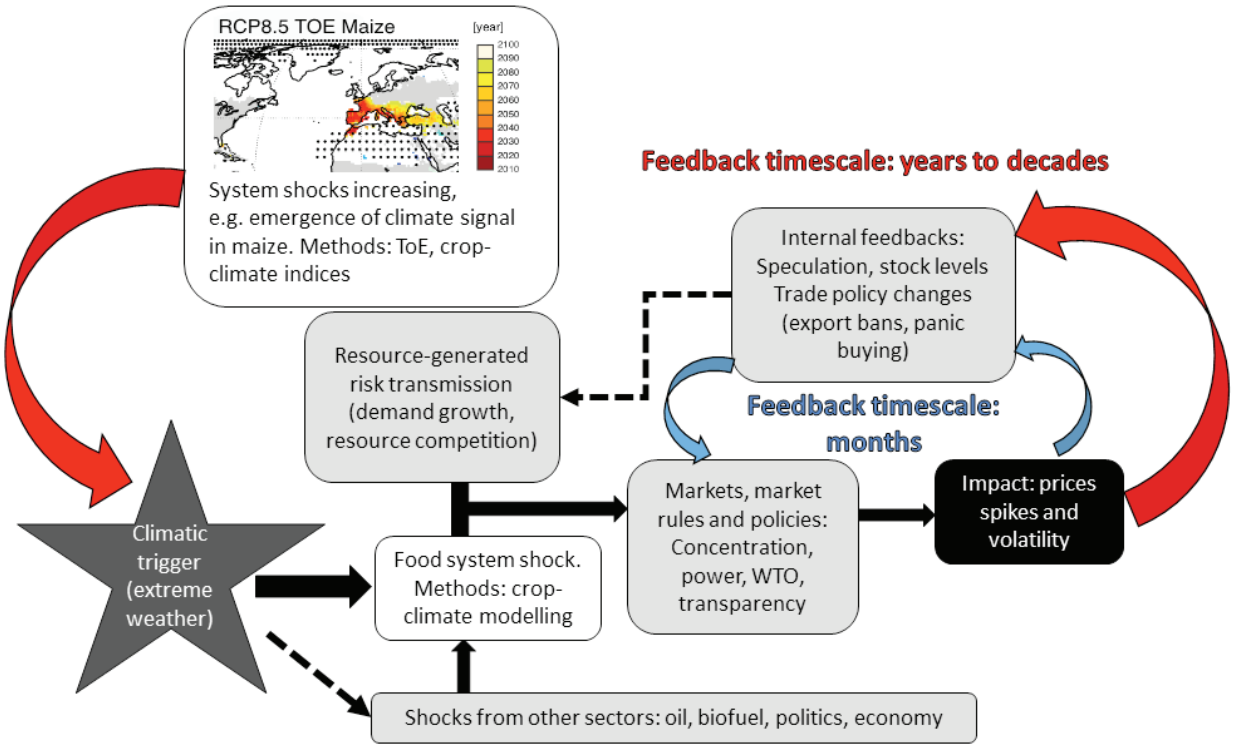

Fig. 1. Processes and feedbacks across timescales (red and blue arrows) for weather-related food system shocks. Relevant modelling methods (use of crop-climate models and indices and techniques to determine the time of emergence of climate signals) are highlighted in the white boxes. After Challinor et al. (2017) and Rojas et al. (2019).

Keywords: impacts, risk assessment, adaptation, mitigation, risk cascades.

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S5-O.02

Historical climate uncertainty in the AgMIP GGCMI ensemble of agricultural models

Ruane Alex[1] (alexander.c.ruane@nasa.gov), Phillips Meridel[2], Müller Christoph[3], Jagermeyr Jonas[4], Elliott Joshua[4]

[1] *NASA Goddard Institute for Space Studies, New York, NY, United States*; [2] *Columbia University, New York, NY, United States*; [3] *Potsdam Institute for Climate Impacts Re, Potsdam, Germany*; [4] *University of Chicago, Chicago, IL, United States*

Introduction

Crop models require daily (or sub-daily) meteorological inputs, and gridded crop model applications are particularly challenged to find consistent spatial and temporal coverage to understand historical conditions and form a basis for comparison against future climate scenarios. Here we present results from the Agricultural Model Intercomparison and Improvement Project (AgMIP; Rosenzweig et al., 2013) Global Gridded Crop Model Intercomparison (GGCMI) Phase I (Müller et al., 2017, 2019), which aligned 15 global gridded crop models and 11 climate forcing datasets (Ruane et al., 2015) to understand how the selection of climate data affects simulated production.

Materials and Methods

The importance of climate forcing dataset selection depends on differences between the climate datasets but also on the crop models' sensitivities to those differences. The climate datasets included mean biases and differences in the probability of extreme events, with larger uncertainty around extreme precipitation and in regions where observational data are scarce (e.g., sub-Saharan Africa). Simulated annual yield shortfalls are driven largely by seasonal precipitation deficits, although there are notable differences in fundamental climate response by region and farm system (e.g., precipitation matters less for irrigated systems; warmth can have positive influences at high latitudes). Uncertainty in configuration in low-input farming systems adds to the uncertainty in climate in much of the developing world (see Figure), leading to regions of much deeper uncertainty across the climate-crop model ensemble.

Results and Discussion

Countries and crop systems with high correlations between simulated and observed national production anomalies (using FAO data) tend to have high correlations across all climate forcing datasets, although the AgMERRA and WATCH Forcing Dataset using the ERA-Interim reanalysis tended to be among the top performing climate forcing datasets across most countries (as measured by correlation). These climate forcing datasets are also comparable to the multi-climate-forcing-dataset ensemble mean, whereas the poorer performing models have much lower FAO correlations.

Conclusions

In the end, it is important to select a high quality climate forcing dataset, but performance is most limited by crop model configuration and the availability of observational climate and production data.

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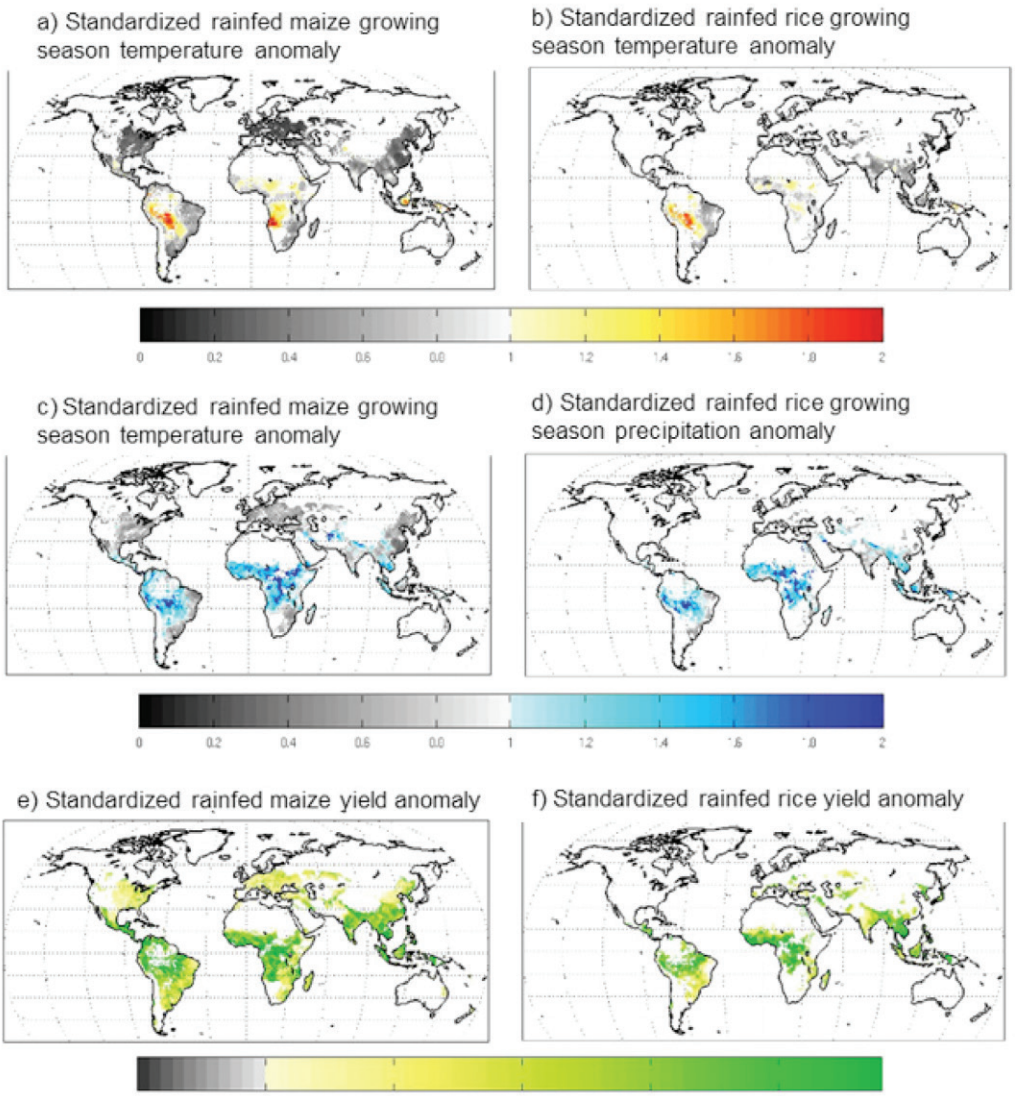

Figure: Standardized anomalies (standard deviation across years / standard deviation across simulations) for maize growing season mean (a,b) temperature and (c,d) precipitation (across all climate forcing datasets) as well as for (e,f) yield (across all Global Gridded Crop Model x Climate Forcing Dataset combinations) for rainfed maize (a,c,e) and rainfed rice (b,d,f). Gray suggests that the yearly anomaly is larger than the standard deviation across datasets, while colored regions indicate the opposite.

Keywords: Maize, AgMERRA, Drought, Climate forcing dataset, Bias-adjustment.

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S5-O.03

Combining stakeholder views and simulations to boost sustainable intensification of cereal production in North Savo

Palosuo Taru[1] (taru.palosuo@luke.fi), Hoffmann Munir[2], Rötter Reimund[3], Lehtonen Heikki[1]

[1] *Natural Resources Institute Finland, Helsinki, Finland*; [2] *ZALF, Müncheberg, Germany*; [3] *University of Göttingen, Göttingen, Germany*

Introduction

Sustainable intensification is needed to cope with the challenges agriculture faces with respect to climate change and increasing food demand. Northern cropping systems may benefit from longer and warmer growing seasons, but the sustainability of production will be challenged due to increased production risks. Farmers and other agricultural stakeholders need information and improved skills to effectively response to these risks (Lehtonen et al. 2018).

Material and Methods

This study combined stakeholder knowledge and simulation modelling in order to find and assess means for sustainable intensification of cereal production in the North Savo region in Finland under current and future climatic conditions. North Savo was one of the selected case studies in MACSUR and SUSTAg projects to perform integrated modelling and assessment studies on climate change adaptation and sustainable intensification. Stakeholder workshop discussions were used to identify promising intensification measures for cropping systems in the region. Different options and their combinations, altogether 19 technology packages, were assessed using the APSIM cropping system model (Holzworth et al., 2014). The model was used to assess cereal yields, grain nitrogen (N) content, nitrate leaching and water productivity for a historical baseline (1981-2010) and mid-century conditions (2041-2070) as projected by five General Circulation Models for different emissions scenarios. Management options simulated included improved cultivars with later maturing characteristics, improved heat-drought resistance and nitrogen-use efficiency, increased N fertilisation levels, improved crop rotations together with improved soils as well as supplementary and full irrigation. The model results were presented to the stakeholders and their comments, reflections and complementary views were gathered.

Results and Discussion

The simulation results indicated that although a warming climate in conjunction with elevated atmospheric CO_2 concentrations generally increases yield levels, N uptake and water productivity, risk associated with higher N leaching due to increased precipitation is a challenge for sustainability of crop production in the region (Table 1). There seems to be, however, a large potential for sustainably intensifying crop production in northern conditions as the sustainability indicators studied were more affected by different SI options than future projected climate. Combining several intensification measures at a time showed large potential. Among a wide set of SI options tested for their sustainability impacts, improved crop cultivars, particularly with some increase in N fertilisation, showed the firmest positive impacts. This was supported by the views of agricultural stakeholders in the region.

Agricultural stakeholder's suggestions for alternative SI options challenged the simulation approach to some extent. For example, grass mixtures, i.e. use of forage crop seed mixes tailored for farm conditions, that were seen important by local stakeholders could not be assessed, because the methodology for modelling the crop mixtures is not yet mature enough for this type of analysis. Simulations results still provided robust information for comparing the sustainability impacts of alternative measures and supported local discussions on how to sustainably improve currently low profitability of cereal production in the region and prepare for changing climate conditions.

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Management option	Baseline	RCP2.6	RCP4.5	RCP8.5	Baseline	RCP2.6	RCP4.5	RCP8.5
	Barley yields				Grain N			
Current management	0	0	+	+	0	+	+	+
Improved cultivar	++	++	++	+++	+	+	+	+
Increased fertilisation level	0	0	+	++	+	+	++	++
Soil improvements	0	0	+	++	0	0	0	0
Supplementary irrigation	+	+	++	++	0	+	+	+
	Nitrate leaching				Water productivity			
Current management	0	+	++	+++	0	+	+	++
Improved cultivar	-	0	+	++	+	+	++	++
Increased fertilisation level	+	++	+++	+++	0	+	+	++
Soil improvements	-	+	++	++	+	+	++	++
Supplementary irrigation	+	++	+++	+++	0	+	+	++

Table 1. Effects of selected management options on simulated sustainability indicators under baseline (1980-2009) and future (2040–2069) climate conditions. The notations depict average changes in comparison to the results for current management under baseline conditions.

Keywords: barley, climate impacts, scenarios, stakeholder interaction, wheat.

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S5-O.04

AFRICAP Diets, Impacts, Mitigation modelling for climate smart food security in sub-Saharan Africa

Jennings Stewart[1] (s.a.jennings@leeds.ac.uk), Challinor Andy[1], Fitton Nuala[2], Macdiarmid Jennie[2], King Richard[3], Clark Heather[2], Benton Tim[3], Smith Pete[2]

[1] *University of Leeds, Leeds, United Kingdom*; [2] *University of Aberdeen, Aberdeen, United Kingdom*; [3] *Chatham House, London, United Kingdom*

Introduction

Compliance with the Paris Agreement is a major global challenge, especially when considering the interconnected challenge of achieving food security in sub-Saharan Africa. Here we present a novel approach to determine the inter-relationships between land use, agriculture and nutrition in sub-Saharan Africa. The framework is specifically targeted to deliver local policy information for climate smart agriculture in Malawi, Zambia, Tanzania and South Africa. The methodology combines both quantitative and qualitative assessment, and can be adapted to other countries and regions.

Materials and Methods

Scenarios of land use and productivity developed jointly with stakeholders form the basis of an analysis of mitigation, food production and nutrition security. The scenarios are used to develop pathways towards a) sustainable emissions, b) climate smart agriculture, c) nutrition security. The novel methodology proposed draws on existing tools and expertise to address the timely and fundamental question of how Paris-compliant agriculture can be achieved.

GLAM (Challinor et al., 2004) gives crop production changes, along with yield changes from AgCLIM50 (van Meijl et al., 2017). ECOSSE (Smith et al., 2010) gives GHG emissions. This informs future Paris-compliance and nutrition security. Policy-relevant land use scenarios are used to see if agricultural land expansion can contribute to 2050 food security.

Food production changes to 2050 are based on modelled production changes and FAO Food Balance Sheets. A trade analysis uses various trade scenarios - drawing on data in Food Balance Sheets and demographic and nutritional datasets - to determine the required changes to trade to achieve nutrition security (Fig. 1).

Results and Discussion

The outcome of this process is an assessment of national nutrition security, GHG emissions and resilience to extremes for policy-oriented future land use patterns. Assessed trade-offs include the reliance on trade for nutrition security. Results show climate-induced losses to maize yields are mitigated by possible expansion of land for crop production.

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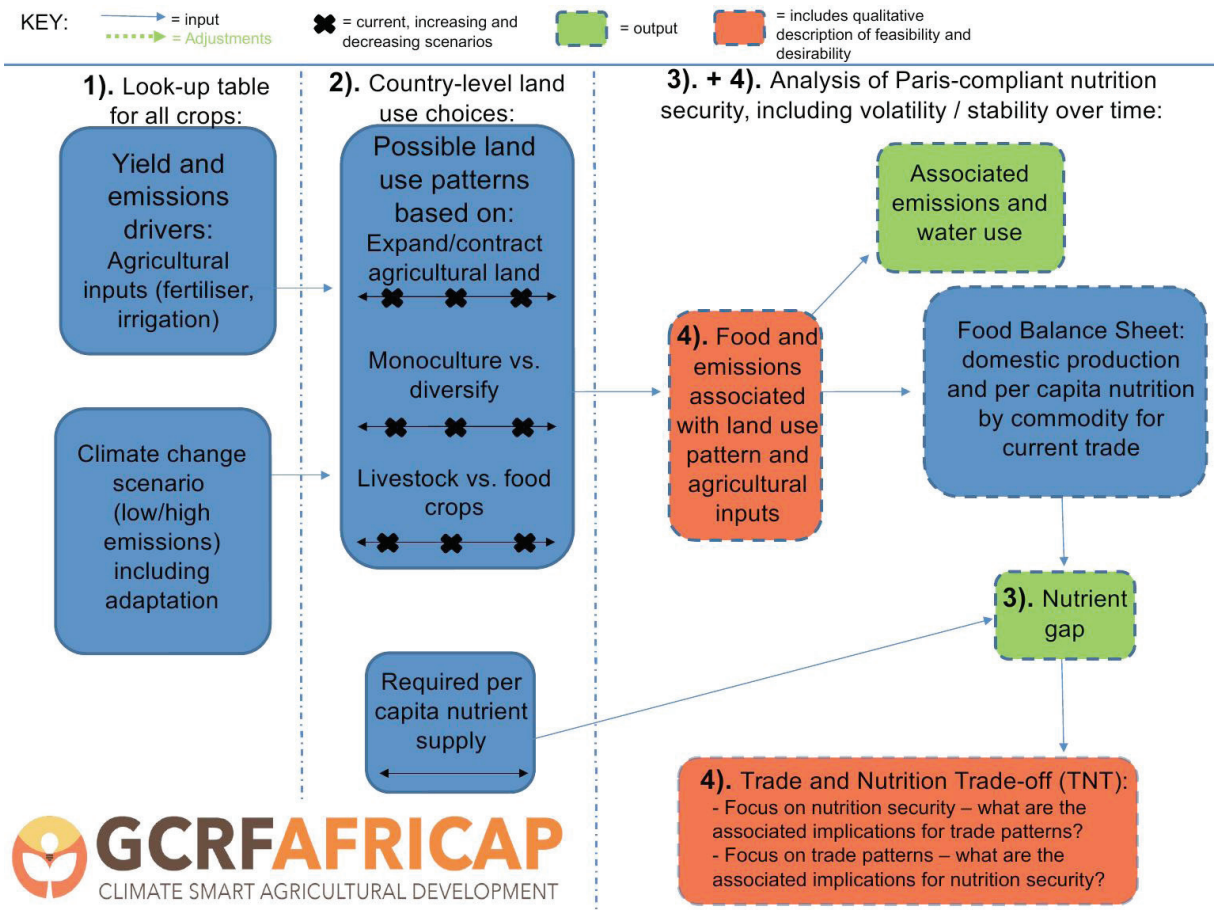

Figure 1: Modelling framework.

Keywords: Climate change, climate smart agriculture, food security, Diets, Modelling.

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S5-O.05

Potential GHG mitigation and carbon sequestration from European cropland by modelling crop residues management

Carozzi Marco[1] (marco.carozzi@gmail.com), Haas Edwin[2], Scheer Clemens[2], Butterbach-Bahl Klaus[2], Recous Sylvie[3], Loubet Benjamin[1], Massad Raia Silvia[1]

[1] *EcoSys, INRA, THIVERVAL-GRIGNON, France*; [2] *Karlsruhe Institute of Technology, IMK-IFU, Garmisch-Partenkirchen, Germany*; [3] *FARE, INRA, Reims, France*

Introduction

Effective agronomic practices are needed to achieve long-term climate objectives. Crop residue management represent a key lever to counteract the net greenhouse gas (GHG) balance in the soil, improve soil organic carbon (SOC) and fertility. Quality and composition of crop residues, management in the field and pedoclimatic conditions are able to increase or decrease nitrous oxide (N_2O) emissions or SOC, modifying the GHG footprint of the agroecosystems. Process based models represent a suitable tool for extrapolating from current knowledge in both time and space, facilitating the analysis of management scenarios and decision making.

The aim of this work is to simulate SOC balance and N_2O emissions from different scenarios of residue management in the European cropping systems and over climate change. This work was carried out in the framework of the project ResidueGAS (FACCE ERA-GAS) with the specific objective to improve the estimation and mitigation of N_2O emissions and SOC storage from crop residues.

Materials and Methods

Two ecosystem models, Landscape-DNDC (Haas et al., 2012) and CERES-EGC (Gabrielle et al., 1995), were applied to evaluate the effects of crop residue management scenarios in the EU-27. Three residue managements were evaluated: i) completely exported, ii) recycled into the soil, iii) exported or recycled in function of the crop species. Models were first assessed to reproduce specific field scale experiment in different European locations. They were later applied to a spatialized dataset (0.25° × 0.25° latitude-longitude grid) composed by climate, soil and crop data. An historical weather dataset (1951-2004) with two IPPC's climate change projections to 2100 were assessed: a "mild" scenario with robust actions to control GHG emissions, RCP4.5, and a "strong" scenario with no actions to counteract GHG, RCP8.5. Soil representative characteristics were extracted from the European Soil Database, whereas crop specie and management data were obtained from the CAPRI model (Britz and Witzke, 2008) and Eurostat statistics. The first 30 years of the climatic data were used to spin-up the models and initialise soil C and N pools. N fertilisation was applied to 91% of the cropping systems with a yearly average spanning from a few dozen to 370 kg N ha^{-1} y^{-1} (mean of 97 kg N ha^{-1} y^{-1}). Crop were irrigated according to their needs.

Results and Discussion

Data are reported for one ecosystem model exploring two climatic scenarios and one crop residue management in function of the crop type (iii). This is assumed as the most reasonable scenario for crop management to assess the most realistic long-term trend of N_2O and SOC.

During the historical period considered (1978-2004) N_2O emissions remain stable to 3.1 kg N-N_2O ha^{-1} y^{-1} to gradually increase to 3.5 kg N-N_2O ha^{-1} y^{-1} towards 2100 in the RCP4.5 scenario. In the RCP8.5 scenario, characterised by a constant increase in air temperatures, N_2O emissions increases on average up to 4.3 kg N-N_2O ha^{-1} y^{-1}.

The net ecosystem exchange (NEE) shows a general net C uptake by the European cropping system. During the historical and over the RCP4.5 climate scenario was observed a slight and constant decline of the ability to stock C by the system, reducing by 9% (from -347 to -316 kg CO_2 ha^{-1} y^{-1} from 2005 to 2100). In the other projection scenario assessed, RCP8.5, the NEE shows an inversion in the trend, with an increase of the uptake capacity of the same magnitude, 9%, from 2005 to 2100.

Given that the net primary production (NPP) is almost equal in the two climate scenarios, it can be concluded that a decline in heterotrophic respiratory activity occurred, which is directly related to low decomposition of crop residues by soil biota. This inversion is also supported by a reduction of about 20% of the crop yields in the RCP8.5 scenario compared to the RCP4.5 scenario, passing from 4.9 to 3.9 Mg ha^{-1} y^{-1}, respectively.

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Conclusions

The use of ecosystem models allowed observing long-term N_2O emission and SOC stock in European cropping systems. Climate change scenarios highlighted a potential reduction in soil C storage associated with a substantial increase in N_2O emissions.

Keywords: Crop residue management, greenhouse gas emission, soil carbon stock, cropping systems, ecosystem modelling.

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S5-O.06

Vulnerability Map for Chilean Agriculture: Using crop and niche models to assess future impacts and adaptation options

Meza Francisco (fmeza@uc.cl), Gonzalez Domenica, Garcia-Gutierrez Victor, Jara Valentina, Duarte Katherine, Pica-Tellez Andres

Centro UC de Cambio Global, Pontificia Universidad Catolica de Chile, Santiago, RM, Chile

Introduction

Occurrence of droughts and floods, temperature increases and local rainfall reductions are recognized as the most obvious impacts of climate change in countries such as Chile. Recent research shows that approximately 25% of the rainfall decrease experienced in Chile can be linked to anthropogenic effects (Boisier et al., 2016). This precipitation deficit has generated impacts on river flow, reservoir volumes and groundwater levels in central Chile. Likewise, there is a substantial decrease in vegetation productivity in the northern region (Garreaud et al., 2017). Projections made by Global Circulation Models, using RCP8.5, show a generalized warming between 2 and 4 ° C. with a greater effect in the Andean zone, with direct effects on snow accumulation and a decreasing trend in precipitation.
The effects that such environmental changes can have on agricultural systems are not easy to anticipate. Despite this, it is known that the increase in temperature has a negative effect on summer crops (with yield losses between 10 and 25%, Meza et al., 2008). On the other hand, winter crops can benefit from the rise in temperature, as long as the water supply is maintained in adequate values to meet the water demands of the crops (Meza and Silva, 2009). The precipitation deficit, meanwhile, generates a reduction in yields in rainfed conditions (MMA, 2016), an increase in the consumption of irrigation water by agricultural species (Meza et al., 20124) and problems in the reliability of water rights (Meza et al., 2012).

The design of adaptation strategies requires the development of tools that allow policy makers, practitioners and farmers to anticipate potential impacts and ex-ante evaluate the effects of intervention actions. Because climate and agricultural systems are spatially heterogeneous, these tools should be able to reproduce the interlinkages between soils, crops and agricultural systems producing results that explore a wide range of adaptation options.
This paper presents the preliminary results of an interdisciplinary research team whose aim is to develop an interactive vulnerability maps of Chilean agriculture for the use of governmental agencies, universities, students and producers.

Materials and Methods

We combine statistically downscalled climate information (Bias correction statistical downscaling ; Ahmed, 2013) at 5 km resolution from 21 different GCMS. This generates gridded time series of daily meteorological variables. We generate homogeneous unit of analysis by selecting the most representative soil type and crop management information. This gridded files are then incorporated into CropSyst (Stockle et al., 2003) and run in a parallel mode (Figure 1).

For horticultural crops a niche model fitted using Maxent algorithm was used. This allow us to explore changes in region suitability for specific crops.

Vulnerability map allow the exploration of new areas for the development of high value crops as well as loses in suitability. The crop model installed allow the search for optimum adaptation strategies and the evaluation of a) Impact of climate change, b) Identification of adaptation and c) Evaluation of residual impact.

Acknolwledgements

The authors would like to acknowledge the support from FONDECYT Project 1170429.

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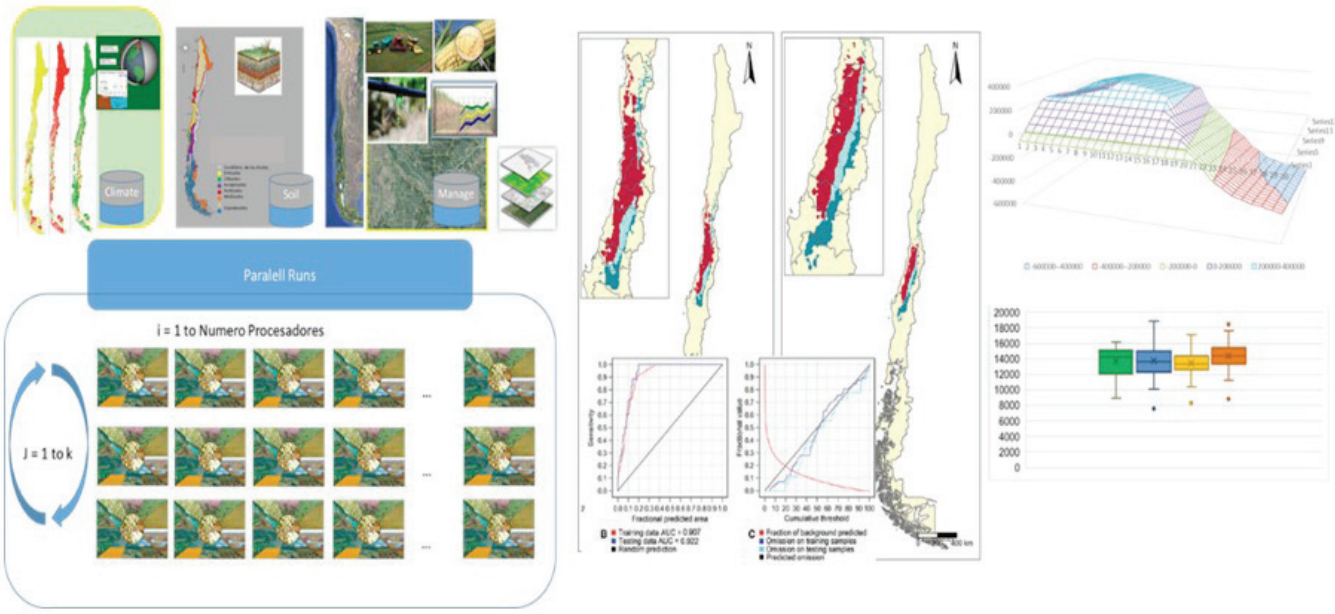

Figure 1. Methodological framework for Agricultural Vulnerability Map and sample of results obtained.

Keywords: Crop models, Niche models, Vulnerability map, Chile, Climate change.

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S5-O.07

Impacts of tropospheric ozone and climate change on Mexico wheat production

Guarin Jose[1] (jguarin@ufl.edu), Emberson Lisa[2], Simpson David[3], Hernandez-Ochoa Ixchel[1], Rowland Diane[4], Asseng Senthold[1]

[1] *Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States*; [2] *Environment and Geography Department, Stockholm Environment Institute, York, United Kingdom*; [3] *Norwegian Meteorological Institute, Oslo, Norway*; [4] *Department of Agronomy, University of Florida, Gainesville, FL, United States*

Introduction

Elevated concentrations of tropospheric ozone (O_3) cause deleterious effects on crop growth and development by reducing photosynthesis and accelerating leaf senescence (Mills et al., 2007). Future climate projections indicate increases in global O_3 concentrations due to growth of O_3 precursor emissions (Cooper et al., 2014). Wheat (*Triticum aestivum* L.) is the second most produced and most harvested crop in the world, which contributes approximately 20% of the global total calories and proteins necessary for human diets (Shiferaw et al., 2013). In Mexico, wheat is one of the five highest produced crops and is a staple food for the population. However, wheat is the most sensitive crop to O_3 exposure when compared to other major agricultural crops (Mills et al., 2007), which could pose a threat to both Mexico and global food security.

The aim of this study is to determine the impact of O_3, in addition to climate change, on wheat production in Mexico using five GCMs under the highest emissions scenario, RCP 8.5, paired with two O_3 emissions scenarios using the Decision Support System for Agrotechnology Transfer (DSSAT) O_3-modified wheat model, DSSAT-NWheat v.4.6.1.01. Recently, the DSSAT-NWheat crop model was modified with an O_3 impact subroutine that accounts for photosynthetic reduction and accelerated leaf senescence associated with O_3 stress in wheat (Guarin et al., 2019b).

Materials and Methods

The O_3-modified DSSAT-NWheat crop model was used to simulate wheat production in Mexico using a baseline scenario with pre-industrial O_3 concentrations from 1980 to 2010 and five Global Climate Models (GCMs) under the Representative Concentration Pathway (RCP) 8.5 scenario from 2041 to 2070 paired with future O_3 concentrations from the European Monitoring and Evaluation Programme (EMEP) Meteorological Synthesizing Centre – West (MSC-W) model. Thirty-two representative major wheat-producing locations in Mexico were simulated assuming both irrigated and rainfed conditions for two O_3 sensitivity cultivar classifications (intermediate and tolerant).

Results and Discussion

The simulations showed large variability (after averaging over 30 years) in yield loss, ranging from 7% to 26% because of O_3 impact, depending on the location, irrigation, and climate change emissions scenario. After upscaling and aggregating the simulations to the country scale based on observed irrigated and rainfed production, national wheat production for Mexico is expected to decline by 12% under the future RCP 8.5 climate change scenario with additional losses of 7% to 18% because of O_3 impact, depending on the cultivar O_3 sensitivity.

Conclusions

The yield loss caused by O_3 in Mexico is comparable to, or even larger than, the impact from projected future climatic change in temperature, rainfall, and atmospheric CO_2 concentration. Therefore, O_3 impacts should be considered in future agricultural impact assessments.

Acknowledgements

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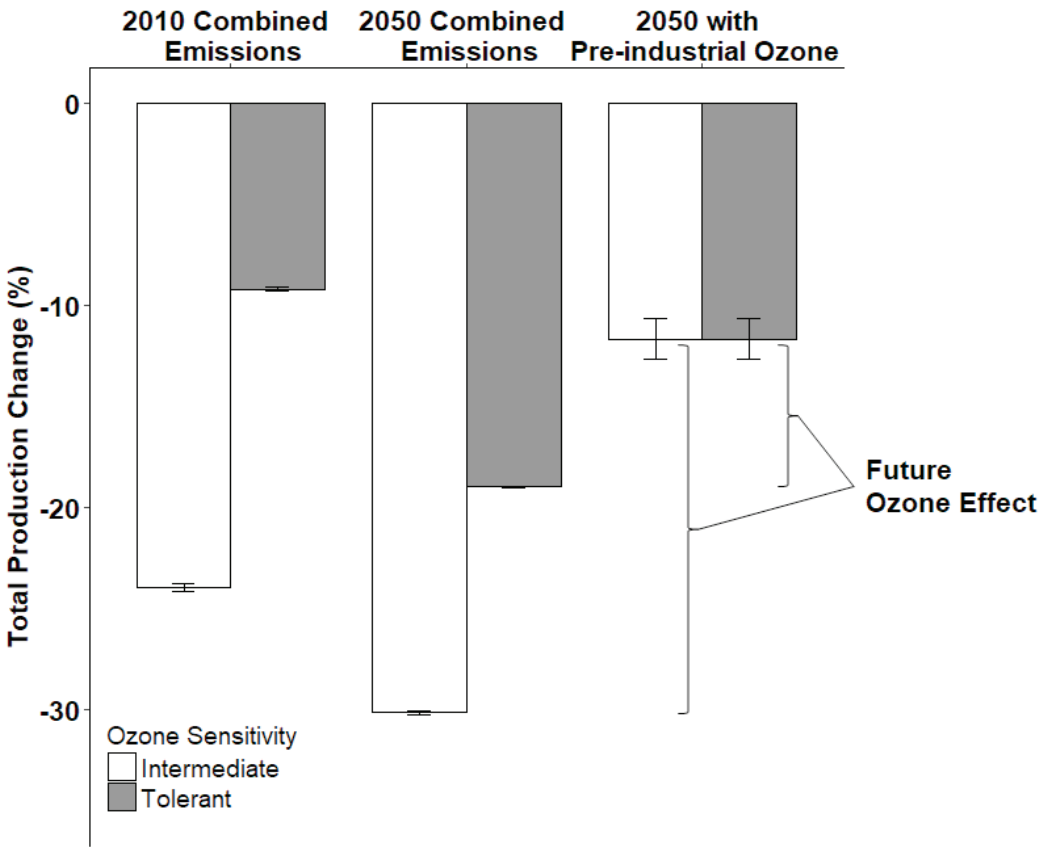

Figure 1. Simulated total aggregated production change from the baseline scenario with pre-industrial O3 for Mexico using the 2010 combined emissions scenario (baseline + 2010 O_3), 2050 combined emissions scenario (RCP 8.5 + 2050 O_3), and the 2050 climate change scenario (RCP 8.5) with pre-industrial O_3 for two different O_3 sensitive cultivar classifications (intermediate and tolerant). Aggregated production was upscaled from 32 representative wheat-growing locations based on 2015 Mexico production data. 2010 and 2050 combined emissions were averaged over five years of O_3 emissions data. Error bars show the standard error of the mean of the five years of the 2010 and 2050 combined emissions scenarios and the five GCMs for the 2050 scenario with pre-industrial O_3.
Source: Guarin et al., (2019a).

Keywords: Crop model, wheat yield, emissions scenario, future impact, food scarcity.

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S5-O.08

Modeling the response of crops to rapid cooling from stratospheric aerosols

Robock Alan (robock@envsci.rutgers.edu), Xia Lili

Department of Environmental Sciences, Rutgers University, New Brunswick, NJ, United States

Introduction

Most studies of crop responses to climate change focus on future scenarios of warming. But there are several ways in which surface climate can cool quickly because of increased stratosphere aerosols. They can be natural, from large volcanic eruptions, or anthropogenic, from implementation of stratospheric sulfate geoengineering or from smoke from fires generated by nuclear war. These scenarios involve either sulfate or soot stratospheric aerosols, which would block sunlight, reduce temperature and change precipitation patterns.

Materials and Methods

Climate changes producing rapid cooling would significantly impact agriculture. In addition, whether produced by sulfate or soot stratospheric aerosols, ozone would be destroyed, either by chemical reactions on the aerosols or by large heating. This would result in more ultraviolet radiation reaching the surface and would change the ozone concentration at the surface (Xia et al., 2017). The aerosols would also produce more diffuse radiation at the surface, which may enhance plant photosynthesis (Xia et al., 2016).

Results and Discussion

Are crop models ready to simulate agriculture responses to this sudden cooling and accompanying climate changes, including enhanced diffuse radiation and reduced direct radiation, more ultraviolet (UV) radiation, and changes in surface ozone concentration? For example, the CERES model (Greenwald et al., 2006) long ago added the capability to address the effects of diffuse radiation and UV. But, in general can models address these forcings, ozone changes, and cold temperatures? We will show examples of crop responses to reduction of surface air temperature, precipitation, and total solar radiation (e.g., Xia et al., 2014; Xia et al., 2015, and see Figure 1), as well as ongoing work with the Global Gridded Crop Model Initiative to look at the impacts of nuclear war on crop production.

Conclusions

We would like to ask for collaboration with crop modelers to add enhanced diffuse radiation and reduced direct radiation, more UV radiation, and changes in surface ozone concentration, as well as the ability of the models to simulate large temperature drops to make simulations more realistic. These capabilities will allow the models to address changes that will accompany global warming, as well as episodic cooling events.

Acknowledgements

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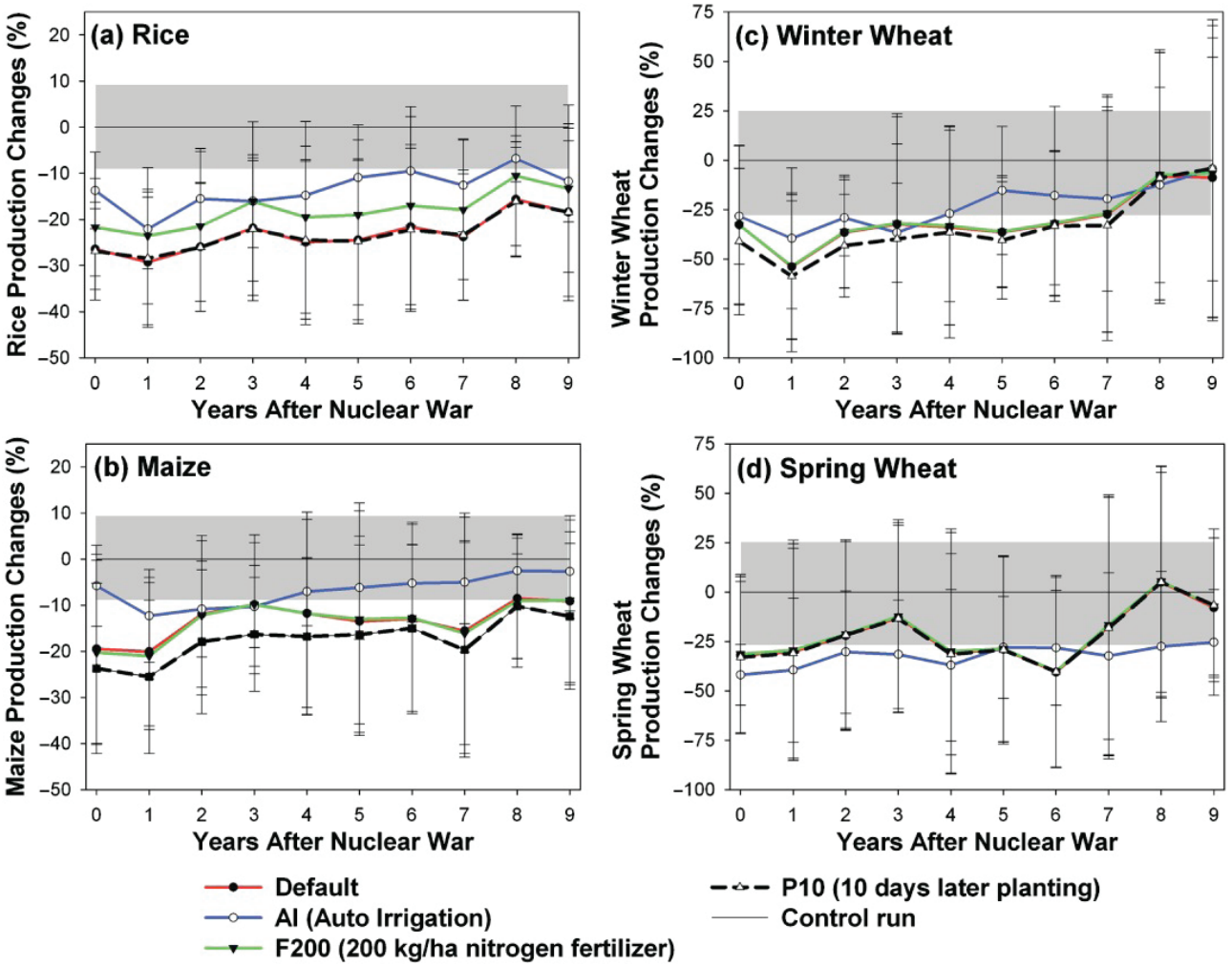

Figure 1. Percentage changes of the major Chinese grains: (a) rice, (b) maize, (c) winter wheat, and (d) spring wheat under different agriculture management practices. Each line is the average of three crop simulations forced by three climate models. The error bars are one standard deviation of grain production changes driven by climate forcing of three climate models including 30 climate conditions for each year. The gray area shows the average of one standard deviation from the four control runs with different agriculture management, illustrating the effect of interannual weather variations. The scale for production changes is different for wheat (c and d) than for rice (a) and maize (b). (Figure 6 from Xia et al. (2015) using DSSAT.)

Keywords: volcanic eruptions, geoengineering, nuclear winter, diffuse radiation, ozone.

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S5-O.09

Future soybean productivity in Europe

Nendel Claas[1] (nendel@zalf.de), Reckling Moritz[1], Stella Tommaso[1], Berg-Mohnicke Michael[1], Constantin Julie[2], Debaeke Philippe[3], Jakšić Snežana[4], Klimek-Kopyra Agnieszka[5], Schoving Celine[3], Webber Heidi[1], Battisti Rafael[6]

[1] *ZALF, Müncheberg, Germany*; [2] *INRA AGIR, Auzeville, France*; [3] *INRA AGIR, Castanet-Tolosan, France*; [4] *Institute of Field and Vegetable Crops, Novi Sad, Serbia*; [5] *University of Agriculture, Kraków, Poland*; [6] *Federal University of Goiás, Goiânia, Brazil*

Introduction

The EU strives to increase the production of protein crops to (i) to further diversify the current cropping systems to enhance ecosystem services and (ii) reduce the dependency on imports from foreign countries, including the control the quality of the produce that enters the EU market. Soybean exhibits the greatest potential for its large content of proteins and high economic potential. Currently, this potential is underutilised in Europe, while it is a dominating agricultural produce in e.g. US and Brazil and one of the ten most important crops at the global scale. Under expected climate warming, agronomists assume that the potential to successfully grow soybean in Europe to achieve competitive yield levels will increase significantly. Here we show the current soybean suitability across European site conditions, predict the potential productivity under current climate and explore the potential productivity under future climate based on multi-model simulations.

Materials and Methods

We use an ensemble of well-tested soybean growth models to simulate soybean yields across Europe. We used experimental soybean growth data from Müncheberg (Germany), Toulouse (France), Kraków (Poland) and several sites Serbia to calibrate three crop models MONICA (Nendel et al. 2011, Battisti et al. 2017), APSIM (Keeting et al. 2003, Mohanty et al. 2012) and STICS (Brisson et al. 2003, Jégo et al. 2010) for early to very early maturity groups in Europe. Soybean data represented maturity groups ranging from 0000 to II. The data was split to calibrate and test the models. We simulated a 30 year time period and calculated the 75% percentile for each grid cell and maturity group and analysed the phenology and the response to average temperature, cold spells and drought. Based on this distribution we produced a maturity group yield probability map.

Results and Discussion

Results demonstrate the northward shift of soybean production across the European continent and how the overall yield potential increases with the higher potential to grow high-yielding maturity groups in central Europe, where water scarcity is still not limiting the production. We also demonstrate that the potential area for rainfed production of soybean is expected to decrease in Southern Europe, with less water being potentially available in the soils.

Conclusions

We conclude that the overall potential to grow soybean across Europe will increase significantly under climate change, based on the new areas becoming available in central Europe outweighing the areas that will be lost in the South. This will increase Europe's potential to become less dependent on soybean imported from overseas.

Acknowledgements

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Keywords: Climate change, EU protein strategy, adaptation.

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S5-O.10

Multi-resolution analysis of aggregated spatial data to simulate yield and irrigation water demand at regional scales

Ojeda Jonathan[1] (jonathanjesusojeda@gmail.com), Eyshi Rezaei Ehsan[2], Remenyi Tomas[3], Webb Mathew[4], Webber Heidi[5], Kamali Bahareh[5], Harris Rebecca[3], Brown Jaclyn[6], Kidd Darren[4], Mohammed Caroline[1], Siebert Stefan[2], Ewert Frank[5], Meinke Holger[1]

[1] *Tasmanian Institute of Agriculture, University of Tasmania, Hobart, Tasmania, Australia*; [2] *Department of Crop Sciences, University of Göttingen, Göttingen, Germany*; [3] *School of Geography and Spatial Sciences, University of Tasmania, Hobart, Tasmania, Australia*; [4] *Natural Assets Spatial Intelligence, DPIPWE, Prospect, Tasmania, Australia*; [5] *ZALF, Müncheberg, Germany*; [6] *Agriculture and Food, CSIRO, Hobart, Tasmania, Australia*

Introduction

Input data aggregation influences crop model estimates at the regional level (Eyshi Rezaei et al., 2015). Previous studies have focused on the impact of aggregating the climate data used to compute crop yields (Hoffmann et al., 2015; van Bussel et al., 2011; Zhao et al., 2015). Little is known about the combined data aggregation effect of climate (DAEc) and soil (DAEs) model inputs. This study explores the implications of using coarse resolution input data on model outputs (irrigated and rainfed yield and irrigation water demand [IWD]) in Tasmania, Australia by (i) separately assessing the DAEc and DAEs of model input data and (ii) assessing the combined impact of DAEc and DAEs. We provide a framework to quantifying the input uncertainty introduced by using aggregated data to meet the objectives of modelling exercises.

Materials and Methods

Daily climate data were aggregated to coarser resolution by computing the mean values of the 5 km grid cells contained in larger grid cells. Soil data were then aggregated from the native resolution by selecting the properties of the dominant soil within each grid cell. The APSIM model was applied for the period 1999-2017 across areas suitable for potato (*Solanum tuberosum* L.) in Tasmania, Australia, using climate (daily rainfall, maximum and minimum temperature and solar radiation) and soil (organic carbon, maximum plant available water capacity, bulk density and pH) input data at 5, 15, 25 and 40 km resolution (Fig. 1). Spatial variance of inputs and outputs were evaluated by the relative absolute difference (rAD) between the aggregated grids and the 5 km grids (Zhao et al., 2015).

Results and Discussion

Our findings indicate that the sensitivity of model outputs to input data aggregation differs with the (i) aggregated input, (ii) model output considered and (iii) cropping conditions. We found that climate data aggregation increased the rAD (0.7-12.1%), especially for areas with pronounced differences in elevation. The rAD of soil data was higher (5.6-26.3%) than rAD of climate data and was mainly affected by aggregation of organic carbon and maximum plant available water capacity. For tuber yield estimates, the difference among resolutions (5 *vs*. 40 km) was more pronounced for rainfed (rAD=14.5%) than irrigated conditions (rAD=3.0%). The rAD of IWD (15.7%) increased when using input data with coarse resolution. In line with previous studies (Hoffmann et al., 2016; 2015), DAEc was mainly driven by differences in elevation and DAEs was largely influenced by soil properties. Climate input data, mainly rainfall, play a key role as a driver of potato tuber yield variability at high spatial resolution. At coarser resolutions, soil data aggregation can strongly affect simulated potato tuber yield (under rainfed conditions) and IWD. Therefore, reliable simulations of rainfed yield require a higher spatial resolution than simulation of irrigated yields. This needs to be considered when conducting regional modelling studies across Tasmania.

Conclusions

This study highlights the need to (i) separately quantify the impact of input data aggregation on model outputs to inform about data aggregation errors and (ii) identify those variables that explain these errors. Our results can also guide crop modellers when choosing the spatial resolution for simulations related to regional water use and climate change impact assessments.

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Acknowledgements
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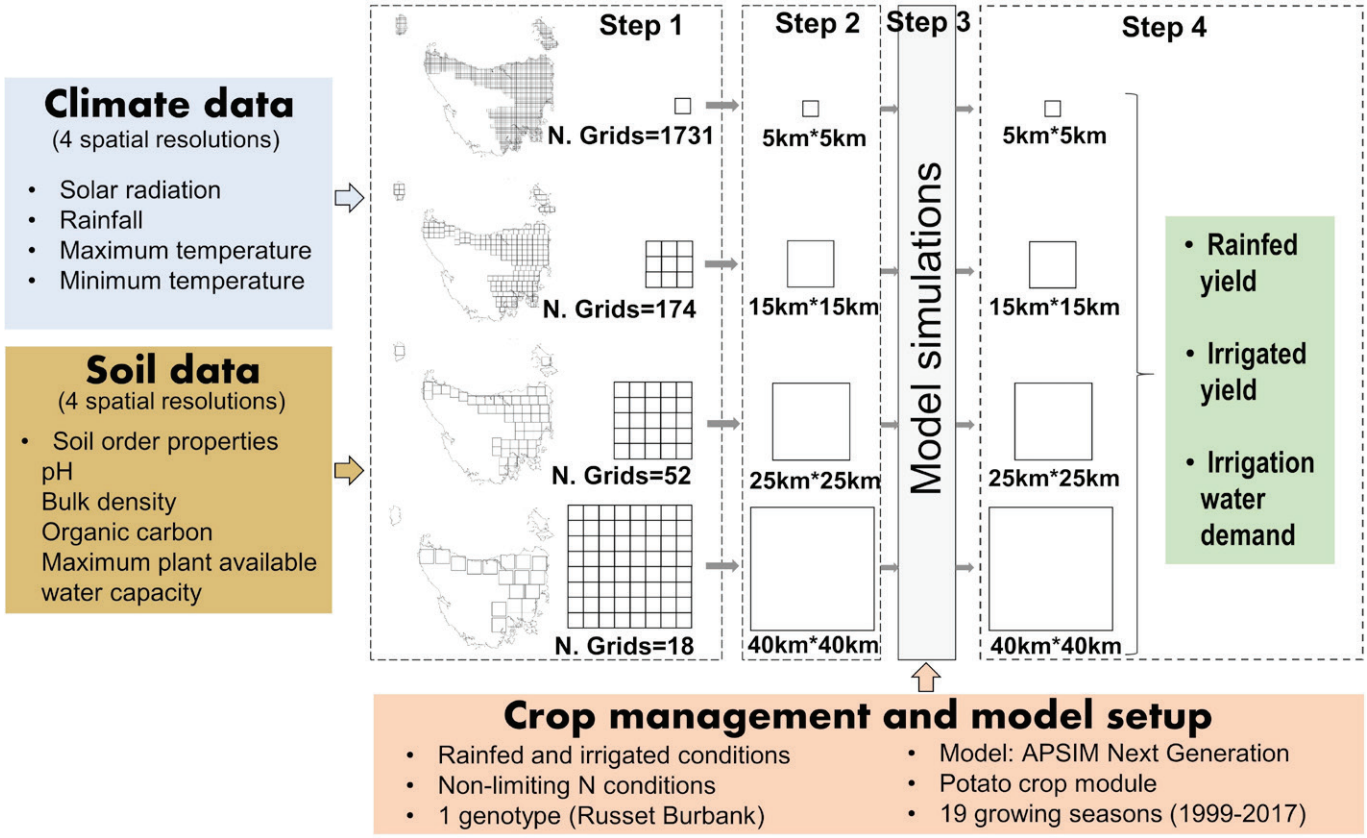

Figure 1. Processing steps to systematically assess the data aggregation effects of model input data (climate and soil) on simulated outputs. Step 1, data collection (climate and soil data at 5 km × 5 km resolution considered as reference in this study); Step 2, data aggregation (from 5 km × 5 km to 15 km × 15 km, 25 km × 25 km and 40 km × 40 km resolution); Step 3, Crop management configuration, model setup and running; Step 4, output analysis (rainfed yield, irrigated yield and irrigation water demand).

Keywords: Data resolution, Scale, Regional modeling, Data aggregation, Spatial heterogeneity.

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S5-O.11

Climate change impact on crop yield in Ethiopia: A multi-model uncertainty analysis

Rettie Fasil Mequanint[1] (fasil.mequanint@uni-hohenheim.de), Sebastian Gayler[1], Tobias KD Weber[1], Kindie Tesfaye[2], Thilo Streck[1]

[1] *University of Hohenheim, Stuttgart, Germany*; [2] *CIMMYT, Addis Ababa, Ethiopia*

Introduction

Process-based crop model simulations driven by climate change projections from climate models have dominated the literatures of climate change impacts on crops. Globally, many crop models with different model structure exist and hence the need to address associated model uncertainties to improve the relevance of crop model outputs (Challinor et al. 2013, Asseng et al. 2015). If not accounted for, this may jeopardize decision-making in the agricultural sector. Recently, the multi-model ensemble approach has been used to study model uncertainty in the predictions of climate change impacts on the production and productivity of crops. Nevertheless, climate change impact studies conducted on crops in Ethiopia so far have been based on a single or on two crop models forced by a few climate model projections (Araya et al., 2017; Timothy et al., 2019). As a result, predictions show a large dispersion in the magnitude and sometimes in the direction of the impact. Therefore, the main objectives of this study were i) to quantify the impact of projected climate change on maize and wheat yields in Ethiopia, and ii) to dissect the contributions of different sources of uncertainties from the overall uncertainty in crop yield predictions. In addition, a sensitivity analysis was performed to see the effects of elevated [CO_2], increased temperature, changes in precipitation and N fertilizer on future crop growth and yield.

Materials and Methods

A multi-model ensemble (n=48) was setup by combining different process representations in the sub-modules for plant growth (4), soil organic matter turnover (2), soil water dynamics (2) and soil heat transfer (3) using the Expert-N modeling framework. The Expert-N agro-ecosystem modeling package provides several models and sub-modules for the description of coupled processes in the soil-plant-atmosphere system (Priesack, 2006). Models were calibrated for phenology and growth using data from field experiments collected over 5-7 years across 3 locations representing the major wheat and maize growing areas in Ethiopia. Simulations were carried out for wheat and maize with each two cultivars for two 30-year periods, i.e., 1981-2010 and 2020-2050, representing baseline and future climates. Future projections were simulated using bias-corrected climate projections from ten global climate models under RCP4.5. The potential impact of climate change on wheat and maize yield were computed by comparing the relative changes between the baseline and future climate simulations. In this study, we compared the contribution of uncertainty in simulated grain yield caused by the i) inter-annual natural variability, ii) climate models, and iii) contribution of output variability caused by the different sub-models represented in the model ensemble according to Asseng et al. (2015). In order to identify the most influential factors that affect grain yield, a sensitivity analysis was also conducted by discretely varying selected input variables and analysing their sensitivity on modelled yield for the 30 baseline years.

Results and Discussion

Referenced to current yields, our study suggested that with [CO_2] elevated to 720 ppm from the current level could increase wheat grain yield by 32-38% and maize grain yield by 3-5%. However, the present study highlighted also the negative effects of increasing temperature on grain yield. For a temperature increase by 6 °C from current climate, the reduction in grain yield could reach 55-60% for wheat and 10% for maize. The effects of precipitation on grain yield were weakest compared to the rest of the treatments. N fertilization played a crucial role in increasing simulated yields. Compared to the unfertilized treatment, application of 160 kg ha^{-1} N increased maize and wheat median grain yields by 80-95% and 80-140%, respectively. Simulations driven by climate projections showed that maintaining future wheat productivity will be a major challenge with a predicted 30-45% reduction in grain yield by 2050s while the impact was modest for maize (< 5% reduction). Differences in crop models particularly, plant growth and soil water dynamics sub-models resulted in large uncertainties in the prediction of future crop yield.

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Averaged over the crops, the coefficient of variations was 19% (crop models), 13% (climate models) and 11% (inter-annual variability). The uncertainties varied among crop types and cultivars examined as well where the uncertainties were relatively higher for wheat than maize.

Conclusions

Grain yields were very sensitive to changes in [CO_2], temperature and N fertilizer where the responses were higher for wheat than maize. Grain yield responses to precipitation changes were weak. Maintaining yield stability for wheat will be a major challenge under the projected future climate. Our study highlighted the strength of predicted impact and demonstrated the importance of multi-model ensemble approach in understanding the associated uncertainties.

Keywords: ExpertN, crop model, maize, multi-model, wheat.

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S5-O.12

Climate change impact on European crop yields: sensitivity to rotations and residue management

Faye Babacar[1] (babafaye@uni-bonn.de), Webber Heidi[2], Gaiser Thomas[1], Stella Tommaso[2], Müller Christoph[3], Reckling Moritz[2], Ewert Frank[2]

[1] *Crop science group, INRES, Bonn, Germany*; [2] *ZALF, Berlin, Germany*; [3] *PIK, Berlin, Germany*

Introduction

Understanding potential impacts of climate change on crop yields is critical to adapting and building more resilient cropping systems. Studies at the European level suggest that in autumn sown cereals, yields are likely to increase due to CO_2 fertilization effects while yields are projected to decrease in spring sown crops due to shortened growth duration and intensified drought under future climate. However, most large scale climate impact studies have assumed mono-crop systems, and additionally re-initialized soil water contents each year. In reality, crops are grown in rotations, and besides marketing and feeding issues, the crops in rotations are selected to manage pests, weeds, soil nutrients and organic matter. While most crop models will not capture the effects of rotations or residues on pathogens and disease cycles, they do capture effects on soil water, soil carbon and nitrogen. The objective of this study was to assess how sensitive simulated climate change impacts on crop yields are to assumptions about re-initialization, crop rotation and residue management in large area simulations for seven arable crops in Europe.

Materials and Methods

The Lintul5 crop model in the SIMPLACE framework was used at a spatial resolution of 0.25° to simulate the crop growth. The SoilCN model (Corbeels et al., 2005) simulated soil organic carbon and nitrogen dynamics in response to biomass input, nitrogen, water and temperature. Simulations were performed for a baseline (1980-2005) and scenario (2040-2065) periods for climate data from 5 GCMs and 3 RCPs. Soil data was from the LUCAS and JRC's European soil databases. Crop sowing dates and variety lengths were based on observations from the JRC MARS database, assumed unchanged in the scenarios for crops. Three main sets of simulations were conducted: 1. re-initialization after crop harvest; 2. continuous mono-crop without re-initialization; and 3. plausible rotation. Rotations were designed for each of 12 environmental zones across Europe based on crops' production area reported in the CAPRI database, common best practices and rules on phytosanitary effects of the preceding crop (Reckling et al 2016). For each rotation, three residue management strategies were implemented: 0, 50 and 100% retention rates. All simulations were conducted assuming nitrogen limitation. Scenario nitrogen rates were adjusted from baseline by same amount water-limited yields changed.

Results and Discussion

Consideration of rotations on climate change impacts on yield differed by crop (Fig. 1). For European aggregates, in winter wheat, relative yield changes were positive and became more positive when rotation effects were included. For grain maize, relative yield changes were generally negative but did not vary with rotation scenarios. Yield changes were more variable across GCMs for maize and other summer crops than for wheat, increasing with warmer RCPs. There was no marked differences between re-initializing the model versus simulating continuously over the 25-year period for either crop.

On the other hand, our preliminary analysis suggests that residue retention strategy has no impact relative yield changes compared to removing all residues. However, the model does not yet consider effects of increased soil organic carbon on water holding capacity. This will be explored in a next step as will changes in SOC under the different residue management strategies. Results for all 7 crops will be presented.

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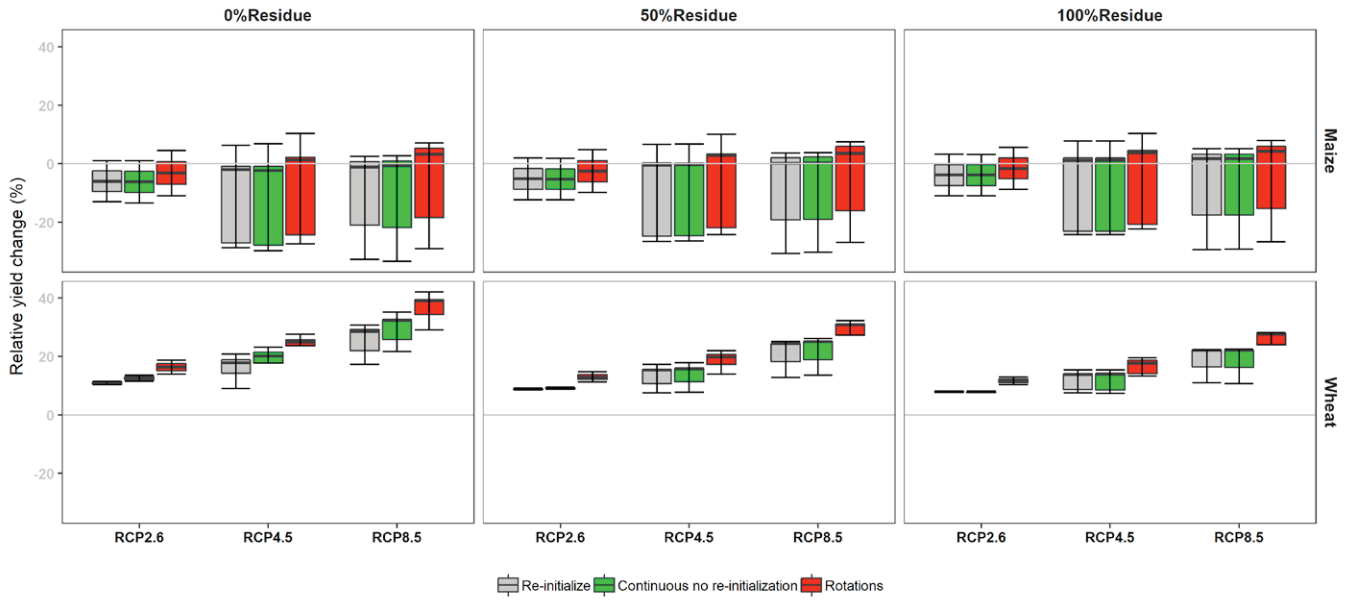

Figure 1: Relative yield change to 2040-2070 for three scenarios (RCPs) compared to a baseline period in European grain maize (top row) and winter wheat (bottom row). Panels are for three residue management strategies (0. 50 and 100% residue retention).For each RCP, three rotation options are shown: single crop with re-initialization between years (grey), continuous cropping without re-initialization (green bar), continuous cropping with re-initialization (grey bar) and rotations (red bar) for three scenarios (RCPs) with error bars GCMs.

Keywords: crop rotation, residue management, climate change, Europe.

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S5-O.13

Impact of Climate scenarios on the yields of cereals among farms in Nioro, Senegal and Navrongo, Ghana, West Africa

MacCarthy Dilys[1] (dsmaccarthy@gmail.com), Freduah Bright[2], Adiku Samuel[3], Adam Myriam[4], Ly Mouhamed[5], Porter Cheryl[6]

[1] *Soil and Irrigation Research Centre,, University of Ghana, Accra, Eastern Region, Ghana*; [2] *University of Ghana, Accra, Eastern Region, Ghana*; [3] *Soil Science Department, University of Ghana, Accra, Greater Accra, Ghana*; [4] *CIRAD, ICRISAT, Bamako, Mali*; [5] *LPAOSF/ESP, Cheikh Anta Diop University, Dakar, Senegal*; [6] *University of Florida, Gainesville, United States*

Introduction

The production of cereals in West Africa is constraint by several yield limiting factors such as poor soil fertility and erratic rainfall distributions and is largely dominated by smallholder farmers. Projected changes in climate thus poses a threat since crop production is mainly rain-fed. In this study, 2 crop simulation models were used to quantify the impact of climate change scenarios on the yield and variation in yield change of cereals on multiple farms under future production systems in West Africa.

Methodology

The Decision Support System for Agro-technological Transfer (DSSAT) and Agricultural Production Systems Simulator (APSIM) were, evaluated for maize, sorghum and millet and used for the impact assessment on multiple farms in Nioro, Senegal and Navrongo, Ghana. Data used were management practices (sowing dates, time and amount of fertilizer) obtained from agronomic surveys, soil data, weather data (historical; 1980-2009 and 5 Global Circulation Models; Mid Century time slice 2040 – 2069 for two representative concentration Pathway; 4.5 and 8.5) were used. Two representative agriculture pathways were developed with stakeholders to capture crop management practices under sustainable development (RAP 4) and unsustainable development pathway (RAP 5). RAP 4 was aligned to RCP 4.5 while RAP 5 aligned to RCP 8.5. The RAPs indicators were quantified and used as management input data.

Results & Discussions

The two models simulate yields of the cereals satisfactorily (rRMSE ranging 15 and 29%). Generally, yield reductions were simulated for all three cereals under climate scenarios. In the case of maize, average yield loses of 22 and 33% were simulated using DSSAT while APSIM simulated yield loses of 19 and 29% in Nioro (Figure 1). In Navrongo, maize yield loses were lower using DSSAT and no change in yield simulated using APSIM. Reductions in yields are partly associated with reduced crop phenology due to temperature and water stress (Faye et al., 2018). Differences in yield changes between the two sites can be attributed to differences in changes in climate parameters with drier and warmer projected changes for Nioro. The magnitude of change in yields differed between models due in part to differences in the sensitivity of phenology in the models to water and nitrogen stresses. While phenology in DSSAT is not sensitive to N, APSIM does respond to this stress factor. Additionally, projected rainfall distribution extended beyond that of the baseline situation, resulting in higher yields than would have been if baseline weather conditions remained. Simulated changes in yields under climate change were generally lower for sorghum and millet compared to maize. Similar results were reported by other studies (Adiku et al., 2015). Yield loses were also generally higher under unsustainable development pathway. There were variations in extent of yield changes among farms under both crop models and all crops. The relative standard deviations were, generally higher under RAP 5.

Conclusions

There is the need to develop adaptation practices taking into consideration the variability in yield change among farms. Reduction in yields are generally higher under the unsustainable development pathway compared to the sustainable development reechoing the need to promote sustainable practices.

Acknowledgments

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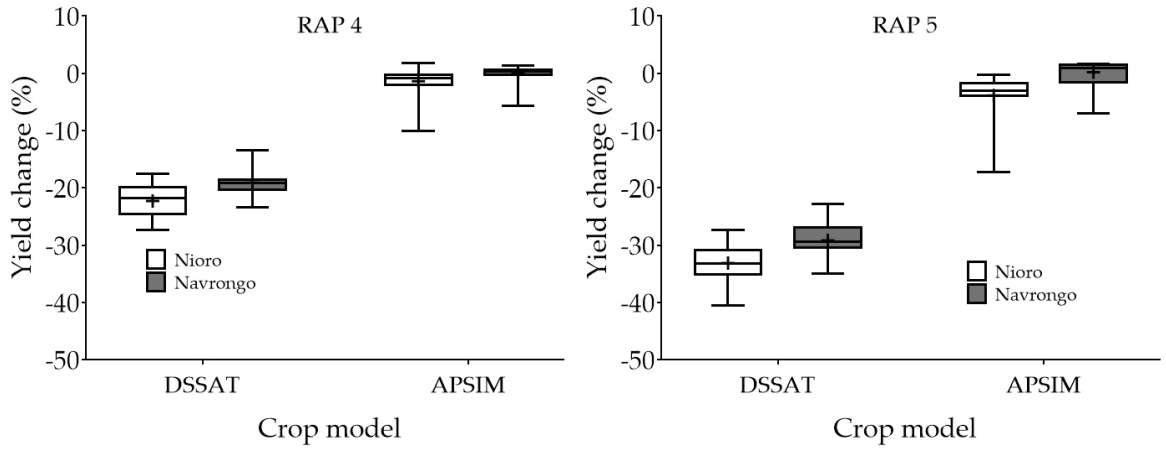

Figure 1: Simulated impact of climate scenarios on maize yields among farms in Nioro, Senegal and Navrongo Ghana. Representative Agriculture Pathway (RAP); RAP 4 is sustainable development while RAP 5 is unsustainable development pathway.

Keywords: Maize, Sub sahara Africa, Representative Agricultural Pathway, Sorghum, AgMIP.

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S5-O.14

Using farmer's field data and crop modelling to benchmark resource use efficiencies of arable crops in The Netherlands

Silva J.V.[1] (joao.silva@wur.nl), Tenreiro T.R.[2], Spätjens L.[3], Anten N.P.R.[1], van Ittersum M.K.[4], Reidsma P.[4]

[1] *Centre for Crop Systems Analysis, Wageningen University, Wageningen, The Netherlands*; [2] *Institute for Sustainable Agriculture, Córdoba, Spain*; [3] *Arable farming unit, Agrovision B.V., Deventer, The Netherlands*; [4] *Plant Production Systems, Wageningen University, Wageningen, The Netherlands*

Introduction

Arable farming systems in The Netherlands exhibit relatively small yield gaps (Silva et al., 2017). These are the result of up-to-date technologies and intensive use of inputs, which often translate in undesirable environmental impacts. Thus, it is important to understand the scope to maintain current yields while improving resource use efficiency. This study aims to quantify the crop yield (gap), resource use efficiency and environmental impacts for the main arable crops in The Netherlands. These are ware potato (WP), seed potato (SP), starch potato (StP), sugar beet (SBt), spring onion (SO), winter wheat (WW) and spring barley (SB).

Materials and Methods

Individual farmer field data from Dutch arable farms during the period 2015 – 2017 containing information on crop management and actual yields (Ya) were used. The sample consisted of a total of 5651 fields located in the main agricultural regions of The Netherlands. A crop modelling framework based on crop coefficients (kc) was used to estimate the potential yield (Yp; Villalobos & Fereres, 2017), and associated yield gaps (Yp – Ya), for each crop. Water productivity (WProd) was estimated as the ratio between Ya and total seasonal water availability (TSWA, the sum of growing season rainfall, applied irrigation, capillary rise and available soil water at sowing). Finally, the framework of the European Union Nitrogen Expert Panel (EUNEP, 2015) was applied to benchmark nitrogen use efficiency (NUE = N output / N input) and N surplus (Ns = N input – N output, which represents environmental impacts). N output equals Ya times the N concentration in the harvested product and N input consists of plant available N applied, atmospheric deposition and N in seeds.

Results

Yield gaps were less than 20% of Yp for SBt, between 30 – 40% of Yp for WP, SO, WW and SB and between 40 – 50% of Yp for StP and SP (Figure 1A). Ya and Yp were on average 86.5 and 93.7 t/ha for SBt and 58.9 and 90.5 t/ha for SO. Consistent differences in Ya and Yp were observed for potato production systems: yields were greatest for WP (Ya = 52.7 and Yp = 78.5 t/ha), intermediate for StP (44.8 and 76.1 t/ha) and lowest for SP (36.6 and 71.9 t/ha). For cereals, Ya and Yp were on average 9.6 and 15.3 t/ha for WW and 6.7 and 10.1 t/ha for SB. WProd was generally greater for the horticultural crops than for cereals (Figure 1B). For the former, WProd ranged between 20.9 for SBt and 13.7 kg DM/ha/mm for SO, with potato fields having an average WProd of 16.1 kg DM/ha/mm. For cereals, WProd was ca. 9.3 kg DM/ha/mm. NUE was within the desirable range of 0.5 – 0.9 kg N/kg N for most fields of all crops except SO and SB, for which greater values were common (Figure 1C). NUE values were associated with high Ns (> 80 kg N/ha) for WP, StP and WW and relatively low Ns for the other crops. This suggests there is scope to increase NUE and decrease Ns for arable crops in The Netherlands.

Conclusion

This study shows how crop models can be used in the benchmarking of crop performance in farmers' fields. Yield gaps were relatively small for most crops, ranging between 10% Yp for SBt and 50% for SO. WProd values were rather low, partly due to yield gaps and water surplus in most fields. Regarding N, it is clear that high efficiency does not always translate into low losses. Our findings further suggest that improving NUE while reducing Ns is best achieved through reductions in N applied.

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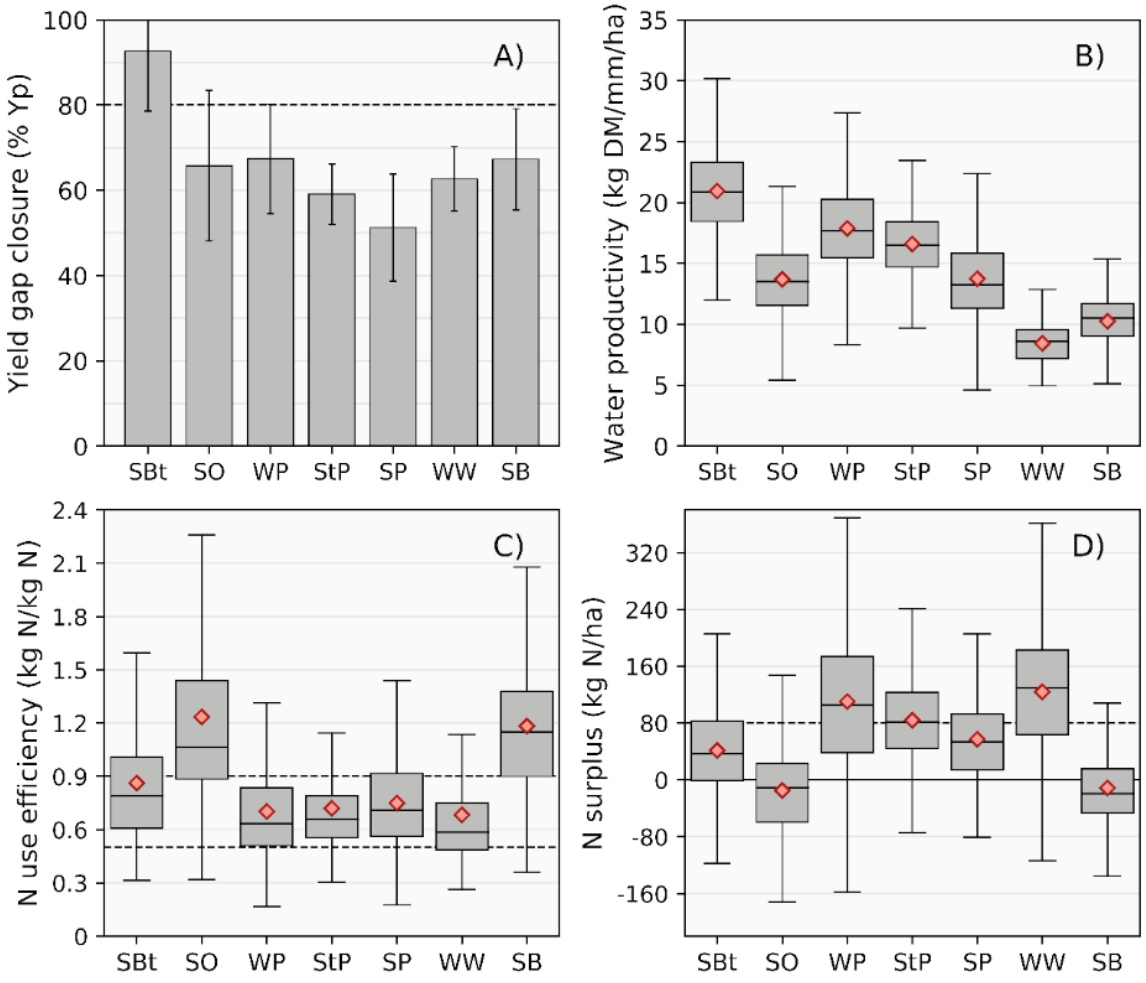

Figure 1. Yield gap closure (% Yp), water productivity (kg DM/ha/mm), N use efficiency (kg N/kg N) and N surplus (kg N/ha) for the main arable crops in The Netherlands. Error bars in A) show the standard deviation of the mean. Dashed lines in C) and D) show the NUE and Ns thresholds proposed by EUNEP. Red symbols in B), C) and D) show the mean of each indicator for a given crop.

Keywords: Crop Ecology, Yield gaps, Water productivity, N use efficiency, N surplus.

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S5-O.15

El Niño–Southern Oscillation Impacts on Agriculture and the National Economy in Ethiopia

Koo Jawoo[1] (j.koo@cgiar.org), Thurlow James[2], Xie Hua[1], Robertson Ricky[1], Azzarri Carlo[1], Kwon Ho-Young[1], Haile Beliyou[1]

[1] *Environment and Production Technology, IFPRI, Washington, DC, United States*; [2] *Development Strategy and Governance, IFPRI, Washington, DC, United States*

Ethiopia has made consistent progress in improving development indicators, but vulnerability to extreme weather events is a continuing concern, especially for people reliant on agriculture for their livelihoods. The 2015/16 El Niño event caused both a severe drought and flooding, which highlighted the remarkable improvements in the country's resilience and the remaining challenges in ensuring that everyone "bounces back" relatively quickly from adverse climatic shocks. With climate change, cyclical droughts, and poverty, and the high cost of emergency humanitarian assistance, the Government of Ethiopia and development partners decided to review the country's resilience programming and identify opportunities and challenges to building greater resilience into the agricultural system. To this end, we used quantitative crop modeling and economywide analyses to inform resilience programming. Crop modeling analysis showed the impact of ENSO-related changes in temperature and rainfall on crop productivity across the country. Yield losses were concentrated in a few subregions, with impacts greatest in the lowlands, where cereal production fell by an estimated 10.0 percent. Cattle herds were estimated to have declined by 22.7 percent in the drought-prone lowlands, based on the climate-induced animal stress analysis. This tool was also used to assess the potential of on-farm interventions. Adoption of improved agricultural technologies and intensification of management practices are shown to reduce yield losses, suggesting that investing in on-farm productivity can be highly effective in reducing vulnerability during a severe El Niño event. A dynamic computable general equilibrium (CGE) model incorporating the estimated crop impacts allowed for economywide analysis of El Niño's impact. A 2015/16 ENSO-type event has considerable spillover impact beyond agriculture, leading to a decline in national GDP by 1.6 percent, as well as losses in agricultural GDP of 3.6 percent nationally and of 11.1 percent in the drought-prone lowlands. Of three potential market and social policy interventions considered—food import subsidies, grain storage, and social transfers, as well as a combination of the three—none are effective at limiting GDP losses. On-farm investments are needed to reduce agricultural GDP impacts and prevent negative knock-on impacts to the rest of the economy. On the other hand, these policy interventions are effective in reducing household welfare losses. Food import subsidies reduce total consumption losses, and cash transfers and grain distribution reduce losses for poorer households. Implementing all policy options at the same time largely eliminates the welfare losses of poor households but raises them for higher-income households.

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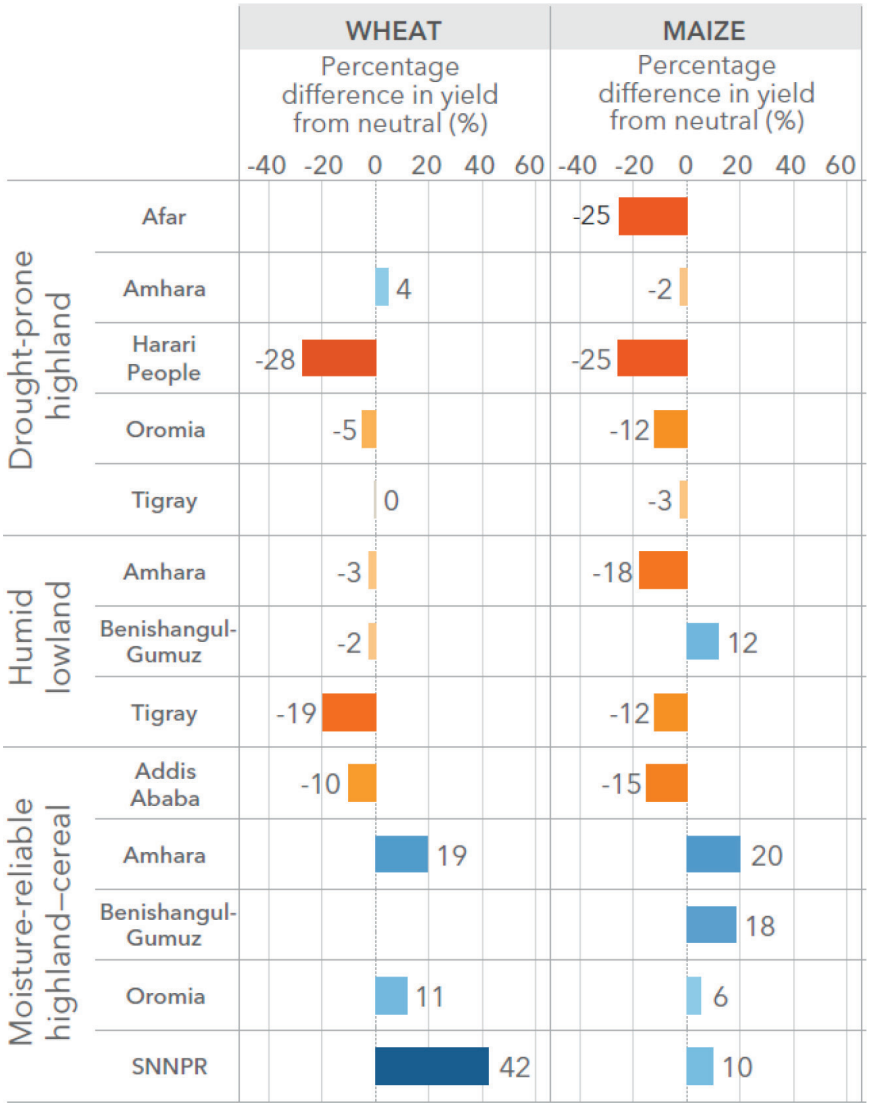

Yield deviations during the 2015/2016 El Niño event are relative to average yields from recent neutral years. SNNPR = Southern Nations, Nationalities, and Peoples' Region.

Keywords: ENSO, Ethiopia, Crop Modeling, DSSAT, Economic Modeling.

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S5-O.16

Efficient land and water use under stochastic climate scenarios and groundwater restrictions in a semi-arid region

Mitter Hermine (hermine.mitter@boku.ac.at), Schmid Erwin

Inst for Sustainable Econ Development, Univ of Natural Resources and Life Scien, Vienna, Austria

Introduction

Interactions between land and water use are very relevant in semi-arid regions, where climate change may reinforce or alleviate tensions between competing demands for land and water. The semi-arid Seewinkel region in eastern Austria represents such a region in such agriculture is the dominant user of groundwater. Saltine lakes with high ecological value require a minimum depth of the groundwater body for the capillary uptake of salts from the soil. Regional water policies are required to reduce conflicts about freshwater resources. We aim to (i) model interactions between land and water use, (ii) investigate impacts of stochastic climate scenarios on these uses, (iii) identify efficient agricultural adaptation measures while considering the soil-plant-water interactions, and (iv) compute the marginal value product of groundwater use to inform efficient water policies under climate scenarios.

Integrated modeling framework

We have developed an integrated modeling framework (IMF) consisting of stochastic climate scenarios (Strauss et al., 2013), a crop rotation model (Schönhart et al., 2011), the bio-physical process model EPIC (Williams, 1995), and a non-linear bottom-up economic land use optimization model BiomAT (Karner et al., 2019). The IMF is applied at 500 m grid resolution for the semi-arid Seewinkel region of 450 km². We consider three climate scenarios – DRY, SIMILAR and WET – which differ in the assumed distribution of dry and wet days in the future. EPIC is used to simulate annual yields and irrigation water use on cropland, intensive and extensive grassland, and vineyards. The land use categories are simulated with various adaptation managements including crop rotations, fertilization and irrigation intensities, and mowing frequency. EPIC simulates the hydrological processes at field scale, i.e. precipitation, evapotranspiration, percolation, surface and sub-surface runoff as well as the CO_2 fertilization effect. BiomAT maximizes regional net benefits subject to land endowments and a regional, monthly explicit water balance. The marginal value product of irrigation water use is computed to inform efficient water policies.

Results

The model results for the Seewinkel region show that the mean groundwater extraction volume ranges between 109 Mio.m³ under DRY, 86 Mio.m³ under SIMILAR and 43 Mio.m³ under WET climate conditions if groundwater extraction is not restricted. The boxplots in Figure 1 show that the variability in groundwater extraction volumes differs between the level of restriction, which is represented by the marginal value product, and climate scenarios. The mean regional net benefit ranges between 7.7 and 33.7 Mio.€ under DRY, 20.3 and 44.8 Mio.€ under SIMILAR, and 38.2 and 49.7 Mio.€ under WET climate conditions, depending on the restriction of groundwater extraction for irrigation use. Higher regional net benefits under WET climate conditions can be achieved through an expansion of vineyards and intensive grassland.

Conclusions

Climate change may increase competition for natural resources such as land and water. Our model results indicate that more restrictive regional water policies would result in lower groundwater extraction volumes from agriculture but also lower regional net benefits. Thus, they may be of interest for farmers, policy makers and water management authorities in order to avoid freshwater limitations and decreasing groundwater levels in a heavily irrigated region with high ecological value.

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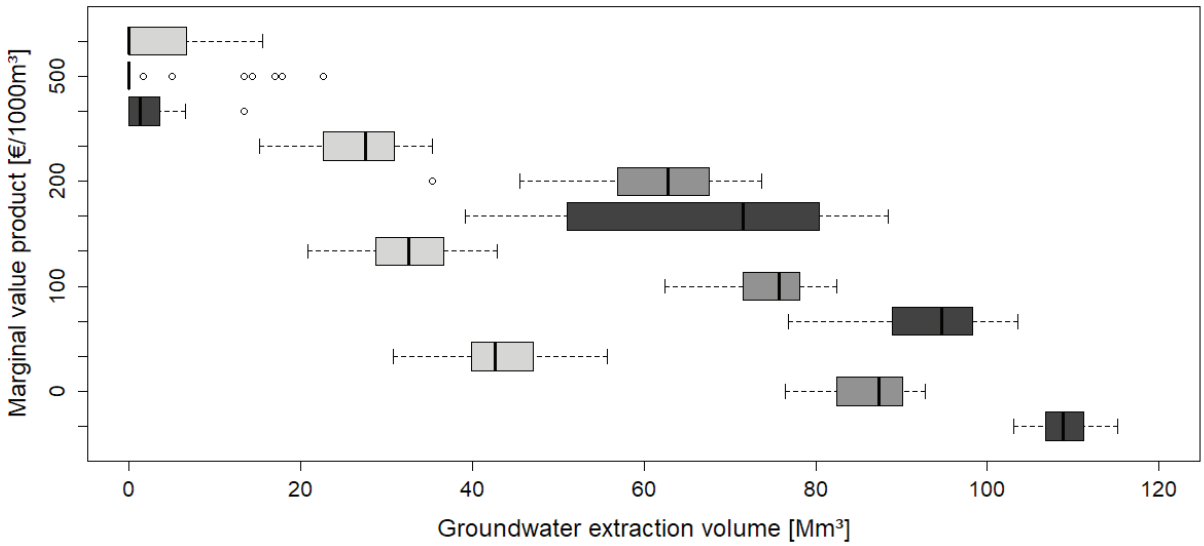

Figure 1. Boxplots with 30 realizations of groundwater extraction volumes in Mm³ and restriction levels represented by the marginal value product of groundwater use in €/1000m³ by climate scenarios DRY (black), SIMILAR (gray), and WET (lightgray).

Keywords: climate extremes, water policy, irrigation water use, EPIC, integrated assessment.

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S5-O.17

Response of grain yield and nitrogen to climate change in Scotland

Cammarano Davide[1] (davide.cammarano@hutton.ac.uk), Rivington Mike[2], Matthews Keith[2], Wardell-Johnson Douglas[2], Miller Dave[2]

[1] *James hutton institute, Invergowrie, United Kingdom*; [2] *James hutton institute, Aberdeen, United Kingdom*

Introduction

Barley is one of the most important commodities for the Scottish and the UK economy due to its use in distilleries to produce whisky (Cammarano et al., 2019). Whisky generates about £5 billion in Gross Value Added to the UK economy, and therefore the industry is interested in maintaining a sustainable supply of barley. Projected changes in climate might affect yield and distilling quality. The rationale of this study is to quantify the risks and opportunities for barley production and quality.

Materials and Methods

The Decision Support System for Agrotechnology Transfer (DSSAT v4.7) was used for this study (Jones et al., 2003). The spring barley cultivar Concerto (most grown in Scotland) was calibrated and evaluated on a separate study (Cammarano et al., 2019). An additional spatial evaluation was made by comparing the spatial simulations with the observed yield from 500 farms. Barley growing area was obtainted from the Land Capability for Agriculture (LCA, 2017). Gridded weather data were obtained from the United Kingdom Meteorological Office UKCP09 (UK Met Office, 2017). The soil data were downloaded from the Scottish Soils Knowledge and Information Base (SSKIB). The baseline was run from the period 1994-2015. The projections used were the HadRM3-PPE afixc ensemble member which divides Scotland into a wetter south and drier north, and the HadRM-PPE afixq ensemble member which projected wetter conditions across all Scotland. The two periods analysed were 2030-2060 and 2060-2090.

Results and Discussion

The mean simulated barley yield for baseline conditions was about 5.6 t DM ha^{-1}, under the climate projections yield estimates vary considerably. A 'wetter' future projection resulted in a mean yield increase of 1.2 t DM ha^{-1} but with large spatial variation. A future with a drier north and wetter south Scotland split has little change from the present in overall mean yield, but greater spatial variability, with some areas seeing substantial decreases. The mid-century sees gains in mean yields, however these decline towards the 2090's, but remain above current levels. Production from some soils is more vulnerable, primarily due to them becoming drier.

In terms of grain nitrogen uptake, the simulated results showed large spatial variability responses (Fig. 1). The 'wetter' projection has a mixed increased uptake in some locations and decrease in others. The 'north-south split' projection as an across the country reduction in uptake. This reflects differences between the projections and how the climate impacts soil nitrogen processes.

Conclusions

This study has shown that climate change may have a significant impact on barley production in Scotland, being a mixture of positive yield increases but with additional levels of risks of negative impacts as well. These are spatially and temporally variable with different soil-weather combinations. Some future climatic conditions are likely to favour growth, whilst others will restrict it. The estimates of yield vary greatly depending on the input climate projections, of which only two examples are provided. Large uncertainties remain in making future projections, but this study has shown that it is possible to gain a better understanding of probabilities of growth and yield responses.

Acknowledgments

This research has been possible through the support of the Scotch Whisky Research Institute. We thank the UK Meteorological Office for permission to use the gridded observed weather data.

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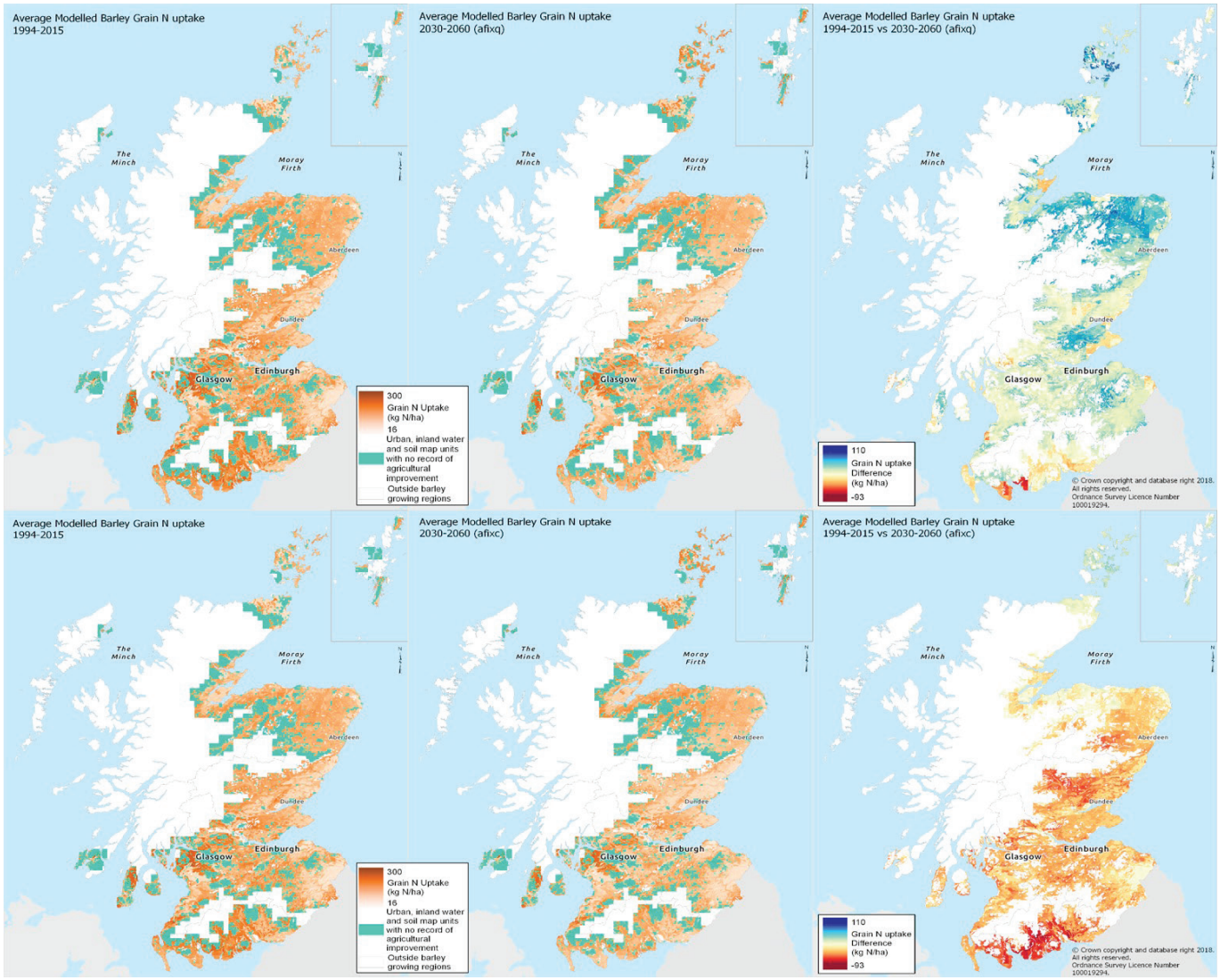

Mean grain N uptake (kg N ha-1) for the afixq and afixc ensemlbe projections.

Keywords: Barley, climate change, climate projections, grain nitrogen.

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S5-O.18

Crop-loss Assessment Monitor (CAM): A Web based Integrated Platform to Monitor Yield losses for Agricultural Insurance

Aggarwal Pramod (p.k.aggarwal@cgiar.org), Shirsath Paresh, Vyas Shalika

CCAFS, CIMMYT, New Delhi, Delhi, India

Introduction

Crop insurance is an important risk management strategy and it's effective implementation require crop intelligence systems with near real-time capabilities of crop-loss. Globally, several crop monitoring and early warning systems are in place; however, they are complex and lack economic/financial capabilities. This paper describes one such tool (CAM), a web-based integrated platform for seasonal crop growth monitoring, near real time yield estimation and with capabilities of insurance scheme monitoring and design.

Materials and Methods

CAM integrates multiple methods like crop simulation modelling, statistical methods, remote sensing based vegetation and weather indices for crop loss assessment at multiple stages (figure 1). It is developed with a simple, user-friendly interface for its use by non-specialists, and its outputs are especially tailored for insurance industry. The inputs for CAM consists of satellite/station based weather, gridded soil dataset and customised management inputs. Methodology has following components viz., crop simulation models and yield modelling through remote sensing, weather indices and integrated modelling. The CAM tool has also been embedded with financial viability analytics, which determines farmers' premium, compensation, loss-cost ratios etc.

Results: the potential and capabilities of CAM tool are demonstrated using case studies from Andhra Pradesh, India. Results are presented including yield loss at multiple stages, and insurance analytics like aggregated premium rates and loss-cost ratios at grid level. The results show how CAM can be used for designing and testing new insurance schemes. Different insurance scheme designs are tested and analysed using CAM, with lowest risk coverage found for remote sensing. Integrated model shows comparatively higher compensation (risk coverage) and moderate premiums collected in the study region.

Discussion and Conclusions

CAM is specially built for developing countries in global south, where lack of publicly available crop production statistics and resource constraints result in low penetration of agricultural insurance. CAM has four key advantages: 1) it facilitates crop loss assessment using multiple methods, which facilitates comparison of the accuracy of different methods , 2) it enables rapid loss assessment for successive crop growth stages, 3) it is integrated with an insurance analytics module which goes a step beyond crop loss estimates, and 4) modular design of CAM allows customization of the tool for different countries and insurance schemes.

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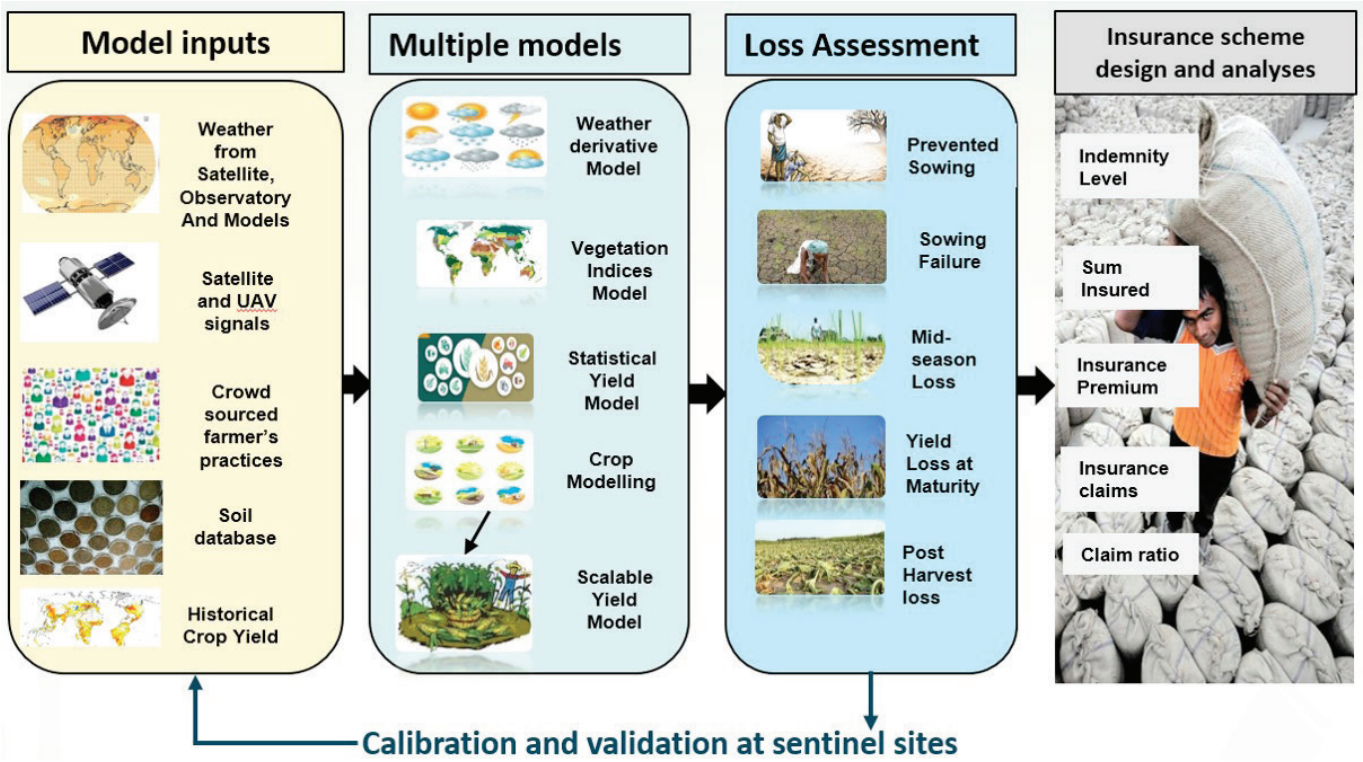

Figure 1 Broad framework for CAM describing inputs, methods, models and outputs

Keywords: Crop insurance, Crop loss assessment.

S5-O.19

Can insurance help farmers mitigate nitrogen pollution from intensive cropping?

Thorburn Peter[1] (peter.thorburn@csiro.au), Biggs Jody[1], McMillan Larelle[1], Webster Tony[2], Everingham Yvette[3]

[1] *Agriculture and Food, CSIRO, St Lucia, Qld, Australia*; [2] *Agriculture and Food, CSIRO, Cairns, Qld, Australia*; [3] *Agriculture and Food, CSIRO, Townsville, Qld, Australia*

Introduction

Nitrogen (N) pollution of ground and surface waters is common in areas of intensive cropping. Farmers commonly over apply N fertiliser as a risk mitigation strategy – that is, to reduce the risk of yields being limited by N. However, the extra N applied leads to extra N being discharged to the environment (Thorburn et al., 2013). In other aspects of farming, insurance is an important risk mitigation tool. Is it feasible for farmers to insure against yield loss if they reduce N fertiliser rates? Crop insurance has been developed to manage exogenous risks (Hatt et al., 2012), such as those coming from climatic events (e.g. too much/too little rain) or multiple issues impacting crop yield (e.g. multi-peril products). Yield responses to N are not purely exogenous, and the existing crop insurance products are not applicable to this problem. Thus a new approach to crop insurance is needed if potential risks to yields from reduced N fertiliser are to be mitigated through insurance. This paper describes the development of a framework for an N insurance product for the dominant intensive crop grown (sugarcane) in the wet tropical catchments draining into the Great Barrier Reef, in north eastern Australia.

Results and Discussion

Several problems need to be solved to develop this insurance product. Firstly, risk of yield loss occurring with reduced N fertiliser needs to be quantified. Empirical data (e.g. yield or climate records) are typically used to characterise risk in crop insurance products. However, insufficient data on crop N responses exist to quantify risk across the diversity of growing conditions in the 176,000 ha of sugarcane cropping in this region. Instead we simulated sugarcane N responses over the past 70 years. Yield loss risk has two components: (1) the *baseline* rate of N fertiliser applied (e.g. historical application rates), and (2) the (lower) *insured* rate being considered. Smaller reductions pose lower risks than larger ones, but even large reductions may pose little risk if the baseline N rate is high. Our risk quantification is compatible with techniques used by insurance companies to price risk (Rolski et al., 1999), allowing us to determine prices that would be charged for insurance. We found that risks and thus prices varied substantially across different soil types, sub-regional climates and management factors, and an insurance product would need to be developed and offered at this scale.

The next problem is determining if crop yield has actually been reduced at the insured N fertiliser rate. We investigated an empirical approach to the problem, e.g. establishing “strips” of crop managed with the baseline N rate on different soils types of a farm. However, the field-to-field yield variability of even uniformly managed crops was too large for this to be workable. The approach would also add considerable costs to the administration of an insurance product from the establishment, maintenance and auditing of the strips. Instead we developed a method of simulating the yield difference between the baseline and insured N fertiliser rate that would have occurred, all things being equal, under the climate the crop experienced. The approach, which we call the *Climate Index Derivative*, creates a parametric product, which is a very efficient structure for insurance products (Rolski et al., 1999; Hatt et al., 2012).

Another problem with crop insurance is moral hazard, where one party changes their behaviour (e.g. crop management) to increase the chance of a particular outcome. Being a parametric approach, our *Climate Index Derivative* greatly reduces moral hazard. Remaining hazards could be guarded against through the insured farmers’ participation in an industry backed, audited best management practice program.

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Finally, we examined the spatio-temporal structure of sub-regional profitability of the product. This entailed calculating insurance cost and thus income from premiums, frequency of realised yield losses and thus payouts on claims, and then profitability for a range of scenarios based on random assignment of insurance to fields in sub-regions over a 30 year period. We found that, for an insurance company, the structure of annual profitability was reasonably "well behaved" (Rolski et al., 1999), i.e. profits and losses over the years was nearly normally distributed, a factor that is important in determining the risk reserve needed to cover payouts. However, there were sub-regions where premiums were commonly larger than the savings from reduced N fertiliser, and some form of price support would be required to make the product attractive to farmers.

Conclusion

We have shown that insuring against yield loss to mitigate the risks associated with lowering N fertiliser rates is technically viable. The approach we developed is generally applicable. Such a tool, if proved commercially viable, will help farmers meet targets for N in waters and support policies to improve water quality.

Keywords: APSIM, Environmental impact, Market based instruments, Parametric insurance, Risk management.

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S5-O.20

Drought not heat stress driving yield losses in extreme years under climate change

Webber Heidi[1] (webber@zalf.de), Ewert Frank[2], Olesen Jørgen[3], Müller Christoph[4], Fronzek Stefan[5], Ruane Alex[6], Bourgault Maryse[7], Martre Pierre[8], Ababaei Behnam[9], Bindi Marco[10], Ferrise Roberto[10], Finger Robert[11], Fodor Nandor[12], Gabaldón-Leal Clara[13], Gaiser Thomas[14], Jabloun Mohamed[15], Kersebaum Kurt-Christian[1], Lizaso Jon I.[16], Lorite Ignacio J[13], Manceau Loic[8], Moriondo Marco[10], Nendel Claas[17], Rodríguez Alfredo[16], Ruiz-Ramos Margarita[16], Semenov Mikhail A[18], Siebert Stefan[19], Stella Tommaso[1], Stratonovitch Pierre[18], Trombi Giacom[10], Wallach Daniel[20]

[1] *ZALF, Muencheberg, Germany*; [2] *ZALF, Muencheberg, Germ*; [3] *Aarhus University, Aarhus, Denmark*; [4] *PIK, Potsdam, Germany*; [5] *Finnish Environment Institute, Helsinki, Finland*; [6] *NASA, NY, USA*; [7] *Montana State University, Havre, USA*; [8] *INRA, Montpellier, France*; [9] *University of Queensland, Brisbane, Australia*; [10] *University of Florence, Firenze, Italy*; [11] *ETH Zurich, Zurich, Switzerland*; [12] *Hungarian Academy of Sciences, Martonvásá, Hungary*; [13] *IFAPA, Cordoba, Spain*; [14] *University of Bonn, Bonn, Germ*; [15] *University of Nottingham, Loughborough, United Kingdom*; [16] *Universidad Politécnica de Madrid, Madrid, Spain*; [17] *ZA, Muencheberg, Germany*; [18] *Rothamsted Research, Harpenden, United Kingdom*; [19] *University of Göttingen, Göttingen, Germany*; [20] *INRA, Toulouse, France*

Introduction

Warmer temperature with climate change will affect crop yields by shortening growth duration and increasing water demand as well as the frequency and severity of heat stress. At the same time, elevated atmospheric CO_2 concentrations will decrease rates of water use and additionally increase growth of C_3 crops like wheat. Understanding the combined effect of these processes in both typical and extreme years could support adaptation planning to reduce the negative impacts of climate change and increased production risks. Process-based crop models are useful in this regard as they can account for each of these factors and how they may compensate for (early maturity to escape late summer heat or drought) or reinforce (drought stress leading to higher crop temperatures and greater heat stress) each other. Here we use an ensemble of six maize models and eight winter wheat models to determine how yields will change in Europe under climate change and which factors will drive these yield changes under average and extreme years.

Materials and Methods

Crop growth and yield was simulated across Europe using gridded input data at 25 km resolution for a baseline (1980 – 2010) and scenario (2040 - 2070) period. All models considered temperature effects on phenology, drought and heat stress and most models considered the interaction between heat and drought by simulating canopy temperature (Webber *et al.*, 2018b). The models were re-initialized each year, did not consider nitrogen limitation and were calibrated for phenology observations in the baseline period which were assumed constant in the scenario period. Climate scenario data were from 5 GCMs for RCPs 4.5 and 8.5 and 2 GCMs for RCP2.6 (https://dx.doi.org/10.4228/ZALF.DK.59). Finally, aggregation of simulated yields to European level used the MIRCA2000 global dataset.

Results and Discussion

Climate change resulted in yield losses for grain maize and gains for winter wheat. Across Europe, on average heat stress did not increase for either crop in rainfed systems, while drought stress intensified for maize only. In years with yields in the lowest decile, drought stress was the main driver of losses for both crops, increasing yield losses by approximately 10 and 5% in maize and wheat, respectively (Fig.1). In these low yielding years, elevated CO_2 offered no yield benefit in mitigating negative effects of drought as there was no water left in the profile. These average responses mask a high level of spatial variation for both historical and scenario projections. Adaptation planning should consider disaggregated soil, climate and management data and plausible scenarios of future developments in agricultural practices.

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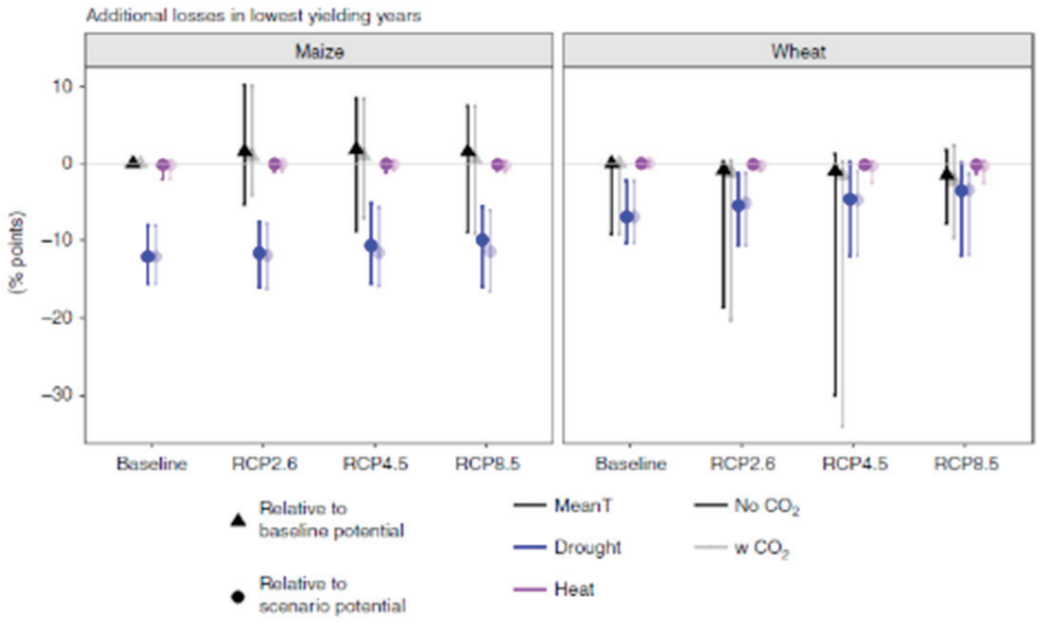

Figure 1. Additional losses (% points) in extreme low yielding years as compared to average conditions in each scenario period due to various climatic drivers of yield losses for European rainfed maize and winter wheat. Baseline simulations and scenario simulations are centered on 1995 and 2055, respectively. The values shown are median values across crop model and GCMs. Figure reproduced from Nature Communications (Webber et al, 2018a).

Keywords: climate change, drought, maize, winter wheat, extremes.

References:

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S5-O.21

Evidence of crop production losses in West Africa due to historical global warming in two crop models

Sultan Benjamin[1] (benjamin.sultan@ird.fr), Dimitri Defrance[2], Iizumi Toshichika[3]

[1] *ESPACE-DEV, IRD, Montpellier, France*; [2] *INRA, Montpellier, France*; [3] *Institute for Agro-Environmental Science, NARO, Tsukuba, Japan*

Introduction

Achieving food security goals in West Africa will depend on the capacity of the agricultural sector to feed the rapidly growing population and to moderate the adverse impacts of climate change. Indeed, a number of studies anticipate a reduction of the crop yield of the main staple food crops in the region in the coming decades due to global warming. Here, we found that crop production might have already been affected by climate change, with significant yield losses estimated in the historical past (Sultan et al. 2019).

Materials and Methods

We used a large ensemble of historical climate simulations derived from an atmospheric general circulation model and two process-based crop models, SARRA-H and CYGMA, to evaluate the effects of historical climate change on crop production in West Africa. We generated two ensembles of 100 historical simulations of yields of sorghum and millet corresponding to two climate conditions for each crop model. One ensemble is based on a realistic simulation of the actual climate, while the other is based on a climate simulation that does not account for human influences on climate systems (that is, the non-warming counterfactual climate condition).

Results and Discussion

We found that the last simulated decade, 2000-2009, is approximately 1°C warmer in West Africa in the ensemble accounting for human influences on climate, with more frequent heat and rainfall extremes. These altered climate conditions have led to regional average yield reductions of 10-20% for millet and 5-15% for sorghum in the two crop models. We found that the average annual production losses across West Africa in 2000–2009 associated with historical climate change, relative to a non-warming counterfactual condition (that is, pre-industrial climate), accounted for 2.33–4.02 billion USD for millet and 0.73–2.17 billion USD for sorghum.

Conclusion

The estimates of production losses presented here can be a basis for the loss and damage associated with climate change to date and useful in estimating the costs of the adaptation of crop production systems in the region.

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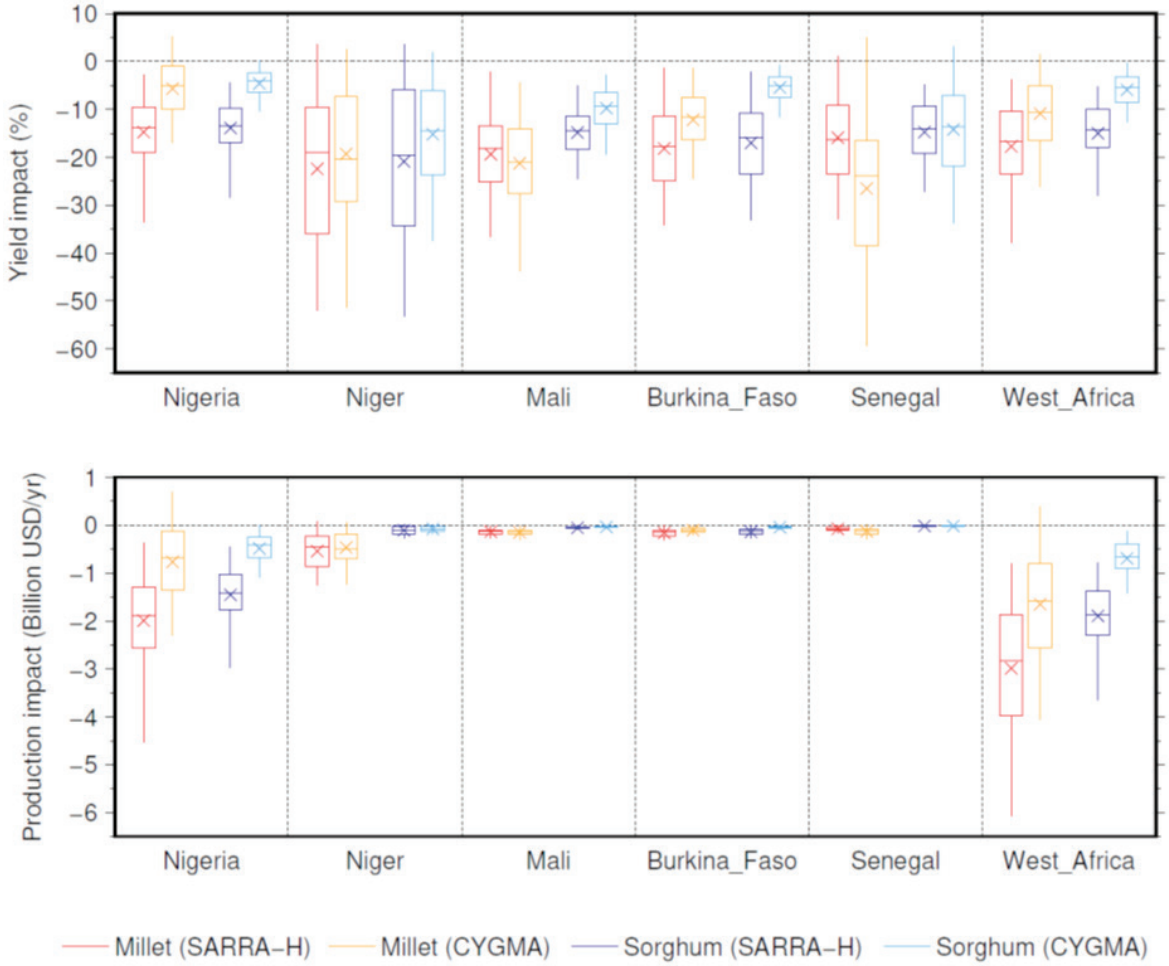

Estimated impacts on the average annual yield and average production of millet and sorghum in 2000–2009 for selected major crop-producing countries in West Africa. The impacts were measured as the difference between the factual and counterfactual crop simulations. Harvested area weighting was considered when computing country and West Africa average yield impacts. Box plots indicate the mean (cross), with 25 to 75% (box) and 5 to 95% (vertical line) confidence intervals derived from ensemble members of the crop simulation. The horizontal lines indicate the median. The regional averaged data for West Africa were calculated by averaging the data over Benin, Burkina Faso, the Gambia, Guinea, Guinea Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. The range of simulated yield change was limited to be within the interval from -100% to +100% to avoid unrealistically large yield impacts in locations where the current yield is very low.

Keywords: Climate change, Crop model, Attribution, West Africa.

References:

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S5-O.22

Spatio-temporal dynamic of crop drought vulnerability in Sub-Saharan Africa

Kamali Bahareh[1] (bahareh.kamali@zalf.de), Dogaru Diana[2], Nendel Claas[1]

[1] *Zalf, Muncheberg, Germany*; [2] *IGAR, Bucharest, Romania*

Introduction

Sub-Saharan Africa (SSA) is far from becoming self-sufficiency in cereal production. The recurrence of droughts in the past decades has exacerbated the situation. Understanding the spatial and temporal dynamics of crop drought vulnerability during phenological development of crops is important to identify relief policy and amicable solutions to drought. However, most studies lack understanding from such multiple perspectives. Here, we quantify the vulnerability of maize, millet, and sorghum to drought during different crop growth using a fuzzy rule-based method. Apart from providing spatial and temporal details, we provide complementary information on various stresses, which trigger vulnerability. The analytical technique integrated with a large geographical scale crop modeling offers the opportunity for drought risk studies over the whole of SSA.

Materials and Methods

Crop yield was simulated using EPIC+ which is an extended version of EPIC (Environmental Policy Integrated Climate Model) equipped with the calibration module [1]. EPIC simulates crop growth processes on daily time step using data such as weather, soil, landuse, and crop management parameters [2]. The crop drought vulnerability index (*CDVI*) was defined through linking drought exposure index (*DEI*) to crop sensitivity index (*CSI*) in a fuzzy rule-based inference system. According to this definition, vulnerability is higher in region where a small drought results in high crop sensitivity compared to regions where high drought led to only negligible *CSI* [3] (Figure 1).

Results and Discussion

During model calibration, we obtained satisfactorily performances at the country level for most countries and three crops. The relative root mean square error were between 0.8 and 1.4. In all countries, over 50% of observed yield data were bracketed with the 95% prediction uncertainty band, which are satisfactory values for crop calibration [1]. The calculated *DEI* based on a combination of precipitation and soil moisture variables could better represent vulnerability compared with *DEI* based on a single variable, indicating that both variables have significant impacts on crop growth. The vulnerability maps of three crops showed higher intensity in southern Africa and some Sahelian countries due to experiencing longer periods of water stress as a result of low precipitation.

Conclusions

The procedure used to calculate *CDVI* advances current approaches as it estimates the time series of *CDVI* and allows better characterization of the *CDVI* dynamics. The produced fine resolution maps improve our understanding for early warning on drought vulnerability. The approach can be implemented to project the vulnerability under future scenarios of

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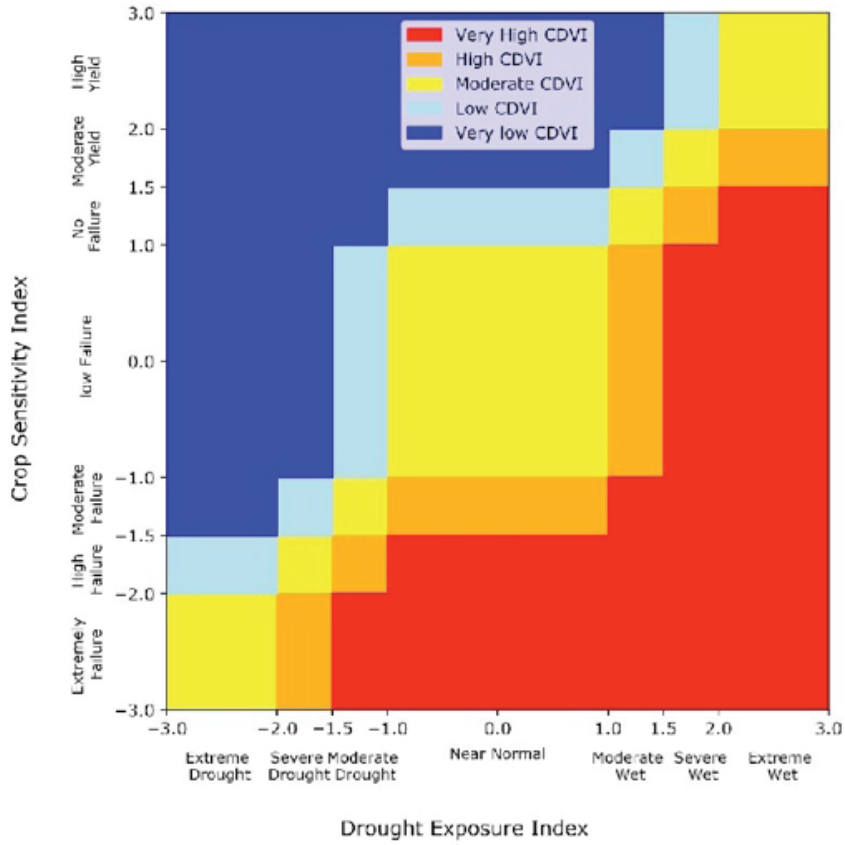

Figure 1. The vulnerability scheme used to aggregate drought exposure and crop sensitivity

Keywords: Crop modelling, fuzzy inference system, drought exposure.

References:

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S5-O.23

Quantifying the uncertainty introduced by internal climate variability in the projected Canadian crop yield changes

Qian Budong[1] (budong.qian@canada.ca), Jing Qi[1], Smith Ward[1], Grant Brian[1], Cannon Alex[2], Zhang Xuebin[3]

[1] *Agriculture and Agri-Food Canada, Ottawa, Canada*; [2] *Environment and Climate Change Canada, Victoria, Canada*; [3] *Environment and Climate Change Canada, Toronto, Canada*

Introduction

Quantification of the uncertainty in crop yield projections is typically ascertained using multiple crop models and using an ensemble of climate scenarios, from multiple global climate models (GCMs), under different forcing scenarios. Although internal climate variability is one of the three major sources of uncertainty in climate projections, the uncertainty due to internal climate variability is seldom quantified for crop yield projections. We attempted to quantify the uncertainty introduced by internal climate variability in the projected Canadian crop yield changes by comparing the simulated yields using climate scenarios from large ensembles of two climate models and using an ensemble of multiple climate models.

Materials and Methods

We utilized climate scenarios from 25 runs in large ensembles of simulations by CanESM2 and CanRCM4, a global climate model and a regional climate model developed in Canada (Kirchmeier-Young et al., 2017; Scinocca et al., 2016), as inputs to the crop models in the Decision Support System for Agrotechnology Transfer (DSSAT v4.6, Hoogenboom et al., 2015) to estimate future crop production changes. The large ensemble of simulations by CanESM2 and CanRCM4 were run with slightly different initial conditions for evaluating internal climate variability in climate projections. With the crop models and the indicated climate scenarios, we simulated both potential (no water and nitrogen stresses) and rainfed (no nitrogen stress) yields for canola, maize and spring wheat under the baseline climate of 2006 -2015 and future climates at the global warming levels at 1.5, 2.0, 2.5 and 3.0 °C above the preindustrial level. The ranges of the projected crop yield changes over the ensemble members are considered as the uncertainty associated to internal climate variability and compared the results from our previous study (Qian et al., 2019) with 20 GCMs in the Coupled Model Intercomparison Project Phase 5 (CMIP5).

Results and Discussion

Our results showed that the projected changes of potential yields for all three crops due to GCMs represent a larger uncertainty than the uncertainty attributed to internal climate variability at all warming levels. Projected changes of rainfed yields demonstrate a similar but larger uncertainty compared to the potential yields, indicating the effects of a large uncertainty in the projected precipitation changes. An example for canola is shown in Figure 1. We also found that the uncertainty due to internal climate variability in the projected rainfed yields is often comparable to that associated with GCMs at the warming level of 1.5 °C, implying the need of accounting for the uncertainty related to internal climate variability in the projected crop yield changes for the near future, such as the time period reaching the climate target of 1.5 °C.

Conclusions

The uncertainty introduced by internal climate variability in the projected Canadian crop yields is likely smaller compared to that associated with multiple climate models, especially for the distant future. However, the uncertainty related to internal climate variability in the near future is often comparable to that associated with climate model structures, thus needs to be accounted for.

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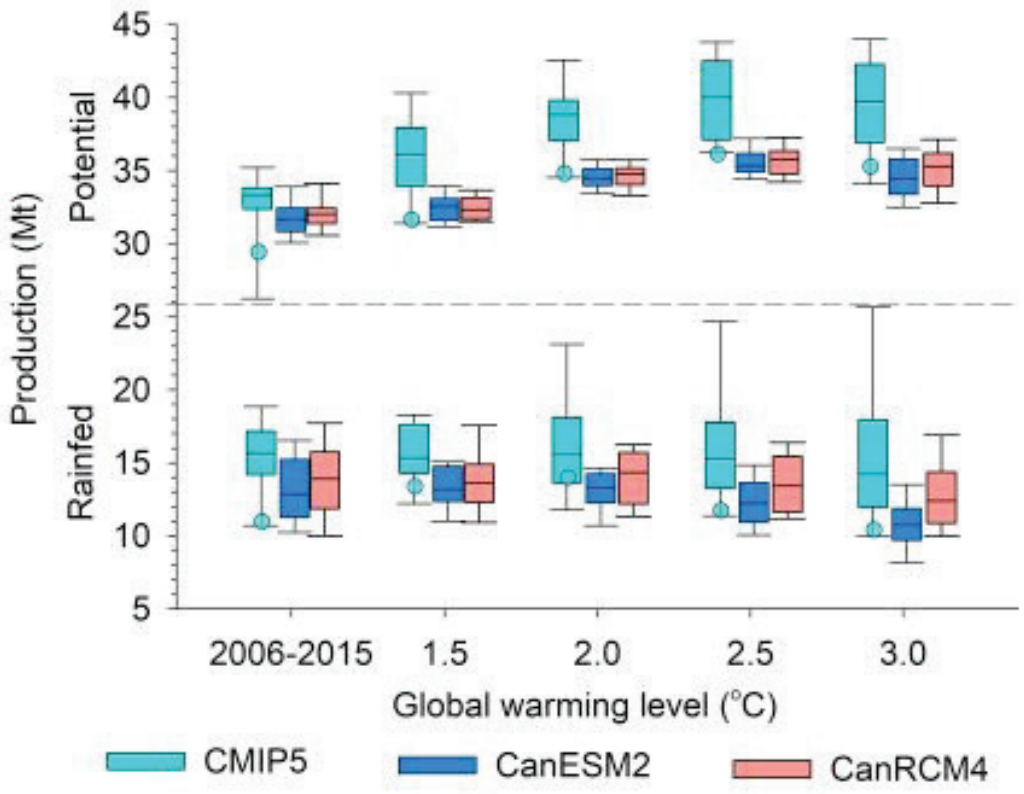

Figure 1. Canola production (million ton) in Canada for the baseline (2006-2015) and the timing of the global warming levels at 1.5, 2.0, 2.5, and 3.0°C above the preindustrial level based on simulated potential and rainfed yields using DSSAT with climate scenarios from CanESM2 and CanRCM4 in comparison with CMIP5 and the average cultivated area in 2006-2015. The boxplots show the 10th, 25th, 50th, 75th, and 90th percentiles of simulated production over the 25 members of the large ensembles of CanESM2 and CanRCM4, and the 20 GCMs in CMIP5. One member of CanESM2 used in CMIP5 is marked with a circle.

Keywords: crop modelling, climate change impacts, crop yield projection, Canada.

References:

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S5-O.24

Patterns and drivers of the risk of crop failure across Europe

Stella Tommaso[1] (tommaso.stella@zalf.de), Webber Heidi[1], Mamidanna Sravya[1], Bregaglio Simone[2], Ewert Frank[1]

[1] *ZALF, Müncheberg, Germany*; [2] *CREA-AA, Bologna, Italy*

Introduction

Variability of crop yields and prices contribute to shape the risk environment faced by farmers. Under climate change, altered growing seasons and increasing extremes of drought and heat stress may modify farmers' exposure to yield risk. Anticipating and understanding changes in risk profiles can support the design of targeted adaptation measures. Crop models allow for the decomposition of the main climatic and environmental drivers of yield variability and their changing future importance. A recent study with an ensemble of crop models (Webber et al., 2018) projected yield gains for winter wheat and losses for grain maize across Europe, the latter associated with an intensification of drought stress. Extending that study, here we explore the possible evolution of the risk of crop failures for a range of climate scenarios. The objective is twofold: (i) characterizing the areas that are expected to experience a changed risk profile in the future and (ii) disentangling the relation between climatic drivers determining yield distribution and yield failure risk.

Materials and Methods

An ensemble of six grain maize models and eight winter wheat models was used to simulate (25 km input data resolution) crop growth and yield across Europe for baseline (1980-2010) and projection (2040-2070) periods (Webber et al., 2018). Climate scenarios were available for five climate models under three forcing scenarios (RCP 2.6, 4.5 and 8.5). Different treatments were simulated by considering the effects of heat or water stress or a combination of the two on crop yields, allowing to isolate the main effects of each stressor and their interaction. The risk of yield failure (i.e., the probability of a loss exceeding 20% of the average annual yield; Webber et al., 2016), the associated prediction uncertainty (Wallach et al., 2016), and the moments of the distributions of potential yields, drought and heat impacts were evaluated. These features were then considered to aggregate simulations into homogeneous clusters. The populations of model simulations from the resulting clusters were analysed using relative distribution methods (Handcock and Morris, 1998) that provided the basis for quantifying shifts between the current and future distributions of yields and for examining hypotheses on the drivers of such shifts.

Results and Discussion

This exploratory study will reveal emergent patterns of crop yield failure risk at European level, under various climate change scenarios. Preliminary results show that rainfed maize is more prone to crop failure in the baseline, but a general increase of risk is projected for both crops in the future across Europe (figure 1). The design of the study allows quantifying the relative importance of different biophysical drivers in determining yield distributions, their spatial scale and, in turns, the yield risk for maize and wheat across Europe. The availability of multiple climate and crop models is essential to estimate the uncertainty bracketing the risk of yield failure, dominated by the variability of crop models predictions.

Conclusions

Multi-model ensemble studies can be a valuable resource for supporting risk management, from the design of subsidizing risk market instruments, to long-term planning of investments in irrigation infrastructure or breeding. The current study explores some of that potential while proposing advanced methodologies for the analysis of model ensemble outputs in large area applications.

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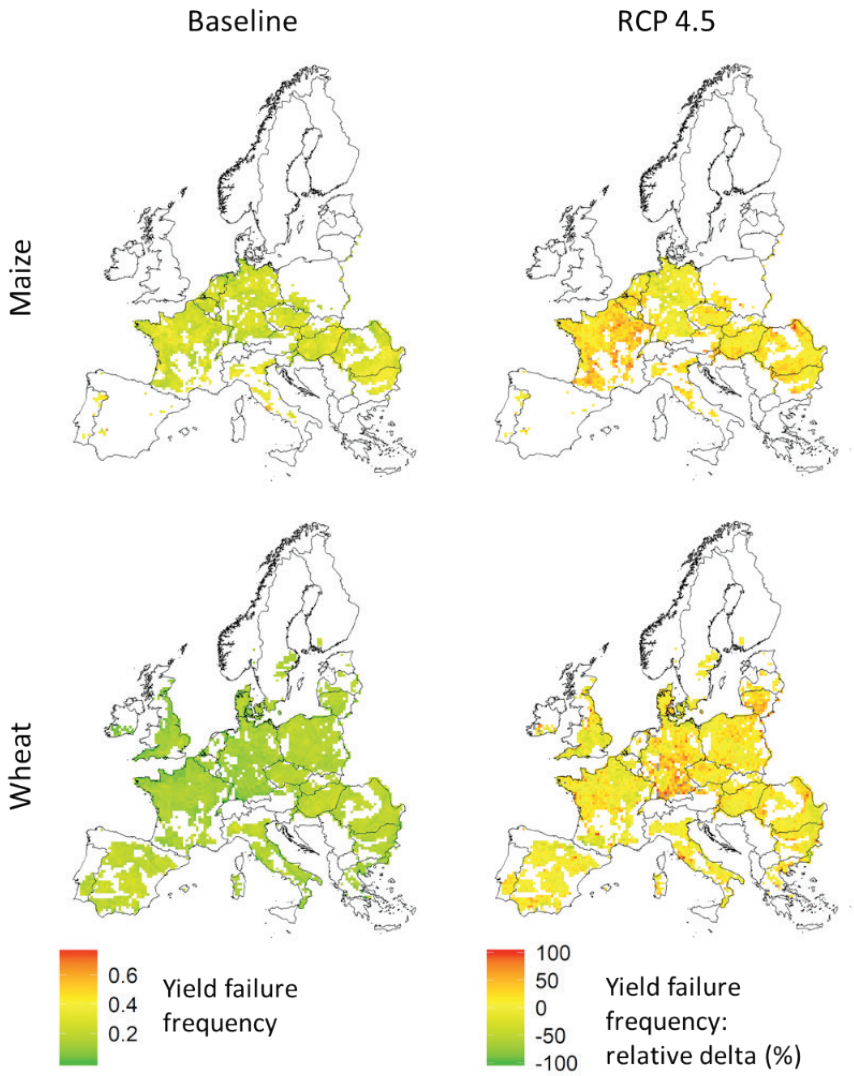

Figure 1. Risk of yield failure in the baseline (left panels) and its relative change under RCP 4.5 (right panels) for rainfed maize and wheat.

Keywords: Risk, Yield failure, model ensemble.

References:

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S5-O.25

Modelling drought and wetness events in 2050 and their impacts on agricultural yield losses

Kapsambelis Dorothée[1] (dkapsambelis@ccr.fr), Moncoulon David[2], Cordier Jean[3], Veysseire Martine[4]

[1] *R&D modélisation – Cat & Agro, Caisse Centrale de Réassurance (CCR), Paris, France*; [2] *R&D modélisation – Cat & Agro, Caisse Centrale de Réassurance, Paris, France*; [3] *Economie et Gestion, SMART-LERECO, Agrocampus Ouest, Rennes, France*; [4] *DSM/EC/ECGC, Météo-France, Toulouse, France*

Introduction

Climate change related impacts on agriculture (Challinor et al. 2014) have focused on the long term trends of agricultural yields under evolving climate parameters (IPCC 2014) . Insurance companies and risk management public strategies are strongly concerned by the climatic accidents that may occur more than slow annual evolutions.
Drought extreme events in 2003, 2011, 2017 and the excess of water in 2016 have caused catastrophic damages to the French farmers with crop yield losses reaching sometimes 40 to 50% of the departmental production.
On this field, understanding the drivers of the climatic extremes and their impacts on crop yield losses is a key point, even more today, at the day before the reforms of the Common Agricultural Policy. By definition, extreme events of low probability require an important historical depth of meteorological datasets and agricultural yields to calibrate a consistent impact model.
CCR, a French Public Reinsurance company, in collaboration with Agrocampus Ouest and Meteo-France, have set up a PhD project to build an impact model of extreme climatic events on crop yields and to project losses in 2050 according the RCP 4.5 and RCP 8.5 scenarios. The impact model will be linked to the outputs of a global climatic model (ARPEGE-Climat), driven by atmospheric and oceanic conditions corresponding to current climate and the two scenarios. 400 years of hourly weather parameters on an 8x8 km grid will be produced for each scenario.

Materials and Methods

The first step of the PhD is to define climatic indices that express extreme drought and wetness with a strong correlation to crop yields. The correlation, built on historical records of meteorological and yield data, is central to the robustness of the impact model.
After reviewing the existing literature, a new index was created, based on a cumulative water balance anomaly (using rainfall and evapotranspiration) on a 10-days-time scale (Kapsambelis et al. 2019). This so-called DOWKI index is computable at every spatial scale and is defined by a unique parameter, the vulnerability period of the crop.

Results and discussion

DOWKI index has been applied for drought and excess of rainfall modelling. Indeed, the extreme negative values of the index are correlated with high yield losses as awaited for drought. On the opposite, extreme positive values (above 250) come along with elevated yield losses. The minimum and maximum values of the index are correlated at 89%: the occurrence of severe drought and severe wetness events cannot happen during the same season on a same department.
DOWKI index is strongly correlated to yield losses for its extreme values (figure 1), predicting more than 90% of yield losses for drought and 76% for excess of water.
After calibrating the impact model on the index-yield loss relationships, the index is calculated on the
ARPEGE-Climat model outputs on the 8x8 km SAFRAN grid. The 8 km SAFRAN grid has been crossed with the RPG (graphical parcel register) to take into account the spatial distribution of the crops.

Conclusions

We develop a new index in order to predict crop yield anomalies due to extreme drought and extreme excess of water.
The proposed model will characterize the extreme events under current and future climate conditions and their impacts on agricultural yield losses. The results on crop exposure and farms exposure could be used to adapt our risk management policies.

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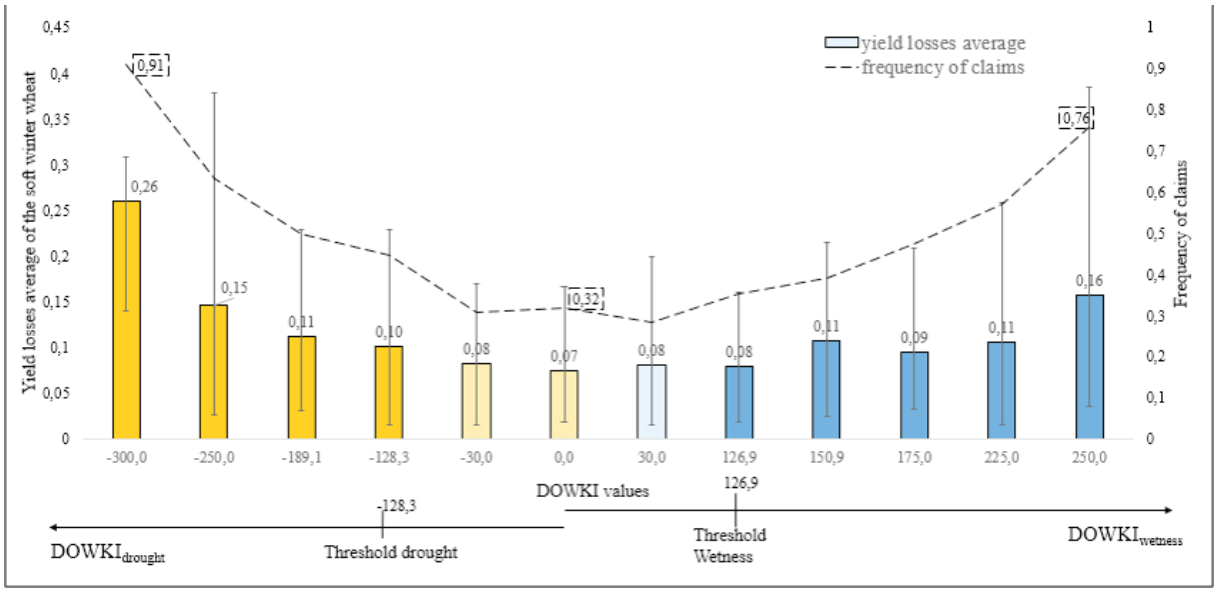

Figure 1. Impact model calibration results: correlation of DOWKI index with crop yield losses for soft wheat.

Keywords: extreme events, climate change, modelling, crop yield losses.

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S5-O.26

Challenges of modeling climate change impact on smallholder agricultural systems in Africa

Rusinamhodzi Leonard[1] (leonard.rusinamhodzi@gmail.com), Corbeels Marc[2], Berre David[3], Lopez-Ridaura Santiago[4]

[1] *Sustainable Intensification Program, CIMMYT, Kathmandu, Nepal*; [2] *AIDA Unit Research, CIRAD, Nairobi, Kenya*; [3] *CIRAD, Ouagadougou, Burkina Faso*; [4] *Sustainable Intensification Program, CIMMYT, Mexico City, Mexico*

Introduction

Simulation modeling tools have been deployed in several situations in sub-Saharan Africa for *ex-ante* impact analyses of an array of improved crop production systems and can help answer most of the what-if questions (Jones et al., 2003). Climatic volatility especially rainfall is a major barrier confronting small scale farmers in the region, and Africa is projected to be affected more by the devastating effects of climate change on food production (e.g. Challinor et al., 2007). Consevation agriculture (CA) based on soil mulch, no-tillage and crop rotations has been suggested as a possible solution (Wall, 2007). The objective of this paper is to illustrate the challenges of modeling the ex-ante impact of climate change on two cropping systems: (a) conventional tillage (baseline), and (b) CA, promoted as a suitable sustainable intensification option for smallholder farmers in the region.

Materials and Methods

Future climatic data and farm typologies from a case study site in Monze, Zambia were used to explore the trajectories of current and alternative cropping systems. The Agricultural Production Systems Simulator (APSIM), version 7.6 (Keating et al., 2003) was parameterised and used to simulate the productivity of maize under conventional and CA options with different scenarios of future climate change generated using an ensemble of 17 global circulation models (GCMs). The management scenarios were derived from different farm typologies created by classifying farmers based on resource ownership and production orientation. Two extreme emission scenarios were considered: (a) the low emission scenario - Representative Concentration Pathway (RCP2.6), and (b) the high emission scenario - Representative Concentration Pathway (RCP8.5). The weather files for the period 2015 to 2050 were generated using MarkSim.

Results and Discussion

Future (year 2050) climate for Monze showed no significant change in solar radiation, but higher total season rainfall compared with current climatic conditions. There was an increase in both minimum (+1°C) and maximum (+1.5 °C) temperatures for the two emission scenarios. However, the ensemble of models showed high variability indicating an uncertainty in future climate prediction. Simulated crop yield results showed that the advantage of CA in the future would be for the low emission scenario only (Figure 1). This is because of the moisture conservation effects of crop residues retention. This result agrees with some studies (Boko et al. 2007), which have pointed to variable future conditions thus indicating high uncertainty on the GCM predictions for Africa.

Conclusions

Climate variability is large in Africa even over very short distances thus future climate cannot be predicted with good certainty. There is need to improve the usefulness of climate change modeling in Africa by: (a) having access to high throughput data, (b) locally developed and well-calibrated process-based simulation models, (c) having greater confidence in the selection of GCMs, and (d) having the ability to set relevant emission scenarios.

Acknowledgements

We thank Dr. Christain Thierfelder for providing data from the long-term trial at Monze, Zambia. Financial support from CCAFS through the CGIAR-CRP Twin Post-Doc Program is greatly appreciated.

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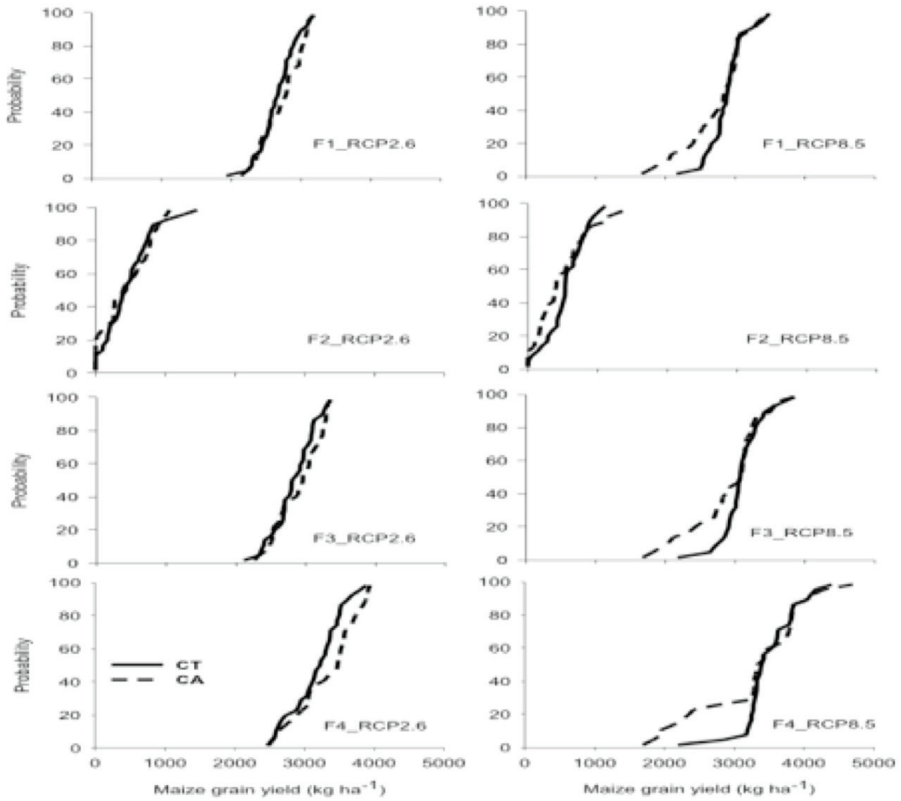

Figure 1. Maize yield probability distribution for conventional tillage (CT) and conservation agriculture (CA) with projected future climate (RCP2.6 and RCP8.5) for the four farm types (F1-F4).

Keywords: poor resources, complexity, soil fertility, risk assessment, re-allocation.

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S5-O.27

CMIP6 climate and crop model ensemble estimates of future extreme event impacts on crops

Jägermeyr Jonas[1] (jaegermeyr@uchicago.edu), Müller Christoph[2], Ruane Alex[3], Lesk Corey[4], Elliott Joshua[1], Frieler Katja[2]

[1] *Department of Computer Science, University of Chicago, New York, NY, USA*; [2] *Potsdam Institute for Climate Impact Res, Potsdam, Germany*; [3] *NASA Goddard Institute for Space Studies, New York, NY, USA*; [4] *Columbia University, New York, NY, USA*

Introduction

Future changes in inter-annual weather variability and linked yield fluctuations can be more important than long-term mean climate change impacts. Extreme events such as heat waves and droughts are expected to become both more severe and more frequent. Related implications for agricultural productivity insufficiently understood.

Materials and Methods

Here we use new CMIP6 climate model simulations from 1900 to 2100 to drive an ensemble of state-of-the-art process-based global gridded crop models to evaluate historical and future impacts of heat waves and droughts on staple crop productivity. Climate projections are bias-adjusted to preserve mean and variability, based on a new quantile-mapping approach developed within the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) (Lange, 2019). Extreme event selection is based on a consistent rule-based metric, largely matching EM-dat disaster records (EMDAT, 2019). Future crop model projections for multiple RCP trajectories are grounded in historical evaluations using FAO national yield statistics (FAO, 2019).

Results and Discussion

Composite analyses of country-level yield losses associated with heat waves and droughts, following the methodology in Jägermeyr & Frieler (2018) and Lesk et al. (2016), are compared for the time periods 1961-2000 and 2061-2100. This work is in progress with CMIP6 simulations currently being down-scaled and bias-adjusted and first results are expected soon. We cannot provide a results figure at this point.

Conclusions

Coming soon.

Acknowledgements

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Keywords: droughts and heat waves, crop yield variability, mechanistic crop modeling, GGCMI, ISIMIP3.

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S5-O.28

Impact of changes in climate and cultivars on winter wheat phenology in Germany

Eyshi Rezaei Ehsan (ehsan.eyshi-rezaei@uni-goettingen.de), Siebert Stefan

Department of Crop Sciences, University of Göttingen, Göttingen, Lower Saxony, Germany

Introduction

Little is known about differences in timing of flowering and maturity of old and modern cultivars and the uncertainty introduced to crop model results by ignoring cultivar changes in climate impact assessments. The objective of the present study is to quantify the sole and combined contribution of changes in cultivars and climate on long term phenology of winter wheat in Western Germany by combining field experimentation and modeling.

Materials and Methods

16 popular winter wheat cultivars released from 1895 to 2007 were cultivated in parallel in two growing seasons (2016-2017 and 2018-2019) to detect the differences in phenological characteristics of old and modern cultivars. The photo-vernal-thermal time (PVTT) required from emergence to flowering and the thermal time (TT) required from flowering to maturity were calculated for each cultivar using SIMPLACE<LINTUL2> model. Next, the phenological events of winter wheat for Western Germany and the period 1952-2013 were extracted from a long term phenology dataset developed by the German Meteorological Service and interpolated to 1 km × 1 km resolution (Eyshi Rezaei et al., 2018). The crop model was executed using fix and cultivar specific phenology parameters to simulate day of heading day of winter wheat (1952-2013 at 1 km × 1 km resolution) to assess the uncertainty introduced when ignoring long term cultivar shift.

Results and Discussion

Results of the field experiments showed that the PVTT for the period emergence-flowering was declined by 13% for modern cultivars (released after 1975) compared to old cultivars. In addition, TT required between flowering and maturity was increased by 15% for modern cultivars (Figure 1a) which means that cultivar change resulted in a prolonged grain filling period. The analysis of trends in the country-wide observations showed that an advancement of 3.2 days per decade, 2.4 days per decade and 1.1 days per decade for day of yellow ripeness, day of heading and day of emergence, respectively (Figure 1b). Trends in day of heading simulated with the crop model parameterized with the field observations indicated that climate warming and cultivar characteristics contributed similarly to trends in day of heading (Figure 1c). The spatial pattern of trend of yellow ripeness showed a more variability compared to trend of heading (Figure 1d).

Conclusions

We conclude that cultivar change and climate change affected winter wheat phenology with similar magnitude within the last six decades. To avoid that effects of cultivar change are erroneously attributed to climate warming, cultivar change effects should be considered in climate impact studies.

Acknowledgements

Research support was provided by the German Federal Ministry of Education and Research (Project: GlobeDrought, grant no. 02WGR1457F).

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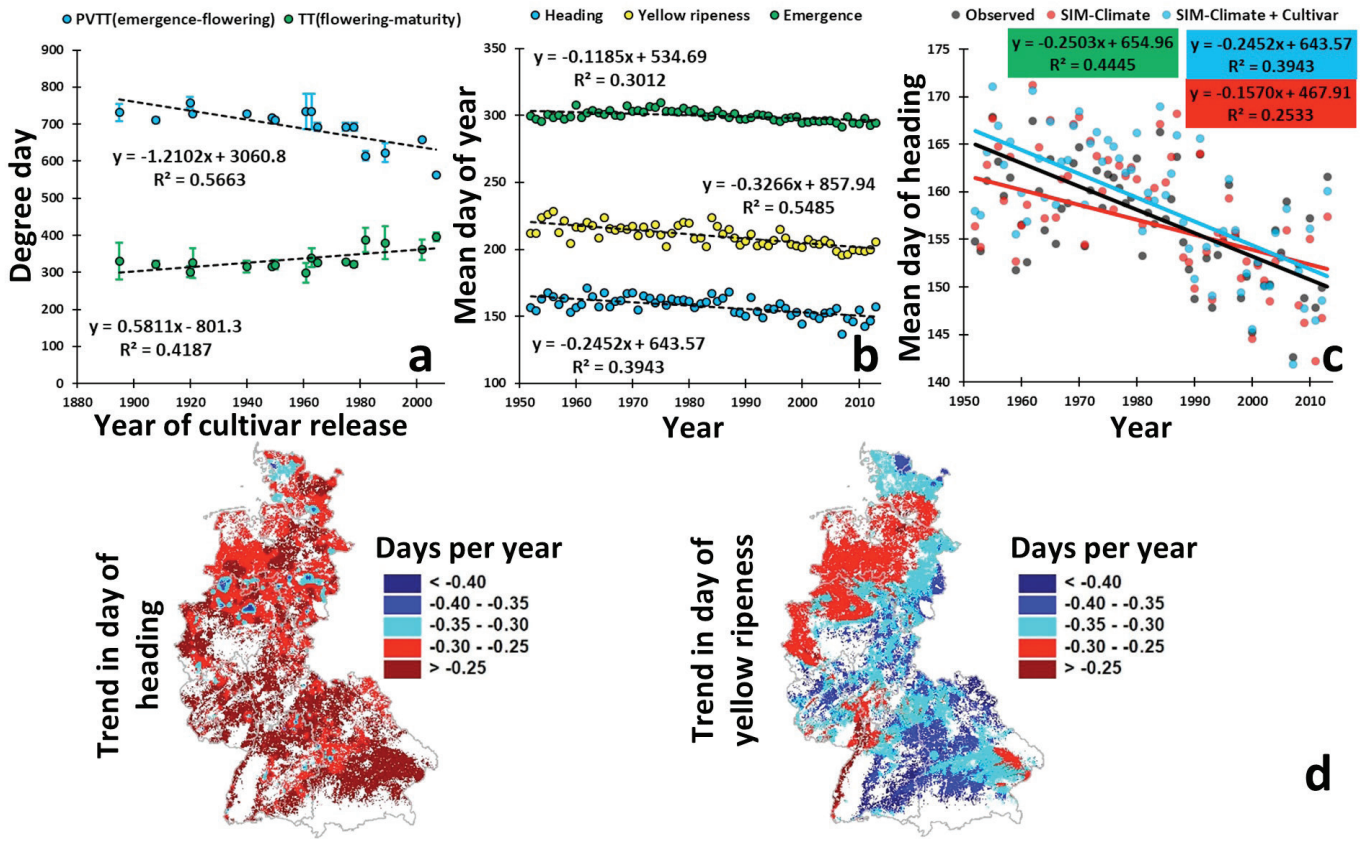

Figure 1. Mean of cultivar-specific PVTT (emergence-flowering) and TT (flowering-maturity) observed in the field experiment in 2016/2017 and 2018/2019 (a). Error bars indicated the standard deviation. Trend of mean day of emergence, heading and yellow ripeness in the period 1952-2013 across Western Germany (b). Mean heading day observed for western Germany and simulated with the phenology model (parametrized separately by field experiments) considering the climate effect (fixed cultivars) and combined climate, sowing and cultivar effects (changing cultivars) for the period from 1952 to 2013 for Western Germany (c). Spatial pattern of observed trend of day of heading and yellow ripeness at the grid-cell level in the period from 1952–2013 at 1 km × 1 km resolution across western Germany (d).

Keywords: Cultivar shift, Climate change, Crop modeling, Winter wheat.

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S5-O.29

Integrating Crop Modelling in the Smart Farming Project Farm/IT in Austria: Achievements and Challenges

Manschadi A. M.[1] (manschadi@boku.ac.at), Soltani A.[2], Fuchs W.[1], Ryall S. P.[1], Koppensteiner L.[1], Eitzinger J.[3], Kaul H.-P.[1], Neubauer T.[4]

[1] *Dep. of Crop Sciences, BOKU University, Tulln, Austria*; [2] *Gorgan University, Gorgan, Iran*; [3] *Institute of Meteorology and Climatology, BOKU University, Vienna, Austria*; [4] *Institute of Information Systems, Technical University, Vienna, Austria*

Introduction

Recent advances in information technologies, sensor-based plant/soil monitoring, and remote sensing have facilitated extensive data collection in farming systems. The lack of transparent, interactive, and easy-to-understand software tools for translating data into informed management decisions, however, has widely been identified as a key limiting factor for the adoption of new smart farming technologies by stakeholders. This paper reports on the conceptualisation and implementation of the FARM/IT project in Austria, which aims to address these shortcomings.

Materials and Methods

The Farm/IT project has been initialised as an interdisciplinary joint effort to facilitate the development of web-based software tools for improved management of cropping systems. In a survey conducted to explore the expectations of farmers and policy makers from smart farming technologies, forecasting season-specific crop growth/yield and demand for inputs (fertilisers, irrigation water) was considered as the most valuable uses of new technologies. Thus, Farm/IT focuses on the following applications: improved nitrogen fertilisation based on spectral sensing and crop modelling, crop yield forecasting, efficient irrigation water management and optimisation of resource use by crop rotation. To address these demands, Farm/IT uses the simple yet process-based crop simulation model iCrop developed by Soltani & Sinclair (2012).

Results and Discussion

The model was first parameterised for wheat, maize, potato, and sugar beet cultivars grown in Austria based on detailed time series of plant and soil data from field experiments conducted in the winter and summer growing seasons from 2016 to 2019. During the parameterisation process, some routines in iCrop, e.g. simulation of leaf canopy development and nitrogen partitioning between plant organs, were improved. Following the model parameterisation, the performance of iCrop was evaluated against independent multi-environment long-term datasets in order to ensure the suitability of the model for applications on farmers' fields. iCrop performed well in simulating the phenological development of crops; e.g. the observed time of heading in winter wheat across several sites and years was simulated with a RMSE of 3.01 to 4.15 days (R^2=0.80) (Fig. 1). The simulated crop yields, however, did not match the observed data well due to unavailability of information on initial soil water and nitrogen contents.

Conclusions

Farm/IT results show that application of crop modelling in the context of smart farming has the potential to improve farm productivity, profitability, and resilience (see https://farmit.at/en/). However, the availability of high-quality and free-of-charge plant, soil, and weather data is currently among the major bottlenecks for adopting smart farming technologies in Austria.

Acknowledgements

We would like to thank the Austrian Research Promotion Agency (FFG) for funding this research.

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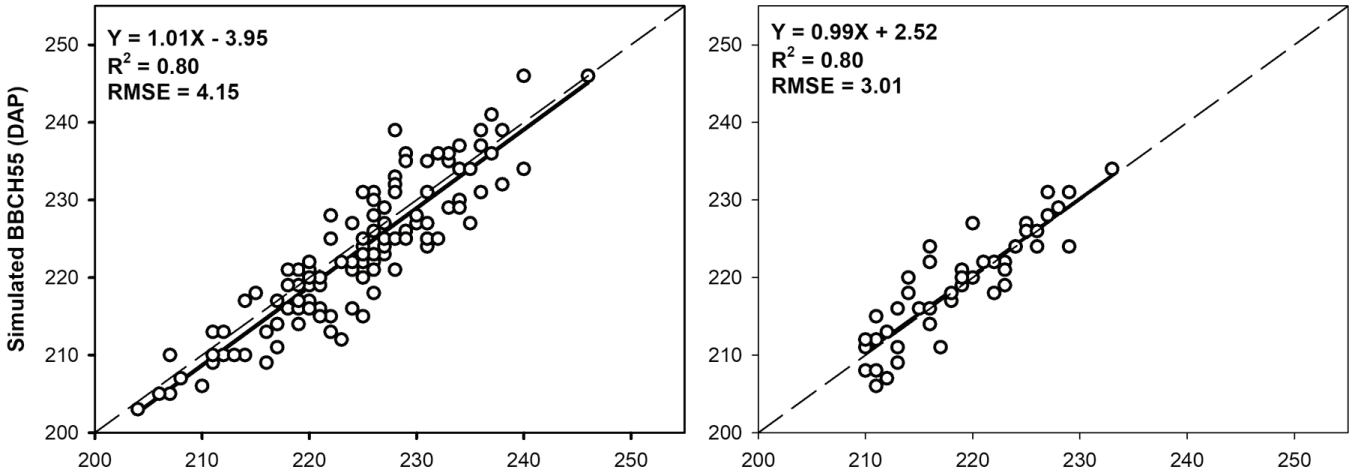

Figure 1: Performance of the iCrop model for simulating the date of heading (BBCH55 in days after planting; DAP) in winter wheat cv. Capo (left) and four other cv. contrasting in phenological development (right) grown between 1991 and 2017 in multi-environment trials in Austria.

Keywords: iCrop model, Parameterisation, Field datasets, Evaluation, Data availability.

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S5-O.30

Precipitation deficit indicators for rainfed crops; a revisit using model-based evapotranspiration

Mesbah Morteza[1] (morteza.mesbah@canada.ca), Pattey Elizabeth[2], Jégo Guillaume[3], Champagne Catherine[2], Ruget Françoise[4]

[1] *Charlottetown R&D Center, Agriculture and AgriFood Canada, Charlottetown, PE, Canada*; [2] *Ottawa Research and Development Centre, Agriculture and AgriFood Canada, Ottawa, ON, Canada*; [3] *Quebec Research and Development Centre, Agriculture and AgriFood Canada, Quebec City, QC, Canada*; [4] *UMR 1114 EMMAH, INRA, Avignon, France*

Introduction

To secure food for growing population, crop production may need to be doubled by 2050 (FAO, 2009). This is a complex challenge particularly when precipitation deficits cause stress to global cropping systems, 90% of which are rainfed. To better quantify the impact of water deficits on crops, indicators (e.g., standardized precipitation index (SPI), McKee et al., 1993) are often used to represent drought with little attention to crop related information. Here, we introduce crop precipitation indicator (CPI) which accounts for crops temporal water demand using model-based evapotranspiration (ET). We compare its performance with cumulative precipitation and SPI via a case study in major corn production (more than 90%) ecozone of Canada.

Materials and Methods

We used the STICS crop model (Brisson et al. 2003) adapted for corn cultivars in Eastern Canada (Jégo et al. 2011). Simulations were performed for 48 to 61 years of daily climate data and 3 contrasting soils in five regions along the Mixedwood Plains ecozone (Figure 1.a). This ecozone has a significant agroclimatic gradient (Figure 1.b) and moderate rainfall deficits. We used measured data obtained using the eddy covariance technique in Ottawa area to verify model performance in predicting daily ET. The model performed well after minor adjustments to a coefficient representing potential bare soil evaporation. CPI was then calculated as integration of 10-day precipitation capped by two thresholds: soil available water capacity and modeled 10-day ET calculated as the sum of daily ET averaged for non-stressed years. A soil-specific transfer coefficient was also included to account for the proportion of water transferred from one 10-day interval to another. This coefficient was optimized via solving an optimization problem with a cost function representing the R^2 of linear fit between yield and CPI.

Results and Discussion

We compared the performance of precipitation, CPI, and SPI in predicting yield and growing season ET. For the majority of regions, CPI outperformed both precipitation and SPI in predicting yield (Figure 1.c). The R^2 of the linear fit between yield and indicators were close to zero in northeast regions, and gradually increased with climatic gradient with highest values in southwest regions. This finding indicated that in central and northeast regions, the precipitation was not a limiting factor. However, in southwest regions where there were more frequent rainfall deficits, the indicators performed better. In Windsor, the R^2 of linear fit to yield-CPI data (0.67) for sandy loam soil was 31% higher than that of yield-precipitation (0.51), and 18% higher than yield-SPI (0.57). While the R^2 of linear fit to ET-CPI data was similar to that of ET-precipitation (0.47), the slope of 1 for ET-CPI fit was an indication that CPI could potentially better represent ET.

Conclusions

Our results indicated that in central and northwest regions of the ecozone, the new indicator lead to marginal improvement in yield prediction. However, in southwest regions where rainfall deficits were more frequent, the CPI was able to better predict yield and improve the linearity with yield for all dominant soil textures. The new indicator can be used as a tool that enables decision makers to develop what-if scenarios to support the resilience of the sector, such as planting new crops or implementing irrigation.

Acknowledgements

This work was funded by Agriculture and AgriFood Canada.

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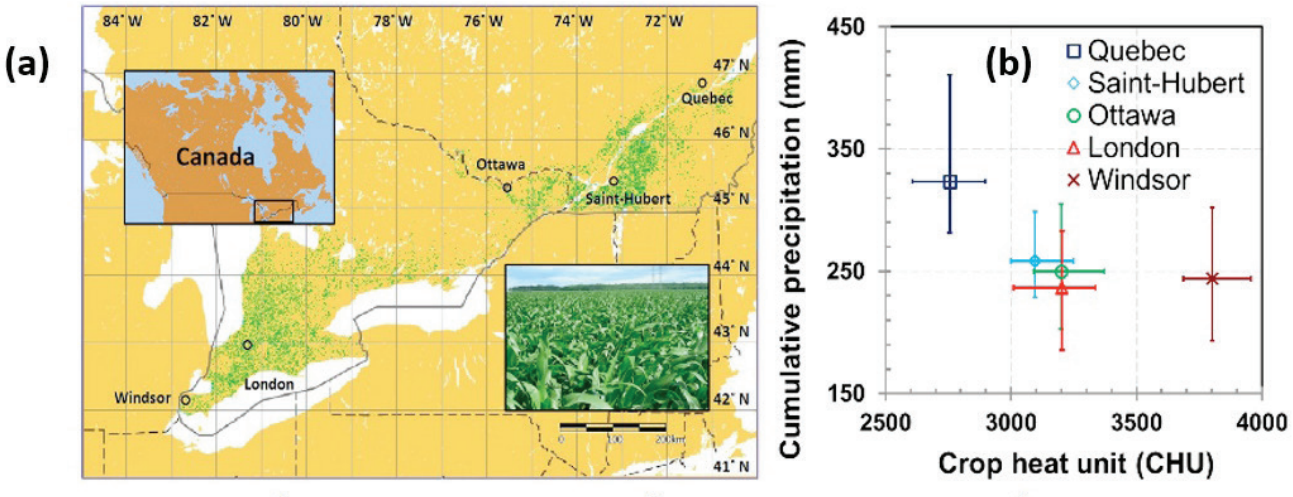

(c)

	$R^2_{(yield\text{-}CPI)}$						$R^2_{(yield\text{-}Pcp)}$						$R^2_{(yield\text{-}SPI)}$					
	C	CL	SC	SCL	L	SL	C	CL	SC	SCL	L	SL	C	CL	SC	SCL	L	SL
Windsor			0.67	0.69		0.67			0.54	0.56		0.51			0.64	0.66		0.57
London				0.34	0.53	0.53				0.28	0.45	0.48				0.40	0.50	0.57
Ottawa		0.20			0.35	0.50		0.13			0.29	0.42		0.22			0.27	0.32
St-Hubert	0.21	0.05				0.23	0.10	0.01				0.12	0.20	0.07				0.11
Quebec			0.02		0.00	0.02			0.01		0.01	0.26			0.02		0.00	0.00

Figure 1. a) Corn cultivated lands extracted from the 2013 Annual Canadian Space-Based Crop Inventory (AAFC) in the Mixedwood Plains ecozone, and b) precipitation (May 1st-August 30th), and the crop heat unit (CHU) calculated as the sum of daily values from May 1st to the first date that temperature drops below -2. Error bars represent quartiles. c) R2 of linear fit to yield-indicator data for three indicators for dominant soils (C: Clay, CL: Clay loam, SC: Silty clay, SCL: Silty clay loam, L: Loam, SL: Silty clay).

Keywords: Precipitation, evapotranspiration, crop modeling, crop precipitation indicator, climate variability.

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S5-O.31

Predicting sorghum performance from big on-farm data in the savannah zone of northern Nigeria

Akinseye Folorunso[1] (f.akinseye@cgiar.org), Ajeigbe Hakeem A.[1], Ahmed Mohammed I.[2], Traore Pierre C. Sibiry[3], Tabo Ramadjita[4], Whitbread Anthony Michael[2]

[1] *WCA, ICRISAT, Kano, Kano, Nigeria*; [2] *Innovation Systems for the Drylands, ICRISAT, Patancheru, Telegana, India*; [3] *agCelerant-Senegal, Manobi Africa PLC, Dakar, Senegal*; [4] *WCA, ICRISAT, Bamako, MD, Mali*

Introduction

Smallholder farming systems in semi-arid regions are characterized by poor soil fertility and low agricultural input use. Sorghum production in tWest Africa is mainly rain-fed with many smallholder farmers dependent on it for their livelihoods. Process crop models serve as powerful tools for evaluating different cropping systems and for devising strategic and tactical decisions therein. The Agricultural Production Systems sIMulator (APSIM) is widely used to test the many combinations of production options and interventions under current and future climatic conditions, and to identify main constraints to sorghum production. Our study explores the adaptation and performance of contrasting sorghum cultivars ranging from early to late maturing, low to high photoperiod sensitivity over a wide range of sorghum production environments. It aims to combine simulation and field experimentation to evaluate crop response to variable climate risk and management practices, across different soil types and climate scenarios.

Materials and Methods

Two datasets provided calibration and validation for five contrasted sorghum varieties. Calibration data came from 2016-2018 on-station field experiments conducted in the Savannah and Sudano-Sahelian agro-ecological zones. Validation data came from 2013-2017 on-farm measurements of the impacts of various improved agronomic practices including: seed treatment, minimum tillage and fertilization strategies. A total of 3,266 yield data points spread from Southern Guinea Savannah to the Sudano-Sahelian zone were assembled that included basic management data (sowing date, fertilizer application rate) and approximative location for each farm. APSIM was used to simulate crop grain yields under two different weather scenarios (historical and future) and three fertility levels (low, medium and high). Spatial information was normalized across scales to match with modelling outputs. Soil maps from FAO, agroecological zones from the national agencies, national and CHIRPS data, observed yield from the multilocal trials were used to understand the connectivity to markets and credit was compiled and used in a mapping framework to generate zones of adaptation.

Results and Discussion

Our results showed that APISM produced robust predictions of phenology (flowering and maturity) captured with high accuracy (MBE: 1-4 days; normalized RMSE < 10%). The prediction of grain yield (GY) and total biomass (TB) ranged from accurate RMSEn (SK5912: 9.2% for GY; 6.9% for TB) to low RMSEn (34.5% for GY; 36.8 % for TB) of the observed mean across the sorghum variety. Being able to accurately predict crop performance over widely differing agro-ecologies and soil types, is the basis for applying such tools for management. Simulated grain yield varied widely among cultivars CV varying from 12 - 31% depending on variety.The spatial dimension to this type of study will add value to predictions by providing a basis for scaling-out over larger areas.

Conclusion

This study is expected to strengthening digital farming solutions towards improving management practices and risk management strategies to cope with uncertainties and benefits African smallholder farmers productivity and financial security .

Acknowledgement

The authors thank the donor for the funding of the study.The study is part of the NADiRA project, which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776309.

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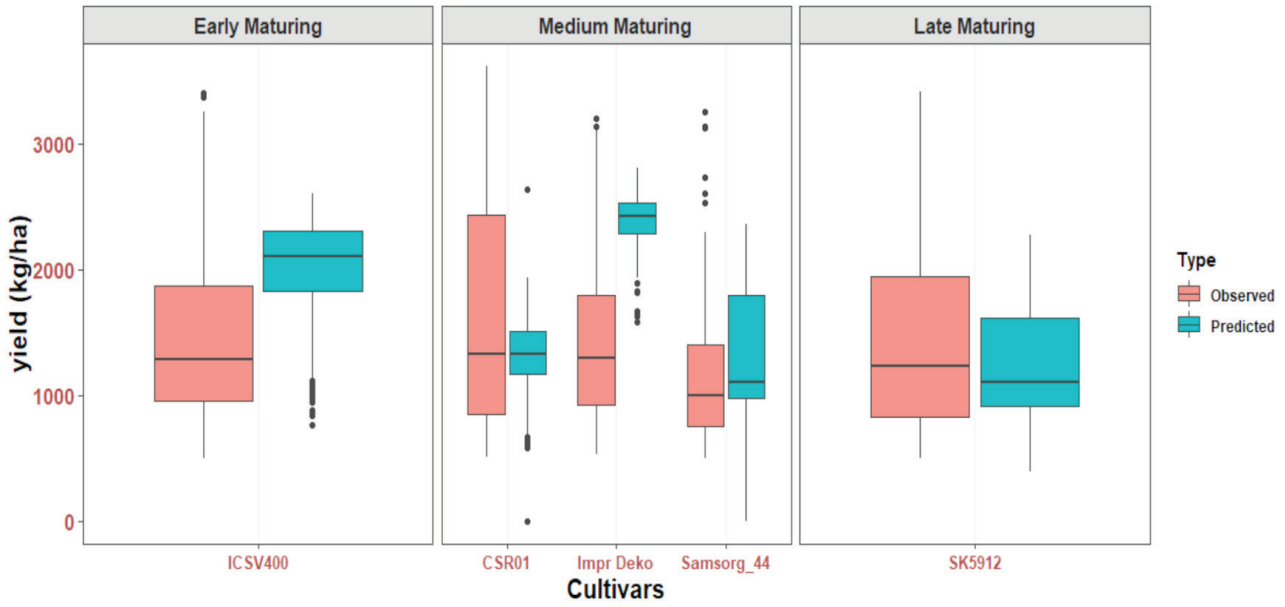

Figure 1: Yield of (observed and simulated) using on-farm data sets from 2013-2017 growing seasons from contrasting environment for five (5) sorghum cultivars ranged from early to late maturing.
ICSV-400 (N=1192; MBE = 535 kgha-1;RMSE =971kgha-1); Improved Deko (N=300; MBE= -960 kgha-1,RMSE = 1169 kgha-1); Samsorg-44 (N=100; MBE= 102 kgha-1;RMSE = 912 kgha-1);CSR01 (N=944; MBE= -228kgha-1,RMSE = 867 kgha-1); SK5912 (N=731; MBE= -219 kgha-1;RMSE = 839 kgha-1. Coefficients of variation (CV) ranged from 12 - 31% depending on variety, N= number of observation

Keywords: Sorghum, Nigeria, APSIM, big data, NADiRA.

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ABSTRACTS PARALLEL SESSIONS

SESSION VI

METHODS AND SOFTWARE TO SUPPORT MODELLING ACTIVITIES

As researchers acquire new data and knowledge about cropping systems, crop models have become increasingly complex. On the one hand, these more complex models often have improved capability to reproduce key processes and to support the analysis and management of a variety of cropping systems. On the other, the introduction of new or improved algorithms often requires users to supply additional input data and results in a general increase in the complexity of the parameter space. Other consequences of increased complexity, especially when model algorithms are coded by domain experts (e.g., biologists, agronomists) and not by professional programmers, could be lower usability or, in the worst case, software instability. These considerations are not intended to cast a shadow on the fundamental research that has driven model improvement for decades. They rather emphasize the need to increase our awareness of the way models behave and of the way uncertainty propagates, as well as the need for using software architectures able to support the algorithmic complexity of modern simulation environments.

S6-Keynote

Crop2ML: A Crop Modelling MetaLanguage shared between different crop simulation platforms

Martre Pierre[1] (pierre.martre@inrae.fr), Midingoyi Cyrille[1], Enders Andreas[2], Fumagalli Davide[3], Raynal Hélène[4], Athanasiadis Ioannis[5], Porter Cheryl[6], Hoogenboom Gerrit[7], Holzworth Dean[8], Garcia Frédérick[4], Thorburn Peter[9], Donatelli Marcello[10], Pradal Christophe[11]

[1] *LEPSE, Université Montpellier, INRAE, INSAAE,, Montpellier, France*; [2] *Institute of Crop Science and Resource Conservation (INRES), University of Bonn, Bonn, Germany*; [3] *Institute for Environment and Sustainability, Joint Research Centre, European Commission, Ispra, Italy*; [4] *MIAT, INRAE, Toulouse, France*; [5] *Wageningen University, Wageningen, The Netherlands*; [6] *Agricultural & Biological Engineering, University of Florida, Gainesville, FL, United States*; [7] *Institute for Sustainable Food Systems, University of Florida, Gainesville, FL, United States*; [8] *Agriculture Flagship, CSIRO, Toowoomba, Australia*; [9] *Agriculture and Food, CSIRO, Brisbane, Australia*; [10] *Research Center for Agriculture and Environment, CREA, Bologna, Italy*; [11] *AGAP, Université Montpellier, CIRAD, INRAE, INSAAE, Montpellier, France*

Process-based crop simulation models are popular tools to analyse and predict the response of agricultural systems to climatic, agronomic and, genetic factors. They are often developed in crop simulation platforms to ensure their future extension and to couple different crop models with a soil model and a crop management event scheduler. Models are implemented in different programming languages, in different platforms that use different formalisms. Even when modular approaches and reuse techniques are proposed by these platforms, there is little exchange of crop model components between them despite theoretical and application interests.

To facilitate crop model intercomparisons and model component exchanges, several leading groups in this field have created the Agricultural Model Exchange Initiative (AMEI). Recently, AMEI has develop a high-level metalanguage, Crop2ML, to enable (1) the description and the assembly (composition) of crop model components independently of the formalism of simulation platforms; and (2) the exchange of components between them. Here, we will present the AMEI vision of crop model exchange and the main features of Crop2ML.

Crop2ML proposes a centralized framework of model exchange and reuse instead of a combinatorial model-to-model transformation between platforms (Fig. 1a). Model reuse issue is addressed at the design level (meta-information, explicit specification of model input/output) rather than at the implementation level. Crop2ML is based on a declarative architecture of modular model representation with an intermediate modelling language to describe biophysical processes and their transformation to existing platforms. Model units and their composite are represented by well defined concepts, which separate the description of a model and its algorithms (Fig. 1b). These structured elements and their attributes constitute the grammar of the declarative language and allow checking if a model conforms to Crop2ML. Composite models are represented by a graph of models to manage complexity by connecting outputs of a model to inputs of another. These concepts and associated attributes were collaboratively defined with the vision of model exchange and reusability.

Given that model algorithms are encoded in different platforms with different programming languages, it requires a meta-level of abstraction of these languages that allow a fully automatic translation to the target languages and provides minimum meta-specifications to encode algorithms. We designed and implemented CyML, a domain-specific embedded language in Cython (Midingoyi et al., 2020). CyML is based on the minimum and sufficient rules to express model algorithms close to mathematical expressions and regardless of simulation platforms artifacts.

In summary, Crop2ML is a unified open crop model representation designed by and for the crop modelling community that takes into account the abstraction of crop component features in crop simulation platforms. Crop modellers willing to contribute to AMEI vision and the Crop2ML framework are warmly welcome to join our effort to develop the next generation methods and tools for crop modelling.

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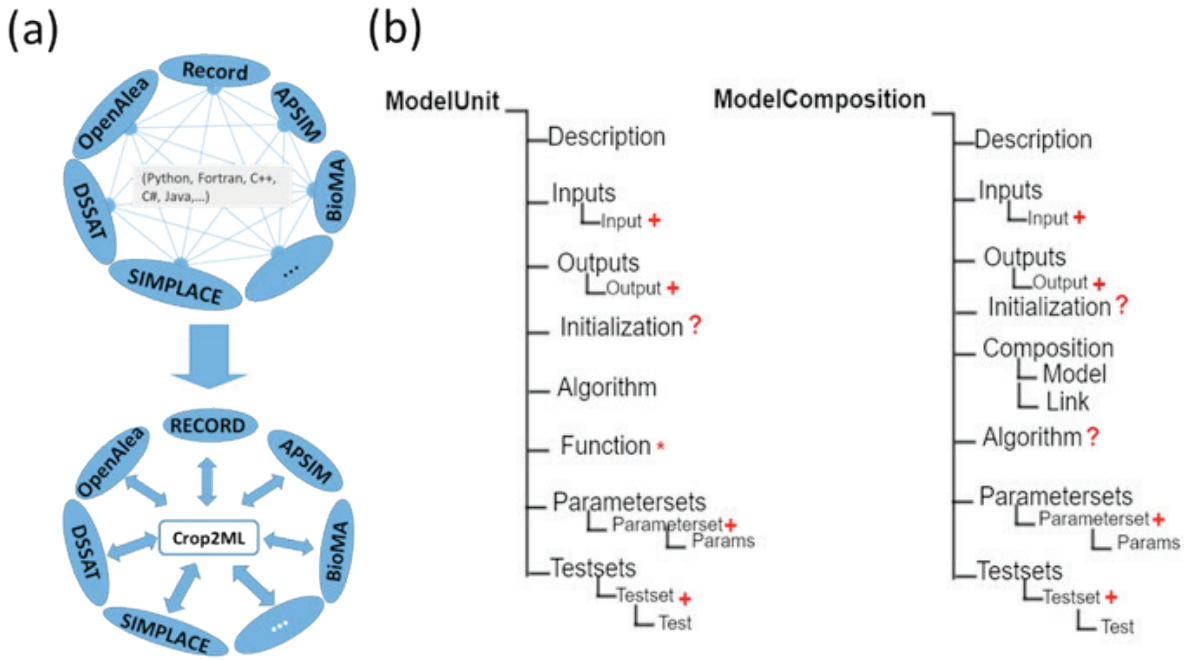

Figure 1. (a) From a combinatorial model-to-model transformation (top) to a centralized framework of model exchange and reuse (bottom). (b) Crop2ML meta-specifications for model unit (left) and composite (right) design. +, one or more elements; *, zero or more elements; ?, zero or one element.

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S6-O.01

Design of declarative crop modeling framework

Yun Kyungdahm (kdyun@uw.edu), Kim Soo-Hyung

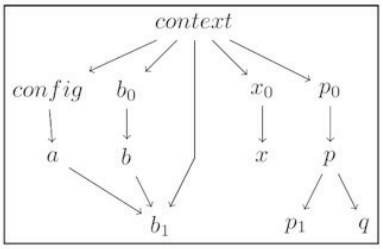
University of Washington, Seattle, WA, United States

Crop modeling is inherently a software engineering problem that requires a systematic translation of quantitative knowledge about crop growth into a computer program. While many models have been developed with different goals in mind, the fundamental concept of describing state variable integrations with separate rate calculation has largely remained the same over the last decades (Van Kraalingen et al., 2003). Such a pattern has covered most, if not all, common requirements raised in crop modeling, but at the same time, the need for more complex patterns arises as evidenced by, for instance, emergence of functional-structural plant models. We now also have more powerful and usable computational tools and platforms did not exist in the past that could potentially change the way we develop crop models. In this talk, we revisit state variable management in crop modeling and propose a new framework that generalizes and extends the concept. A crop model is essentially an integrated network of state variables which can be described by a few types of patterns, possibly more than just integration of differential equations. Our framework provides a domain specific language (DSL) that automatically generates a dependency graph of state variables and enclosing systems translated into Julia programming language code. Each state variable is mapped to a node in the graph tagged with specific computation stage associated with its type. For example, `accumulate` type, which indicates integration of rate variable in discrete time step, may have two separate nodes in the graph to accommodate self-referencing without causing cyclic dependency. `solve` type abstracts a iterative process of bisection method by distinguishing read and update nodes which are flipped to infer correct execution order. It was a key piece for coupling photosynthesis and stomatal conductance models in our application. `produce` type can generate a set of state variables enclosed in a new system which is attached to its own container. Such dynamic behavior is essential for describing organ growth such as initiation of individual leaves and development of root segments. Our framework also supports explicit binding of units for each state variable and automatic conversion during calculation which greatly reduces a source of error in model development. In order to test viability of our approach, a garlic growth model originally developed in C++ was ported into our framework (Hsiao et al., 2019).

.../...

```
@system S begin
    aaa: a ⇒ 1 ~ preserve(parameter)
    b(a) ~ accumulate
    x(x) ⇒ 2x-1 ~ solve(lower=0, upper=2)
    p ⇒ produce(S) ~ produce::S
    q(x=p["*"].b) ⇒ sum(x) ~ track
end
```

(a) model defined in domain specific language



(b) dependency graph with topological sorting

context → p_0 → p → q → p_1 → x_0 → x → b_0 → b → config → a → b_1

```
struct S <: System
    context::Context
    config::Config
    aaa::Preserve{valuetype(Float64, nothing)}
    a::Preserve{valuetype(Float64, nothing)}
    b::Accumulate{valuetype(Float64, nothing), valuetype(Float64, hr), valuetype(Float64, rateunittype(nothing, hr))}
    x::Solve{valuetype(Float64, nothing)}
    p::Produce{S}
    q::Track{valuetype(Float64, nothing)}
    function S(; #31#_kwargs...)
        #21#_names = (names.([mixins(S)..., S]) ▷ (Iterators).flatten) ▷ collect
        #22#context = (context = if haskey(#31#_kwargs, :context)
            #31#_kwargs[:context]
        else
            Context(; )
        end)
        #23#p = Produce(; _name=:p, _alias=(), _value=nothing, unit = nothing, _type = S)
        #24#q = Track(; _name=:q, _alias=(), _value=unitfy(let x = value((#23#p["*"]).b)
            sum(x)
        end, value(nothing)), unit = nothing, _type = Float64)
        #25#x = Solve(; _name=:x, _alias=(), _value=nothing, unit = nothing, upper = 2, lower = 0, _type = Float64)
        #26#b = Accumulate(; _name=:b, _alias=(), _value=unitfy(value(nothing), value(nothing)), unit = nothing, _type = Float64, time = (#22#context).clock.tick)
        #27#config = (config = context.config)
        #28#aaa = Preserve(; _name=:aaa, _alias=(:a,), _value=let #29###o#421 = option(#27#config, #21#_names, Symbol[:aaa, :a])
            unitfy(if isnothing(#29###o#421)
                let
                    1
                end
            else
                #29###o#421
            end, value(nothing))
        end, unit = nothing, _type = Float64, parameter = true)
        #30#a = #28#aaa
        new(#22#context, #27#config, #28#aaa, #30#a, #26#b, #25#x, #23#p, #24#q)
    end
end
update!(self::S) = ...
```

(c) automatically generated Julia code

Keywords: domain specific language, state variable.

References:

1. Van Kraalingen et al., 2003, Eur J Agron,18: 359–361; 10.1016/S1161-0301(02)00131-4.
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S6-O.02

yggdrasil: A Python package for connecting models across programming languages in support of model reuse and modularity

Lang Meagan (langmm.astro@gmail.com)

NCSA, University of Illinois Urbana-Champaign, Urbana, IL, United States

Introduction

Computational models are excellent tools for answering questions about our universe, but are often designed to answer a specific scientific question about a particular process or scale that only represents one piece of a much larger puzzle. At its boundaries, a model must then either approximate the behavior of the larger system or connect with a new model capable of capturing that behavior. By connecting models across these boundaries, scientists can replicate more complex phenomena and gain insights into emergent properties of the larger system. However, technical barriers can arise at these boundaries. Differences in programming languages, units, data formats, and terminology can all prevent models from working together. The yggdrasil package was designed to overcome these challenges and make it possible to combine models like building blocks to create complex systems that can easily be disassembled and reassembled to answer new questions and incorporate new discoveries.

Methods and Materials

yggdrasil is an open-source Python package for connecting models across technical barriers and harnessing parallel and threaded processing to improve the performance of model integrations. Based on a user provided specification file containing information about the target models and the connections between them, yggdrasil launches each model in its own process and then coordinates asynchronous communication between the models using threading. yggdrasil supports models written in Python, C, C++, MATLAB, and R, handles unit and data type transformations, and works on Linux, Mac, and Windows operating systems. Although written in Python itself, yggdrasil users do not need to be familiar with Python in order to use it. In addition to providing interfaces written in each of the supported programming languages, yggdrasil also now supports automated wrapping of models that can be written as functions.

Results

yggdrasil was used during the first phase of the Crops in Silico project (Marshall-Colon et al., 2017) to begin connecting crop models in order to eventually create a complete crop model capable of explore methods for improving crop yield under a changing climate (Lang, 2019). Figure 1 shows the full model integration network as it existed at the end of the first phase; three sets of models were successfully connected. The first set of integrated models included a genetic regulatory network, metabolic model, and leaf-level micrometeorology model. This integration has already help provide new insights into the response of photosynthesis in soybeans to rising levels of CO_2 (Kannan et al., 2019). The other two sets of models were connected using yggdrasil, but still require additional work before they will be ready for publication. One set included leaf and root models, while the other included a metabolic model, canopy geometry model, and ray tracer. During phase 2 of the Crops in Silico project, these model integrations will be fully developed and a new ecosystem model will be added to the network to take the place of static environmental input parameters used in phase 1.

Conclusions

By making it easier to combine existing models, yggdrasil allows researchers to explore complex systems, yielding new insights and encouraging model reuse. yggdrasil has already yielded new insights as part of the Crops in Silico project and is poised to yield even more both in phase 2 of the project and within the broader modeling community.

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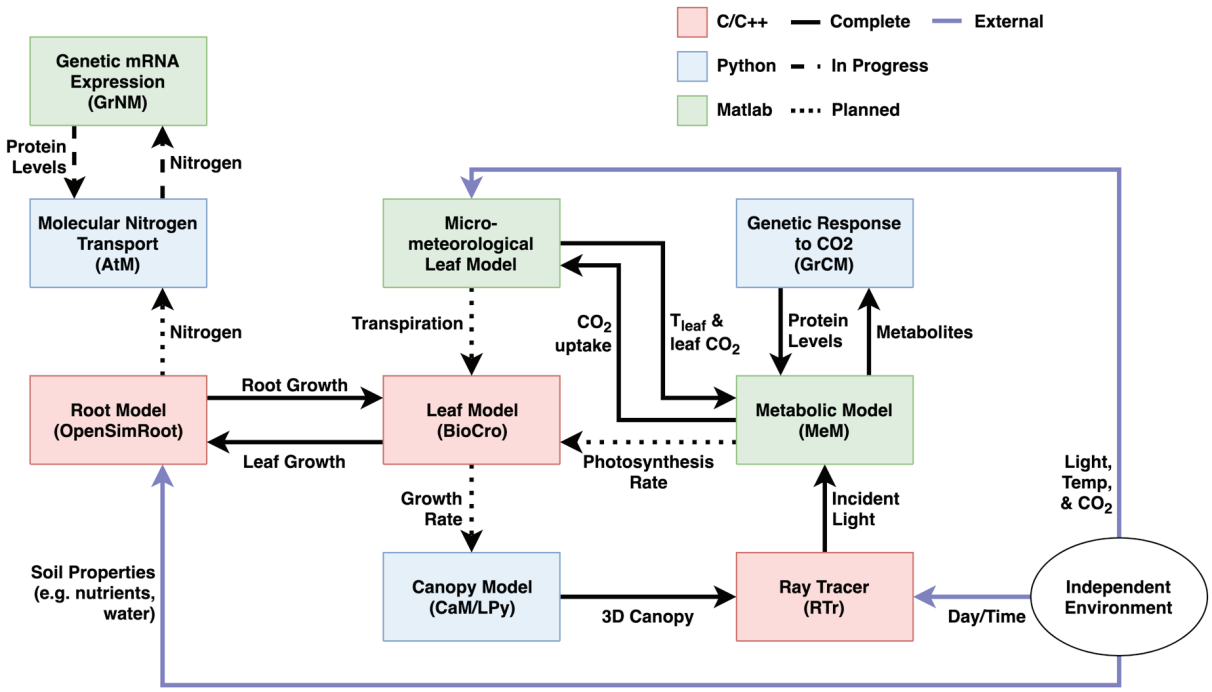

Network of models connected using yggdrasil during phase 1 of the Crops in Silico project.

Keywords: software, open-source, parallel processing.

References:

1. Kannan K, Wang Y, Lang M, Challa GS, Long SP, Amy Marshall-Colon A (2019) Combining gene network, metabolic and leaf-level models shows means to future-proof soybean photosynthesis under rising CO_2. in silico Plants, 1, https://doi.org/10.1093/insilicoplants/diz008
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S6-O.03

New sources of data for crop model evaluation and improvement: recycling existing agronomic data using AgMIP protocols

Porter Cheryl[1] (cporter@ufl.edu), Villalobos Christopher[2], Devare Medha[3], Parr Cynthia[4], Singh Upendra[5], Hoogenboom Gerrit[6]

[1] *Agricultural & Biological Engineering, University of Florida, Gainesville, FL, US*; [2] *Agricultural & Biological Engineering, University of Florida, Gainesville, FL, United States*; [3] *IFPRI, Montpellier, France*; [4] *ARS-National Agricultural Library, USDA, Washington, DC, United States*; [5] *IFDC, Muscle Shoals, AL, United States*; [6] *Institute for Sustainable Food Systems, University of Florida, Gainesville, FL, United States*

Introduction

Large amounts of agronomic research data are collected through on-station and on-farm experiments, surveys and other means by research organizations including the CGIAR international agricultural research for development centers, USDA Agricultural Research Service, US Land Grant Agricultural Experiment Stations, and the International Fertilizer Development Center (IFDC). These organizations are applying FAIR (**F**indable, **A**ccessible, **I**nteroperable, **R**eusable, Wilkinson et al, 2016) principles to facilitate re-use of their data for quantitative analyses, including for use in modeling activities, by extending methods and protocols developed by the AgMIP modeling community (Porter et al, 2014).

Re-use of older datasets is one focus of data interoperability efforts at these organizations. Legacy data are often archived in distributed locations and diverse formats, and generally do not use a consistent vocabulary. These datasets are often archived by the data collector with a permanent Digital Object Identifier (DOI) which prevents modification of the original data using standardized vocabularies for automated interpretation. Many of these datasets from CGIAR are accessible through the GARDIAN portal (gardian.bigdata.cgiar.org); USDA's data are increasingly discoverable through the Ag Data Commons (data.nal.usda.gov); and IFDC is currently developing a discovery portal for their publicly available research data. Efforts are underway within CGIAR and USDA to add metadata annotations to accompany existing archived datasets to facilitate automated discovery and translation to standardized formats so that these data can be used for model evaluation and improvements as well as other types of quantitative analyses.

Materials and Methods

In the initial phase of this effort, as part of CGIAR's Big Data Platform, dataset annotations were developed and manually implemented for selected datasets as a proof of concept. These dataset annotations consist of three "sidecar files" which can be considered as additional metadata beyond the CGIAR core institutional metadata. Regardless of the physical location and format of the raw data in this open distributed system, the sidecar files are readily available for rapid data searches and analytics within the GARDIAN system. New translation and interpretation apps help the data provider or end user to generate the sidecar files and facilitate translation of data to formats that are convenient for quantitative analyses, such as multiple crop modeling formats. Once datasets are fully annotated, they -can be filtered, combined with other annotated datasets, and analyzed.

A similar effort has been funded by USDA National Institute of Food and Agriculture (NIFA) to work with legacy datasets in the US. Initially, datasets from five US institutions will be converted to AgMIP harmonized format or annotated with sidecar files as with CGIAR GARDIAN data and registered for discovery and download through Ag Data Commons.

IFDC is also committed to making their research data available in a harmonized format, compatible with CGIAR, USDA, and AgMIP.

Conclusions

Because compatible data formats are being implemented at these institutions, it will be possible to aggregate datasets across institutions and platforms to allow novel combinations of data, reduce the need for repetitive and redundant data collection, and make available a wider set of data for use in model evaluation and development.

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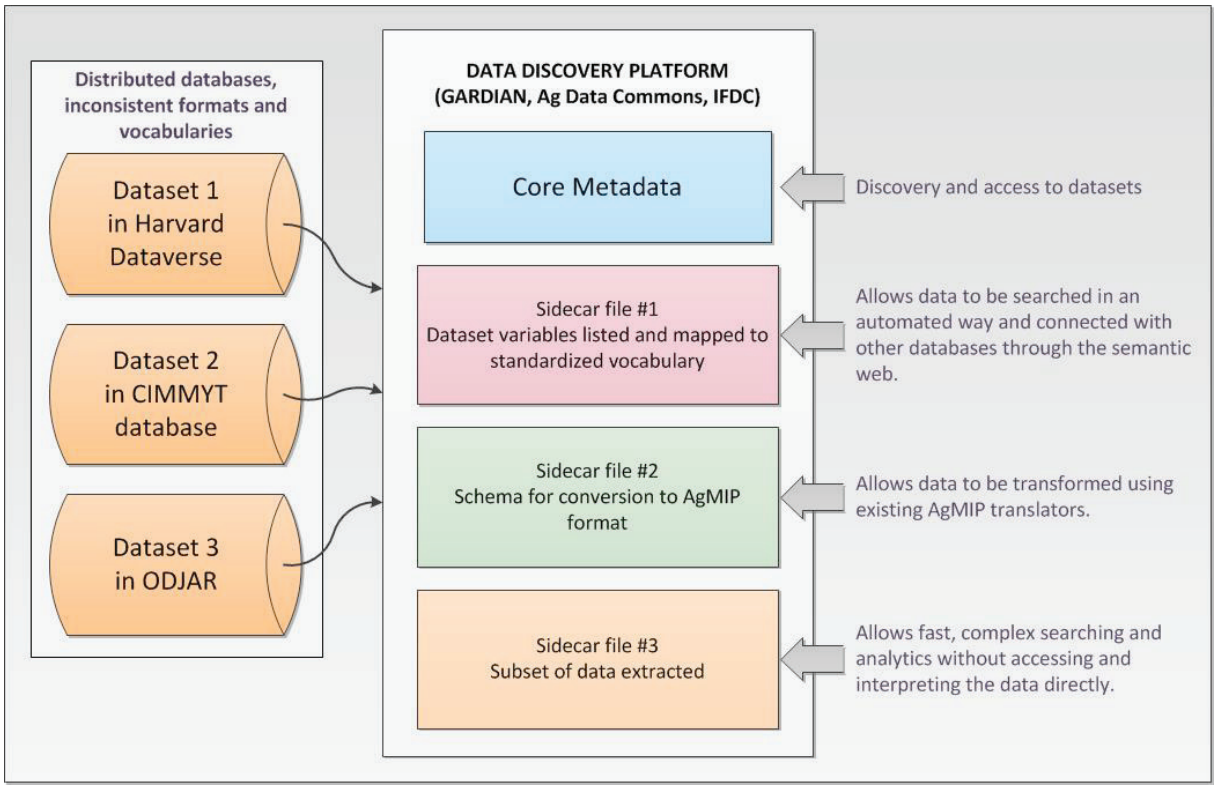

Annotation to allow search, access, aggregation, and translation of legacy datasets.

Keywords: data interoperability, crop experiment data, crop models, data analytics.

References:

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S6-O.04

AgGlob: Workflow for simulation of agronomic models at a global scale

Raynal Hélène[1] (helene.raynal@inra.fr), Ancelet Estelle[1], Le Bas Christine[2], Bertuzzi Patrick[3], Cahuzac Eric[4], Casellas Eric[1], Chabrier Patrick[1], Constantin Julie[5], Pomeon Thomas[4], Toutain Benoît[6]

[1] *UR 875 MIAT, MIA, INRA, Castanet Tolosan, France*; [2] *US 1106 INFOSOL, EA, INRA, Orléans, France*; [3] *US 1116 Agroclim, EA, INRA, Avignon, France*; [4] *US 0685 ODR, SAE2, INRA, Castanet Tolosan, France*; [5] *UMR 1248 AGIR, EA, INRA, Castanet Tolosan, France*; [6] *INFOSOL, EA, INRA, Orléans, France*

Introduction

Simulation of biophysical models over large areas is used in different contexts linked to global agronomy issues (Müller et al., 2017). It is useful for analyzing crop performances at a regional scale (Shelia et al., 2019), for estimating vulnerability of crop production to climate change (Elliot et al., 2014, Montella et al., 2015)... One of approaches is Global Gridded Biophysical Models (GGBMs). It consists to use a crop model developed at field scale and to run it on different sites in order to take into account the heterogeneity of soils, climates and farming practices over the area. The sites are organized according to a spatial grid, with a fine resolution (some km^{-2}). It is possible to run these massive simulations thanks to the development of clusters. It is also possible because more and more data are available to characterize soil, climate and farming practices at fine resolution. Nevertheless, many difficulties remain. They concerned i) the coordination of the actors involved in the process of production of results, ii) the heterogeneity of data formats that makes tricky to reuse them iii) the design and the realization of the campaign of simulations, iv) the validation of simulation results by automated tests, v) the reproducibility of results and traceability, vi) methods and visualization tools suitable to the mass of results to analyze. To overcome these problems, we propose the AgGlob framework, based on a workflow developed on a Galaxy platform instance. (https://galaxyproject.org/).

Materials and Methods

A workflow consists in a sequence of treatments where each step is dependent on occurrence of the previous step. The first treatments concern the access to data stored in external databases and their processing in order to make them compatible to the crop model. For this step, we have developed basic bricks of the workflow.

- *"Climate data" tool*: access to datasets composed of daily observations of temperature, radiation, rain and PET. These data are provided under conditions by SICLIMA database, (INRA climate series provider). The SAFRAN grid is used (Meteo France standard with a resolution of 8km). Queries and post-processing are automated.
- *"Soil data" tool*: access to BDGSF (French Soil Geographic Database) maintained by Infosol (INRA provider). An SQL query requests the data. It puts the data into the format expected by the crop model.
- *"Land use" and "Farming practices" tool:* All the information concerning soil land use in France and farming practices come from the national surveys: "French Land Parcel identification system" and "Enquêtes pratiques agricoles". The information are stored in ODR database (INRA provider) and aggregated at the grid scale. The objective is to have for each cell of the grid, the most representative i) soils, ii) rotations and iv)farming practices. All these layers of information are combined based on the conceptual work done in INRA study «Evaluation Française des Ecosystèmes et des Services Ecosystémiques» . The results is a table where each line corresponds to a point to simulate with all the information required for simulation (crop rotation, sowing date …) on a concise form.

The second step of the workflow consists in preparing the campaign of simulations with the bricks:

- "Simulation Campaign" tool: The previous table is transformed into a text file. The user can download and modify it, in order to design a new simulation campaign (scenario). The tool includes algorithms for testing the validity. Then, this text file is sent to the parallelization service of RECORD simulation platform (Bergez et al., 2014), embedded in the tool.
- "Crop simulation" tool: The model used is STICS encapsulated in RECORD (Bergez et al., 2014). It runs the campaign simulation on the cluster.

The third step concerns the post-processing of simulation results, with automated checks of simulation results, and the production of indicators.

.../...

Results and Discussion

AgGlob is available on an INRA Galaxy instance. It is connected to a distant cluster (Meso@LR) where the simulation jobs are run. It includes a formalization of GGBMs campaign simulation, that we consider as a standard reusable in other projects. A campaign of simulations generates large amount of results. Some consistency checks have been integrated in order to help the user in detecting problems. The workflow can be plugged on other Galaxy instances.

Conclusion

AgGlob is an interesting framework for GGBMs simulation. It helps in coordinating the actors involved, because the different steps of processing are clearly identified and formalized. It also offers a solution for the integration and aggregation of data necessary for simulation, by using automated processing algorithm. It is enough generic to be easily extend to other crop models and to other data. It is also an implementation of the FAIR principles in the domain of GGBMs work, therefore it enhances the reproducibility and traceability of results.

Keywords: Crop modeling, Computational modeling, Parallel computing, Global simulation.

References:

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S6-O.05

Application of the crop simulation model WOFOST at parcel scale through distributed cloud computing

Boogaard Hendrik (hendrik.boogaard@wur.nl), Van Kraalingen Daniel, Lokers Rob, De Wit Allard

WENR, Wageningen, The Netherlands

Introduction

Crop simulation models are indispensable to study different aspects of agricultural production. Such models are used to explore potential crop yield levels (e.g. Global Yield Gap Atlas; Van Ittersum et al., 2016). Advanced crop monitoring systems like the MARS Crop Yield Forecasting System (MCYFS) of the European Commission use models to assess the impact of weather and crop management on growth and development within the on-going cropping season (Lecerf et al, 2019). The impact of climate change on global and regional agriculture is also assessed with crop simulation models (e.g. Blanco et al., 2017).

With the latest developments in big data (e.g. EU Copernicus services), data science (e.g. data cubes, machine learning) and ICT (e.g. e-infrastructures and distributed cloud computing), the technical requirements and restrictions set to crop simulation models change. For example, with the new generation of satellites, like Sentinel, crop specific vegetation information at parcel level can be derived. It allows parcel specific modelling using this vegetation information (e.g. phenology and leaf area dynamics) to improve simulations. Going down to this detailed spatial level in our regional studies requires more computational resources, which can be solved by using cloud computing. Dedicated e-Infrastructures for researchers, such as D4Science (d4science.org), are being developed, that improve the accessibility to cloud compute and storage resources. D4Science facilitates constructing Virtual Research Environments (VREs), for example to support the agro-climatic modelling community (see Ballis et al., 2018, and Assante et al., 2019).

Materials and Methods

To cope with these new developments, crops simulation models need to facilitate: 1) easy scaling of model runs to secure sufficient performance, and 2) standardized interfaces to allow dynamic management of state variables. Therefore Wageningen University and Research decided to re-implement WOFOST, a widely used crop simulation model (see Wit et al., 2019). A new WOFOST version was built in the Wageningen Integrated Systems Simulator (WISS). WISS is a newly developed, Java-based, light-weight simulation model framework targeting the agro-ecological modelling domain. In WISS, models are constructed from components that are essentially stateless and whose states and rates are managed by a dedicated state exchange object. Among other features, WOFOST-WISS provides runtime checking of bounds of states as well as automatic unit conversion.

Results

Within the EU funded project AGINFRA+ a D4Science VRE was deployed and a use case developed to perform parcel specific crop simulation taking data from the AgroDataCube. The AgroDataCube provides a large collection of both open data at parcel level for use in agri-food applications in the Netherlands (https://agrodatacube.wur.nl/). This AGINFRA+ VRE provides access to a compute cluster, of scalable size. A core component of D4Science, DataMiner, handles adding and running algorithms on the cluster, while also making them available through OGC WPS (Web Processing Service) interfaces. On top of that, a dashboard has been created to select crop parcels, activate WOFOST, and visualize and inspect results.

Conclusion

This new set-up, using WOFOST-WISS in a dedicated VRE, leads to many new opportunities like improved farmer advisory services and a more accurate regional crop monitoring and yield forecast service.

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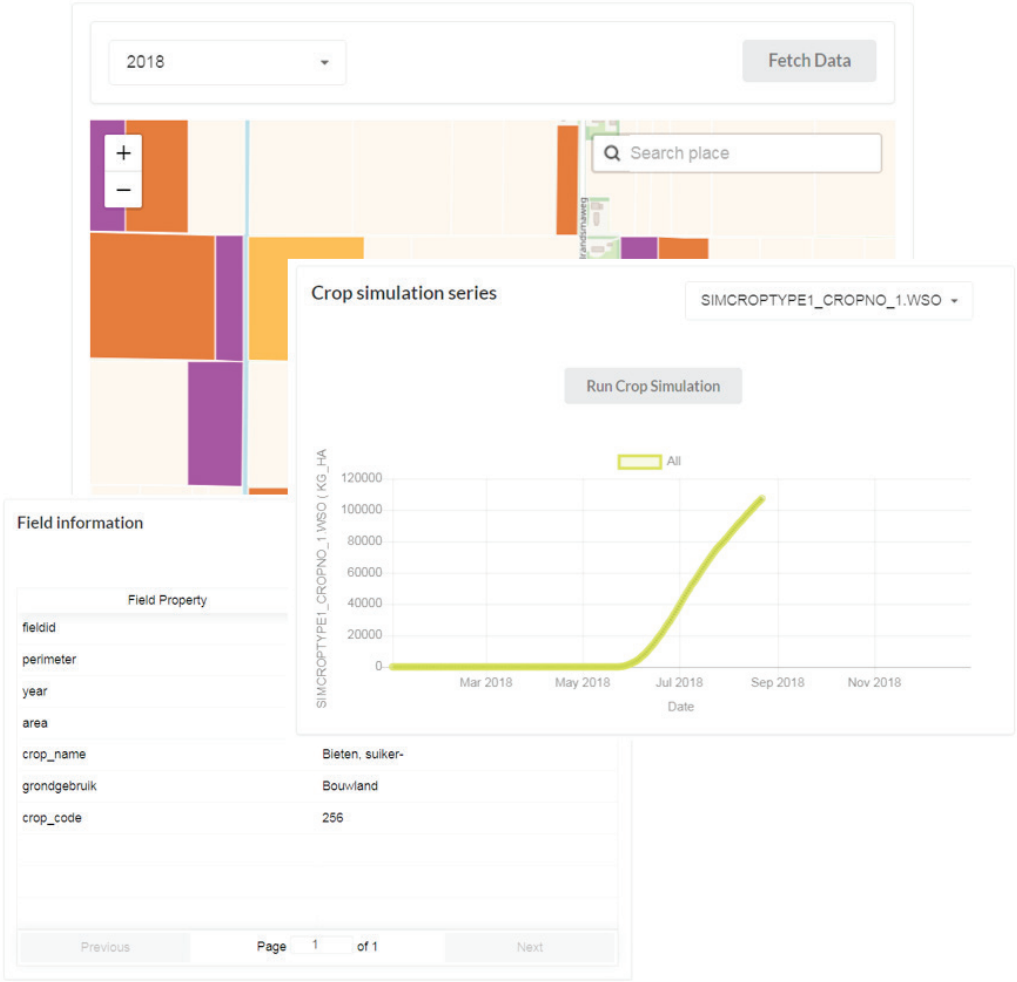

Keywords: Modelling frameworks, WOFOST-WISS, crop monitoring, crop production, virtual research environments.

References:

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S6-O.06

Future of permanent grasslands in Germany: implications for grassland management

Kamali Bahareh[1] (bahareh.kamali@zalf.de), Stella Tommaso[2], Berg-Mohnicke Michael[2], Nendel Claas[2]

[1] *ZALF-FPM, Leibniz Centre for Agricultural Landscap, Muncheberg, Germany*; [2] *ZALF(Leibniz.Agricultural Landscap), Muncheberg, Germany*

Introduction

Permanent grasslands, covering over 28% of the agricultural land area, are one of the most widespread vegetation types in Germany and significantly contribute to food security. Their dynamic ecosystem is complex due to high interactions among soil, water, and vegetation components. Simulating grassland productivity at large scale allow identifying the best trade-offs among mowing time, mowing frequency, and productivity of grasslands. Therefore, the objective of this paper is to develop and implement a generic model of grasslands across Germany. The power of the proposed model lies in capturing principle interactions among soil, water, and vegetation dynamics at national scale and simulating grassland productivity under future scenarios of climate change and different management systems.

Materials and Methods

The MONICA (model for nitrogen and carbon dynamics in agro-ecosystems) model was adapted for simulating permanent grasslands [1]. First, a sensitivity analysis was applied to select the most relevant parameters. Next, an uncertainty-based multi-objective calibration procedure was implemented to simultaneously optimize state variables. Two criteria judge the goodness-of-fit of the model. The *p-factor* represents the fraction of measured data bracketed by the 95% prediction uncertainty (95PPU) band and *r-factor* is the average width of the 95PPU band divided by the standard deviation of the measured variable [2]. The calibrated model was then extended to German-wide level at 1 km2 resolution (1999-2018) and the impact of two scenarios of climate change (RCP2.6 and RCP6.0) under different mowing frequency was investigated.

Results and Discussion

The results of model calibration based on the selected parameters with *R2* larger than 0.65 indicated the agreement between simulated and observed state variables. For both soil moisture and LAI, the *p-factors* with values above 0.60 show that over 60% of data were bracketed with the uncertainty band. The *r-factors* smaller than 1.2 were also found to be satisfactory (Figure 1). The map of grassland productivity captured spatial variability across Germany during historic period with higher inter-annual variability for future scenarios. We also that the productivity is highly correlated with annual precipitation regimes more than with temperature.

Conclusions

Our results highlighted the importance of multi-objective calibration for simulating inter-connected soil, water, and vegetation processes. The newly proposed algorithms contributed to a satisfactory simulation of grasslands. Simulations showed consistency under variety of environmental conditions. The developed model holds promise for studying the possible pathways to improve the quality and quantity of grasslands through assimilation of remote sensing data.

Acknowledgements

This work was supported by the Federal Ministry of Food and Agriculture (BMEL) of Germany.

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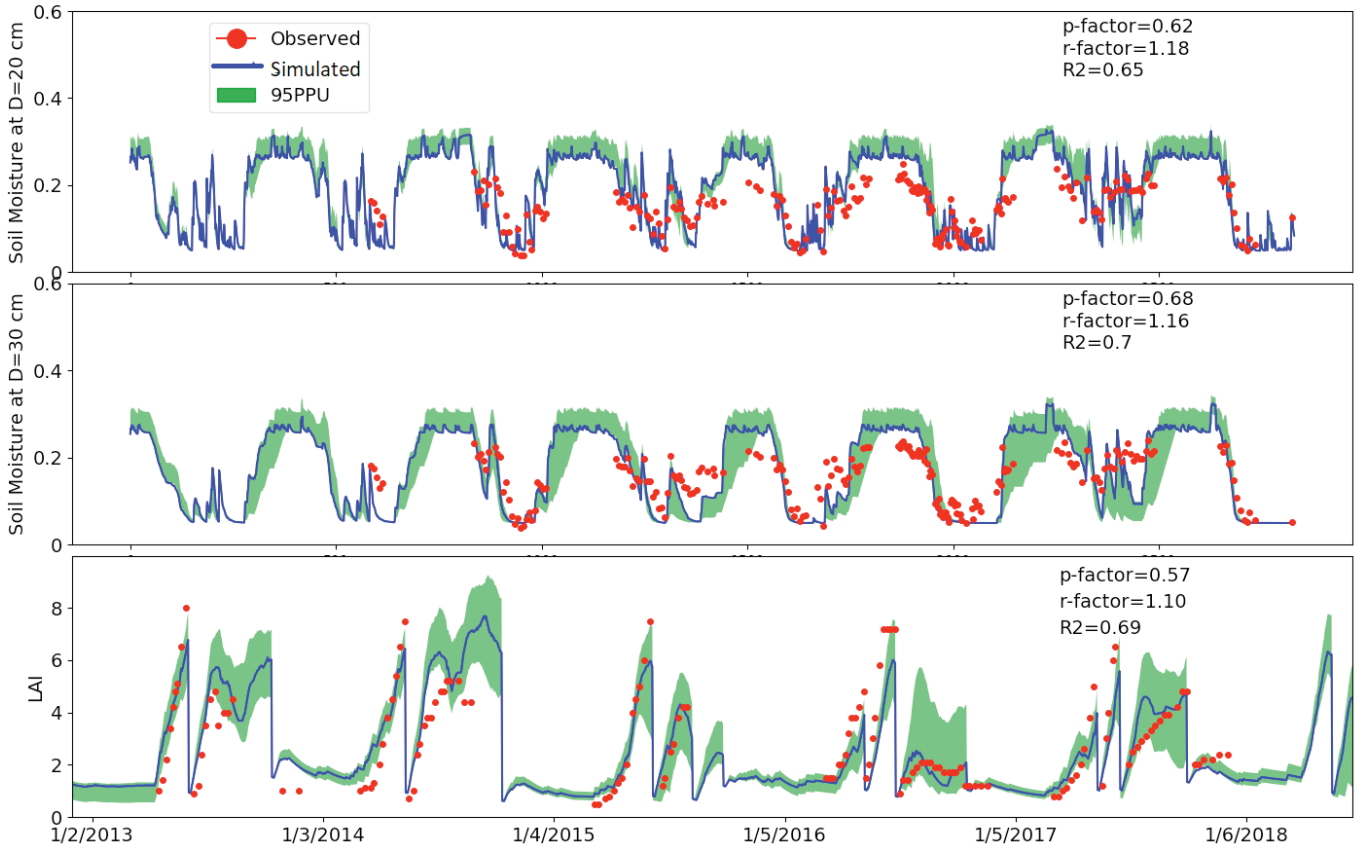

Figure 1. Comparison of the measured and simulated soil moisture and LAI in Braunschweig.

Keywords: Permanent grasslands, multi-objective calibration, large scale modelling.

References:

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S6-O.07

Reducing a model of sugar metabolism in peach fruit to explore genetic diversity

Kanso Hussein*[1] (hussein.kanso@inra.fr), Quilot-Turion Bénédicte[1], Memah Mohamed-Mahmoud[2], Bernard Olivier[3], Gouzé Jean-Luc[3], Baldazzi Valentina[3]

[1] *GAFL, INRA, Montfavet, France*; [2] *PSH, INRA, Avignon, France*; [3] *BIOCORE, INRIA, Sophia Antipolis, France*

Introduction

Nowadays, increasing efforts are made to select varieties that respond to a large panel of criteria, including abiotic and biotic stress tolerance, increased yield and quality of food products. Gene-to-phenotype models have been considered as the tools of the future since they can help to test the performance of new genotypes under different environment and management conditions. A kinetic model of sugar metabolism has been developed by Desnoues et al., 2018 to simulate the accumulation of different sugars during peach fruit development as a set of parametric ordinary differential equations. The model correctly accounts for annual variability and for the phenotypic variations observed in ten peach genotypes issued from an inter-specific population. Two major drawbacks of this model are the number of parameters to estimate and its integration time that can be costly due to non-linearities and time-dependent input functions. Together, these issues hamper the use of the model for the whole genetic progeny of 106 genotypes, for which few data are available (six data points or less per sugar). Several reduction and approximation approaches exist in literature, each one addressing a specific aspect of model complexity (Caribboni et al.,2007; Heinrich and Schuster, 1996). In this work, we present a model reduction scheme that combines different methods in several parallel steps. The purpose is i) to obtain a simplified model showing comparable predictions as the original model while reducing its calibration time and number of parameters. ii) to calibrate it for the genotypic progeny and develop an integrated genetic-kinetic model.

Methods

First, multivariate sensitivity analysis (Lamboni et al., 2009) was applied to identify those parameters having a significant influence on the outputs of the model, over the whole dynamics. Second, we operated three structural simplifications in terms of network and reactions rates to reduce the complexity of the model. Third, timescale-based approaches and quasi-steady-state approximation (López Zazueta et al., 2018) were applied to reduce the number of ODEs of the model. The quality of individual and combined reduction steps was systematically evaluated with respect to the original model according to three criteria of major importance for our application: the Akaike Information Criterium (AIC), the calibration time and the expected error over a population of virtual genotypes.

Results and Conclusions

Results from the reduction steps were combined into a final reduced model. This model has only 9 parameters to be estimated, linear flows, 9 ODEs and just one temporal enzymatic capacity, common to all genotypes. Comparison between the reduced and the original model showed an equivalent fit quality and confirmed a strong benefice for most genotypes. Results showed a satisfactory agreement between predictions and experimental data. Thanks to the reduced calibration time, the whole progeny of 106 genotypes 'could be' calibrated. The parameter values obtained were considered as quantitative genetic traits and used for a Quantitative Trait Loci analysis. Results from this analysis will be then used to define a genetic model to be incorporated in the reduced kinetic model. This opens the possibility of predicting sugar metabolism of genotypes carrying diverse combinations of alleles at the markers controlling the parameters.

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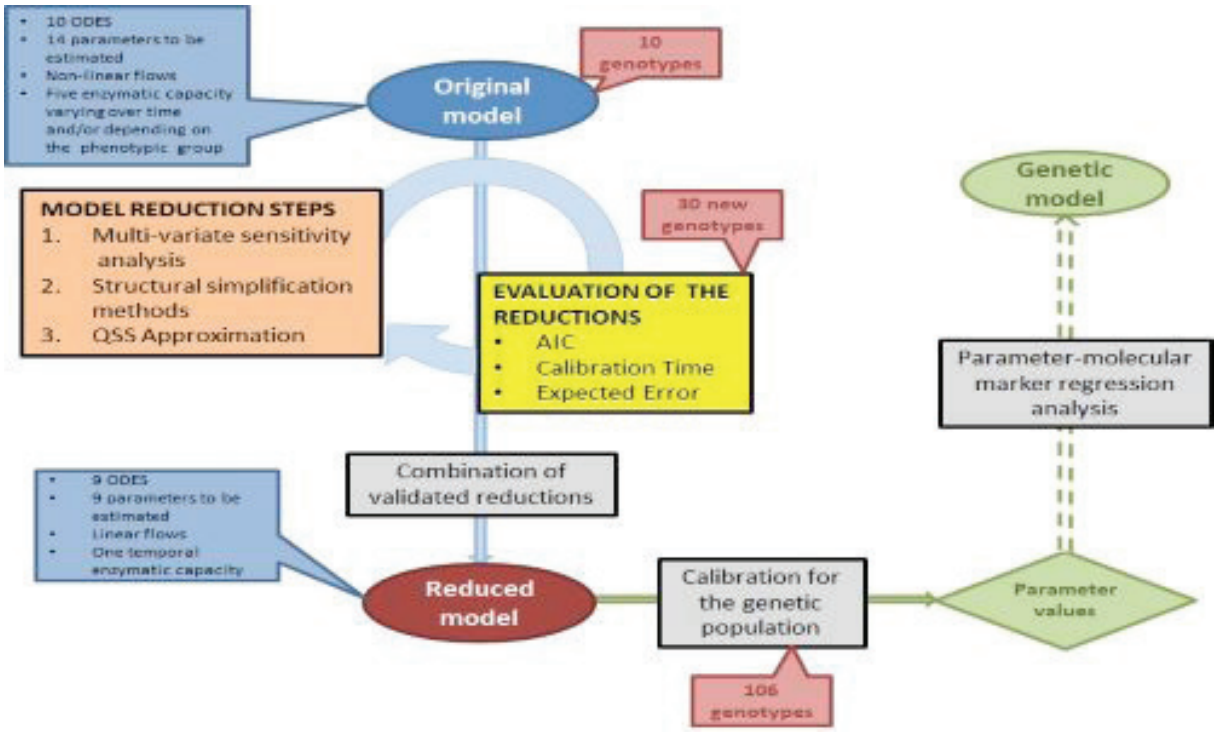

Graphical representation of the proposed strategy to calibrate 106 genotypes. Orange rectangle represents reduction methods. Yellow rectangle represents model evaluation steps by means of 3 criteria: AIC, calibration time and expected error. The specificity of the original and reduced models are indicated in blue rectangles. Green dashed line represents the perspective part

Keywords: kinetic model, model reduction, gene-to-phenotype, peach fruit, model calibration.

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S6-O.08

Genotype-specific parameterization of functional-structural models using smart technologies: rice and leaf architecture

Yang Yubin[1] (yyang@aesrg.tamu.edu), Paleari Livia[2], Wilson Lloyd T.[1], Invernizzi Mattia[2], Wang Jing[1], Confalonieri Roberto[2]

[1] *Texas A&M AgriLife Research Center, Beaumont, TX, United States*; [2] *Cassandra lab, ESP, University of Milan, Milan, Italy*

Introduction

The amount of solar radiation intercepted by the crop and the variation of light quality penetrated through the canopy are crucial factors impacting the photosynthetic efficiency and structure of the canopy (Truong et al., 2015). Functional-structural plant models explicitly reproducing the three-dimensional (3D) plant architecture have been developed to analyze light harvesting and conversion efficiency. However, their parameterization can be difficult, since it often relies on costly (e.g. LIDAR) or field-unsuitable technologies. The aim of this study was the development of a methodology to derive genotype-specific parameter sets for functional-structural plant models using cost-effective and easy-to-use technologies like smart-apps. As a case study, the focus was on leaf architecture in rice.

Materials and Methods

A field experiment (16 rice genotypes × two plant densities × three transplanting dates) was conducted in 2018 at the Texas A&M AgriLife Research Center in Beaumont (TX, USA). The experiment plots were kept weed-free and under optimal water and nutrient management regime. Data on leaf architecture were collected during the season using the smart-app PocketPlant3D (Confalonieri et al., 2017), which records leaf angles (°) with respect to the zenith and the azimuth every 200 milliseconds while the device is moved along the leaf laminas. Leaf length, nodal position, and appearance were also recorded. Leaf angles were converted into Cartesian coordinates using trigonometric functions, and genotype-specific parameters of a quadratic Bézier function were derived through optimization. Bézier functions are widely used in computer graphics to model smooth curves given their computational efficiency and versatility. To analyze error propagation from the angles of leaf segments to the canopy level, extinction coefficient for solar radiation was calculated according to Campbell (1986) using both measured and simulated leaf angles.

Results and Discussion

PocketPlant3D successfully captured the leaf blade shape at different nodal positions (Fig. 1a-c) and allowed deriving genotype-specific Bézier parameters (differences among genotypes significant in most cases). Cross validation showed good agreement between measured and simulated leaf shapes, with average RRMSE close to 15% and an average Nash-Sutcliffe Efficiency of 0.75. Good agreement was also found in terms of light extinction coefficient, with an R^2 value of 0.84 between values estimated from observed and simulated leaf shapes (Fig. 1d).

Conclusions

The proposed approach for the genotype-specific calibration of functional-structural plant models opens new opportunities for fully exploiting their potential to analyze canopy architecture and light harvesting, as well as for supporting breeding programs for related traits.

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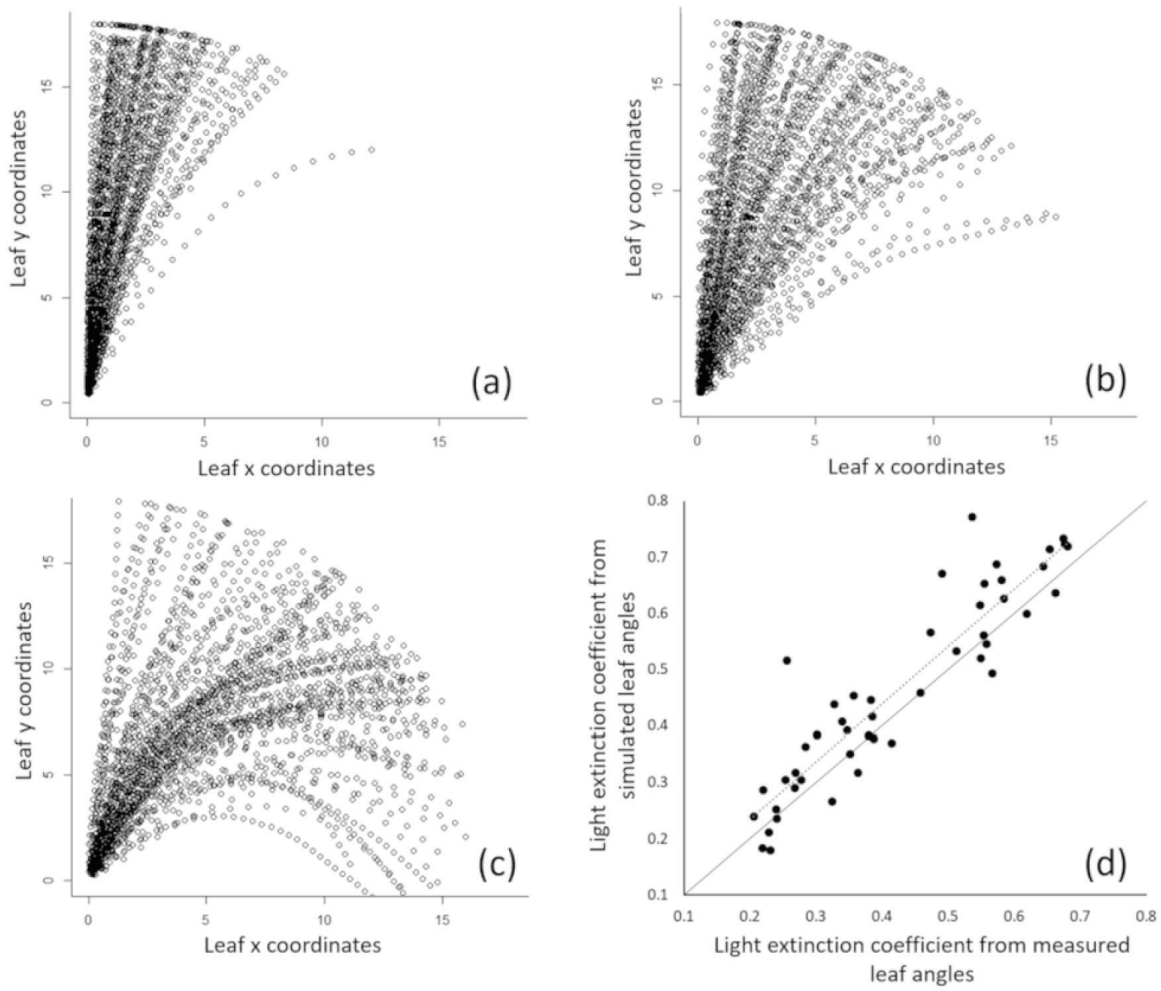

(a-c) Example of PocketPlant3D data for leaves at a different nodal position, from the top (a) to the bottom (c) of the culm. Leaf length is here kept constant to highlight leaf shape variation. (d) Agreement between light extinction coefficients estimated according to Campbell (1986) using measured and simulated leaf angles.

Keywords: Plant architecture, Bézier function, PocketPlant3D.

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S6-O.09

Bayesian sequential updating for crop yield prediction in soil-crop-atmosphere systems

Viswanathan Michelle[1] (michelle.viswanathan@uni-hohenheim.de), Weber Tobias K. D.[1], Gayler Sebastian[1], Mai Juliane[2], Streck Thilo[1]

[1] *University of Hohenheim, Stuttgart, Germany*; [2] *University of Waterloo, Waterloo, Canada*

The imminent risk of climate change impact on food security emphasises the need to improve yield predictions while taking socio-economic aspects into consideration. Crop yield is controlled by weather, soil properties, nutrient and water availability, cultivar specific traits and pests. With the development of soil-crop-atmosphere system models, the complex interactions between these variables are captured, facilitating the study of yield prediction. There is a rising trend in the use of digital farming solution tools with better on-field data gathering systems. These tools are expected to help farmers in making informed, cost efficient and sustainable field management decisions. However, before this can be established, model-data integration studies have to be carried out. With the help of observed data, inference about model parameters and process representations can be made, enabling better predictions of state variables. Bayesian methods provide a suitable framework for the sequential incorporation of observed time series data as prior information, while accounting for uncertainty in measurements, parameters and model structure. While Bayesian calibration has been applied in soil-crop-atmosphere models (Ceglar et al., 2011, Woehling et al., 2015), there have been limited applications of Bayesian sequential updating to analyse the progressive evolution of posterior distributions (Cao et al., 2016). In this study, the value of Bayesian sequential updating of crop model parameters is assessed for better yield predictions of the silage maize crop, grown in two climatically contrasting regions of southwest Germany.

The soil-crop-atmosphere system is modelled using the agro-ecosystem program package Expert-N 5. The SPASS crop model is used to simulate crop growth and development. Simulations are carried out for silage maize that was grown at six sites located within two regions in southwest Germany between 2009 and 2018. Meteorological conditions, soil moisture, soil mineral nitrogen, leaf area index, biomass, plant carbon and nitrogen content and crop phenological development were monitored and field management information was gathered at these sites. The observations from each year are sequentially incorporated starting with prior parameter distributions based on expert knowledge. The posterior parameter distributions are then used to make predictions for subsequent years. Simulated phenology, leaf area index, biomass and crop yield are compared with observations. Bayesian sequential updating is carried out using the R programming language and Monte Carlo methods are used to evaluate the posterior distribution.

Predictions from the initial few sequential updates are relatively poor when they are based on prior information from sites or years with different environmental conditions (Figure 1). The prediction is expected to be more accurate, perhaps at the cost of precision, as more data are incorporated from different sites and years. A possible improvement in precision could be achieved by accounting for these differences in environmental conditions and cultivars during the sequential updates.

The evolution of posterior parameter distributions over time and the quality of predictions from sequential updates highlight the key aspects to consider in selecting appropriate prior information. This is expected to facilitate better predictions, which can be implemented in digital farming solution tools.

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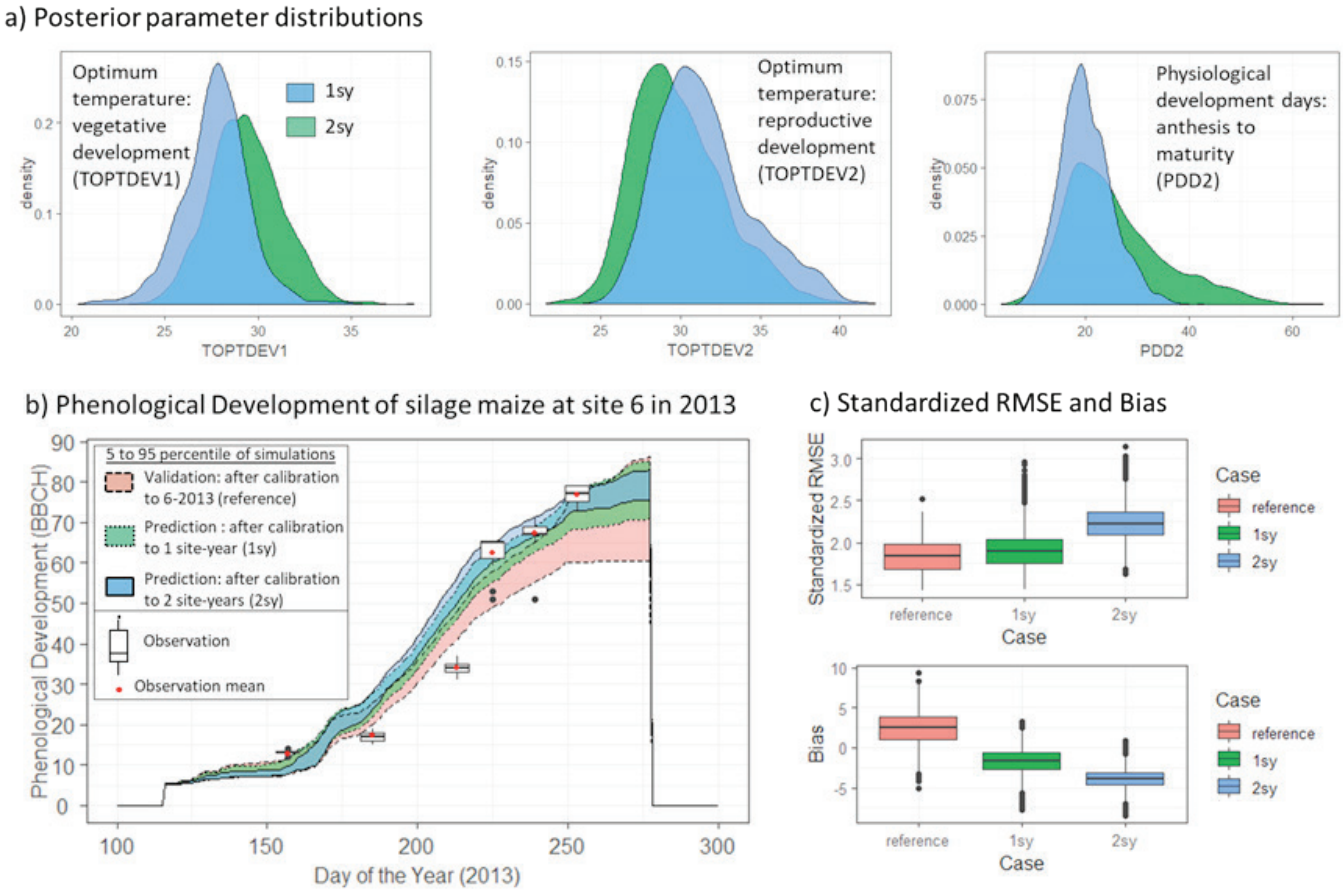

Figure 1: a) Posterior parameter distributions for 3 out of 9 parameters from the SPASS model used in Bayesian sequential updating. b) Comparison of predicted phenological development using two sequential update cases (1sy and 2sy), with the calibrated phenological development (reference) and observations from site 6 in 2013. c) Comparison of standardized RMSE (standardized to standard deviation of observed data) and bias between the calibrated reference case and two prediction cases for phenological development of silage maize at site 6 in 2013. (1sy: sequential update using data from one site-year 6-2010; 2sy: sequential update using data from two site-years, 6-2010 and 5-2011; reference: Bayesian calibration with site-year 6-2013).

Keywords: Bayesian calibration, maize, Expert-N, SPASS, Monte Carlo.

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S6-O.10

The AgMIP crop model calibration activity: documenting, evaluating, improving calibration techniques

Wallach Daniel[1] (daniel.wallach@inra.fr), Palosuo Taru[2], Seidel Sabine Julia[3], Thorburn Peter[4]

[1] *INRA, UMR AGIR, Castanet Tolosan, France*; [2] *Natural Resources Institute Finland, 00790 Helsinki, Finland*; [3] *Crop Science Group, INRES University of Bonn, Bonn, Germany*; [4] *Integrated Agricultural Systems Program, CSIRO Agriculture and Food, St Lucia, Australia*

Introduction

Crop modeling is important for projecting and understanding the trajectory of food production under global change. Crop model evaluation and improvement are essential to fully exploit the potential of crop models. Much of the emphasis to date has focused on crop model structure, i.e. the mathematical form of the equations that make up crop models. However, the values of the model parameters also determine the simulated values and therefore model performance. Thus crop model calibration, i.e. parameter estimation, has a major effect on the quality of simulated results. Despite its importance, calibration has received comparatively little attention in the modelling literature. This paper reports on the activities of the calibration activity within the Agricultural Model Intercomparison and Improvement Project. The overall goals of this activity are to 1) build a knowledge base as to the diversity of calibration practices, and to identify the major decisions required for calibration and the possible choices 2) to develop guidelines for calibration, with a view toward optimizing prediction accuracy and obtaining reliable information on parameter uncertainty 3) help modelers implement best practices, in particular by encouraging and aiding model developers to develop software tools consistent with those practices.

Material and Methods

The project is envisioned to have several phases. We started by implementing a broad survey of calibration practices by crop modelers (Seidel et al., 2018). Currently, we are comparing calibration performance of more than 20 modelling groups for crop phenology with datasets from France and Australia (Wallach et al., preprint). In these multi-model studies each modelling group applies their "usual" calibration strategy. The results of these studies will lead to the next phase where we define calibration guidelines for phenology and thereafter implement a multi-model study where each modelling group applies the suggested guidelines for calibration. These steps will then be repeated for the more complex problem of simulating crop growth and yield.

Results and Discussion

In the survey of the calibration approaches (phase 1), we received 211 responses to a web-based survey of calibration practices. The survey questions covered multiple methodological choices that must be made during a calibration exercise. Concerning data used for calibration, most respondents used field data, but regional data was also used. Almost all respondents used multiple data types, the most common being phenology and yield data. The median number of estimated parameters was 6, and often this number was only slightly smaller than the number of environments that provided the data. Most respondents fit the data in multiple stages, starting in most cases with phenology data. Many of the respondents searched for parameter values that minimized a sum of squared errors, while some groups used an *ad hoc* measure of goodness- of-fit and others adopted a Bayesian perspective. Nearly half the respondents simply used trial-and-error to search for the best-fit parameters. Slightly less than half the respondents obtained information on parameter uncertainty. The median time devoted to crop model calibration was 25 days, which emphasizes the need for efficient calibration tools.

In the study using each team's usual calibration technique on the French data set, overall the models provided quite good predictions of phenology (median of mean absolute error of 6.1 days) and did much better than simply using the average of observed values as predictor. It was found that goodness-of-fit to the calibration and evaluation data were significantly correlated, emphasizing the importance of a calibration procedure that gives a good fit to the calibration data.

Calibration was found to compensate to some extent for differences between models, specifically for differences in simulated time to emergence and differences in the choice of input variables. The different modelling groups using the same model structure had quite different calibration approaches, which led to quite different errors of fit to both the calibration and the evaluation data.

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Conclusions

The results of the studies completed to date clearly show the large diversity of calibration approaches and the importance of calibration. Thus, there is a clear and urgent need for guidelines and tools to aid with calibration. Arguably the most important and difficult choice for calibration is the choice of parameters (which and how many) to estimate. Other aspects of calibration that guidelines and tools should address include the form of the objective function, in particular the best way to use data representing multiple outputs (e.g. phenology and yield), the way to estimate uncertainty and algorithms and software for calibration. Development and application of such guidelines will simplify and improve crop modelling studies.

Keywords: model calibration, parameter estimation, phenology, prediction quality, wheat.

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S6-O.11

A new method for sensitivity analysis of models with dynamic and/or spatial outputs

Buis Samuel[1] (samuel.buis@inra.fr), Ruget Françoise[1], Lafolie François[1], Lamboni Matieyendou[2], Roux Sébastien[3]

[1] *EMMAH, INRA, Avignon, France*; [2] *Espace Dev, University of Guyane, Cayenne, French Guiana, France*; [3] *MISTEA, INRA, Montpellier, France*

Introduction

Global Sensitivity Analysis (GSA) is recognized as a powerful tool for measuring the impact of models inputs on simulated outputs under prescribed inputs' variability. Although many simulation models, among which crop models, produce temporal and/or spatial data, extracting relevant information from GSA of such outputs is still challenging. This requires the use of Multivariate Sensitivity Analysis methods (MSA) that are often based on a dimension reduction principle: model outputs are projected onto predefined or data-driven orthogonal bases such as polynomial or eigenvectors (Lamboni et al., 2011). They are however so far limited by the selection of the associated bases which is constrained by orthogonality requirements. Indeed, these bases do not always allow extracting relevant and interpretable information on structural properties of multivariate outputs. More applicable MSA methods are thus expected to be developed (Wei et al., 2015). In this work, we propose a new MSA method combining GSA and clustering.

Cluster-based GSA

Clustering methods have been designed to identify groups of similar objects in multivariate data sets. They may thus be particularly adapted to capture the variability of behaviors of models' temporal and/or spatial outputs. However, while binary clustering has been extensively used in scalar sensitivity analysis to assess the importance of factors leading to a region of interest (Raguet and Marrel, 2018), there is still a lack of quantitative sensitivity analysis methods taking benefit of a clustering of multivariate outputs with any number of clusters.

The main idea of the proposed method is to apply clustering to model outputs simulated on a numerical design-of-experiment generated using a given GSA method, and to compute standard GSA indices (e.g. Sobol' indices) not on the models outputs but on new variables indicating the membership of each output to the different clusters (see Fig. 1). We propose to use a fuzzy clustering method: the new variables are thus the so-called membership functions (MF, valued in [0, 1]) that quantify the degree of membership of any model simulated output to each cluster. The computation of sensitivity indices on either the MF or MF differences allows discussing which parameters influence the membership to a given cluster or drive the output from one cluster to another. A generalized sensitivity index (Lamboni et al, 2011) is also introduced to quantify the overall contribution of the parameters wrt any change of clusters.

Applications

The method has been applied using Sobol' and FAST GSA methods to:

(i) a dedicated toy model producing temporal signals with one or two maxima in response to five parameters,

(ii) the Cantis model (Garnier et al., 2003) simulating the transformations of carbon and nitrogen in soils (10 parameters varying),

(iii) the Stics crop model (Coucheney et al. 2015), on the Multi-Model Ideotyping Agmip 2019 exercise (27 parameters varying).

Results have shown that the model behaviors can be efficiently reported by the newly proposed method.

Conclusions

The proposed method is particularly adapted to models with dynamic and/or spatial outputs that produce distinguishable sets of responses, i.e. when clustering of these outputs lead to well separated and interpretable clusters. In this case, it is particularly powerful for identifying the model inputs that drive these different behaviors. The method is generic wrt clustering and GSA method used.

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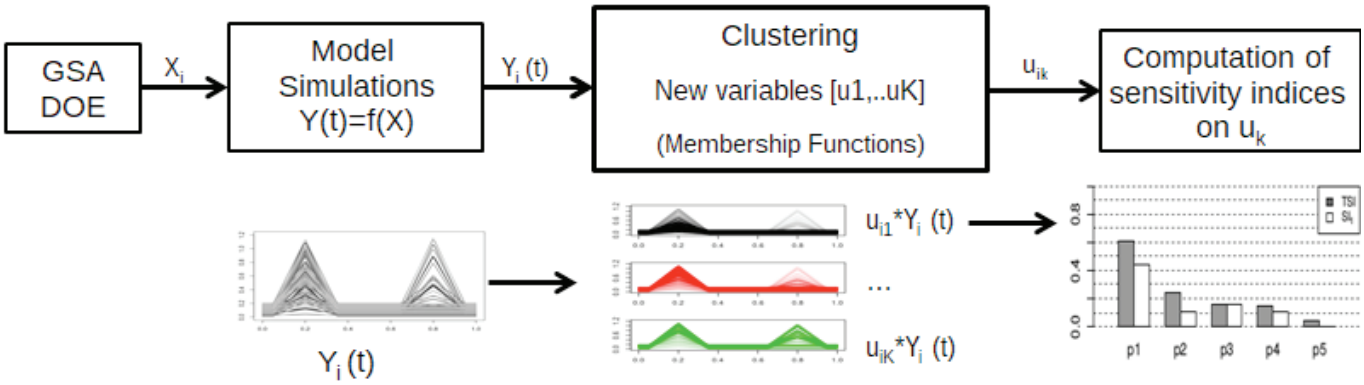

Figure 1. Workflow of the Cluster-based GSA. X represents the vector of model inputs that vary in the sensitivity analysis, Y(t) the (temporal in this case) output simulated by the model. K is the number of clusters, i the index in the Design-Of-Experiment.

Keywords: Global Sensitivity Analysis, multivariate outputs, Multivariate Sensitivity Analysis, Generalized Sensitivity Indices.

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ABSTRACTS POSTERS

SESSION I

IMPROVEMENT OF CROP MODELS

S1-P.01

Modelling Memory: do crop models need to become nostalgic?

Magno Lethicia[1] (lethicia.magno-massuia-dealmeida@unicaen.fr), Mollier Alain[2], Couceiro Miguel[3], Avice Jean-Christophe[1], Brunel-Muguet Sophie[1]

[1] *UMR 950 EVA, Normandie Univ, UNICAEN, INRA, Caen, France*; [2] *ISPA, Bordeaux Science Agro, INRA, Villenave d'Ornon, France*; [3] *LORIA, CNRS, INRIA, Univ. Lorraine, Vandoeuvre-lès-Nancy, France*

Background

Increased frequency of stress events such as heat waves has been observed for the last decades. Based on the last IPCC report, they are expected to be more frequent, to last longer and to increase in intensity during the reproductive phase of economically important crops. Many recent studies pointed out induced memory effects of stressing events when plants are challenged several times with similar stresses throughout the crop season. These memory effects were shown to be potentially beneficial since the plants are 'primed' and thus more prepared to develop an earlier, more rapid, intense and/or sensitive response when the stress recurs [1]. Therefore, the new climatic patterns prompts to take into account stress memory into predictive crop modelling approaches so as to estimate the effects of repeated stresses and their consequences on crop yield, quality of harvested products. During the last decades**,** the use of crop models have been enlarged to climate change driven predictions [2]. While evidence for improving crop climate models and especially the temperature response functions in order to reduce uncertainty in yield simulations before any decision making in agriculture, no modelling studies have attempted to decipher and interpret simulation bias in the light of stress memory nor they focused on methodologies to take into account stress memory effects.

Aims

The objectives of the work is to (i) identify thermo-priming patterns that can explain alleviated crop responses to extreme stress events and (ii) better predict crop performances i.e. yield and grain/fruit quality criteria in this climatic context characterized by higher frequency of heat waves. We make the assumption that the effects of several successive stress events do not equal the sum of the effects of each events thus leading to unexpected crop responses to repeated stresses.

Materials and Methods

In this study we will use the ecophysiological model SuMoToRI to develop distinct approaches to take into account the memory effects of heat stress. This model was implemented in oilseed rape and used under a range of climatic scenario and management practices [3]. Although deleterious effects of high temperature on growth, yield and grain quality were observed [4], evidence for beneficial effects of repeated stresses throughout the spring period on protein content, acquisition tolerance to desiccation and seedling vigour were also observed (unpublished results).

Therefore, based on these prior experiments and newly acquired datasets, we will develop two distinct modelling approaches to identify and formalize thermo-priming patterns actions on crop performances: (i) a **mechanistic approach** aiming to define physiological responses rules to temperature sequences and (ii) a **statistical approach** based on Knowledge Discovery in Databases (KDD) which is the process of discovering knowledge from implicit information provided by datasets. In this method, prior hypotheses are excluded so as to explore without a priori assumptions. This data mining technique can be performed by either models emergence (e.g. classifiers, multiple linear models, neural network) or patterns extraction which describe relationships between the given variables [5].

Conclusion

This study aims at demonstrating the need to model the effects of stress memory especially with the new features of climate change so as to better predict crop performances. It will act as a proof of concept that crop models can be modified with efficient approaches whether they are mechanistic or statistics-oriented. The analysis of the memory of high temperature stresses could be extended to other stresses which are expected to be more frequent by the end of the century.

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Acknowledgements
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Keywords: heat waves, crop model, stress memory, clmate change, priming.

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S1-P.02

Crop growth models for tropical perennials: current advances and remaining challenges

Rozendaal Danaë M.A.[1] (danae.rozendaal@wur.nl), Slingerland Maja[1], Zuidema Pieter A.[2], Giller Ken E.[1], Anten Niels P.R.[3]

[1] *Plant Production Systems Group, Wageningen University and Research, Wageningen, Netherlands*; [2] *Forest Ecology and Forest Management, Wageningen University and Research, Wageningen, Netherlands*; [3] *Centre for Crop Systems Analysis, Wageningen University and Research, Wageningen, Netherlands*

Introduction

Production of major global commodities like cacao, coffee, and palm oil largely depends on smallholder farmers that have little access to inputs. Yields lag far behind from what is theoretically possible, and climate change is expected to strongly influence future production. The perennial nature of these crops implies that initial decisions on cropping system design will determine crop yields over decades. Crop growth models for perennials are much-needed to design sustainable, climate-smart production systems, because long-term empirical data on the physiology, growth and yield of perennials are scarce. Compared to annual crops, model building for perennials faces specific challenges. Perennials develop over multiple years, thus effects of climate, and management practices like fertilizer application, can have long-lasting effects on growth and yield (van Vliet and Giller 2017; Woittiez et al. 2017). Effects of specific management practices, like pruning, have also to be taken into account.
We are developing and updating process-based models for cacao and oil palm to improve yield projections. We will discuss ongoing model development and general challenges associated with building crop models for perennials, and we will provide an outlook to future model development.

Materials and Methods

Physiological crop growth models for cacao (CASE2; Zuidema et al., 2005) and oil palm (PALMSIM; Hoffman et al., 2014) were constructed, and further development of these models is ongoing. In both models, crop growth is modelled as a function of solar radiation, and both potential and water-limited yields can be simulated. Soil nutrient availability is assumed to not limit growth. For cacao, the perennial growth form is incorporated based on a feedback mechanism between biomass investment and loss. Rules of biomass gain and loss are based on allometric relationships between total tree biomass and biomass investment in parts of the tree (leaves, stems and branches, roots and fruits; Zuidema et al., 2005). For oil palm, a realistic plant structure is maintained in the model by including root mortality as a function of root biomass and an age-specific maximum leaf (frond) biomass controlled by pruning (Hoffmann et al., 2014).

Results and Discussion

Model validation indicated that CASE2 and PALMSIM perform well, thus these models offer potential for estimating yield gaps over large geographic areas, projecting influences of climate change on yield, and tailoring cropping system design to current and future climatic conditions. We will show current advances on the incorporation of effects of increasing CO_2 on crop yield, which may buffer negative effects of increasing temperature on future yield (Verhage et al., 2017).
We will also show results of new model parameterization and validation. Remaining challenges are (1) the validation of long-term output of the models, because long-term, high quality yield data are scarce; (2) the incorporation of soil nutrient effects; (3) accounting for long-term, temporal variation in flowering and fruiting phenology; and (4) the incorporation of effects of pruning (for cacao) on crop growth and yield.

Conclusions

Physiological models for tropical perennials are essential tools to evaluate the effects of climate change and management on yields. Yet, further model development on global change responses (CO_2 fertilization, drought) and management practices (nutrient effects and pruning) are needed.

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Keywords: Physiological models, cacao, oil palm, climate change.

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S1-P.06

Phenology of grasslands: a new model

Rouet Simon[1] (simon.rouet@inrae.fr), Leclercq Denis[2], Bernicot Marie-Hélène[2], Combes Didier[1], Barillot Romain[1], Durand Jean-Louis[1]

[1] *INRA, Lusignan, France*; [2] *GEVES, Lusignan, France*

Introduction

Understanding the phenology of grasses is crucial for grasslands management as it strongly affects the quantity and quality of the biomass. The floral transition (FT) of the apex is induced by the exposition to specific conditions of temperature and photoperiod. Under non-inductive climatic conditions, the apex is vegetative and continually produces leaves. After exposure to cold temperature and long photoperiod, the meristem completes its floral induction and starts floral development. Heading date (HD) constitutes a main marker of the reproductive development. Determinants of the HD identified are the advancement of floral induction, the final number of leaves and the development of the leaves and the spike. The aim of the present work is to present a model of FT for perennial grasses driven by environmental conditions. The HD is simulated from the phyllochrone and organ size, given by a functional-structural model of ryegrass. Model behaviour is assessed using a dataset of HD.

Material and Methods

The model of FT is based on an obligatory dual induction where the second phase follows the first one without any overlapping (Heide, 1994). Primary induction is achieved by a function of low temperature accumulation adapted from Sirius-wheat (He et al., 2012). Secondary induction is achieved after a given number of days with a minimum daylength. During the secondary induction phase, we assumed the plastochrone to decrease (leaves are initiated at a higher rate). When the secondary induction is completed, the apex produces spikelets instead of leaves. Until the start of the flag leaf growth, spikelet production stops. The model of FT is coupled with the L-grass structural-functional plant model (Verdenal, 2009) that describes leaf growth for ryegrass based on a self-regulation approach of architecture development. The growth of internodes and spike was implemented in the model based on coordination rules. After appearance of all leaves, the HD is then achieved when the cumulated length of the spike and the peduncle exceeds the length of the flag leaf sheath.
Calibration and validation of the model are realised with the HD of perennial ryegrass cultivars in seven sites in France over seventeen years.

Result and Discussion

Fig.1 presents intermediary demonstrative results of our model functioning. Finally, it provides the HD of the tiller. The model allows a dynamic calculation of the final leaf number in relation to environment. It shows the great importance of the climatic windows of tiller development on the final number. The tiller appears before the cold period (1st Oct.) produces more leaves than later tillers, mainly due to its longer vegetative period. Tillers appeared during the cold period (1st Dec. and 1st Feb.) reach their FT later than the previous one because of the need to complete primary induction. For these two cases, convergence of the final number of leaves can be explain by higher temperature between the two inductions for the tiller appeared on the 1st February. The tiller produced after the cold period (1st Apr.) produces an indefinite number of leaves due to the deficit of low temperature to complete primary induction.
This new model combined with a model of tillering and tiller mortality will help to study grassland dynamics (seed yields, perenniality).

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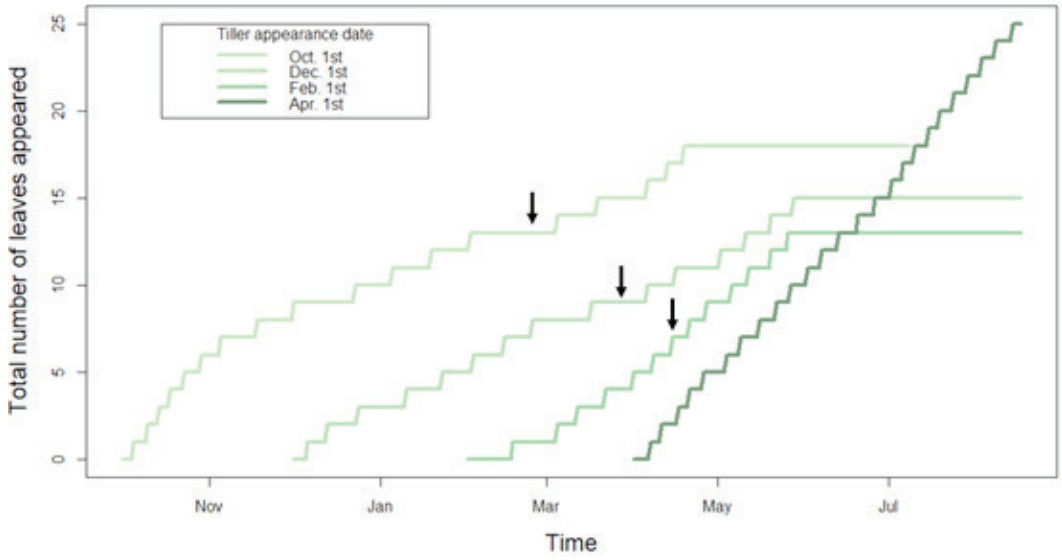

Figure 1. Simulated cumulated leaf on a tiller in relation to climate depending tiller appearance date. Arrows indicates dates of FT. Climatic data correspond to the year 2017-2018 in Lusignan, France.

Keywords: heading date, flowering, ryegrass, leaf number.

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S1-P.07

Modelling the transpiration of single maize plants using an explicit xylem flux model

Heinlein Florian (florian.heinlein@helmholtz-muenchen.de), Duan Xiaohong, Priesack Eckart

Institute of Biochemical Plant Pathology, Helmholtz Zentrum München, Neuherberg, Germany

Introduction

Climate change will increase extreme weather events like heavy rain or drought periods. This will have an impact on crop yields. Most traditional crop growth models are based on daily time steps (Heinlein et al., 2017), and thus may not adequately simulate the impact of drought conditions on crop growth. Therefore, new mechanistic models, which consider plant-internal water transport, are developed. Until now this new modelling approach has been successfully applied to simulate the water flux in trees (Bittner et al., 2012; Hentschel et al., 2013; Janott et al., 2010), but crops as for example maize have rarely been considered so far.

Materials and Methods

The following measurements have been conducted at the research farm Scheyern in the North of Munich: (i) sap flow (Heat-Ratio-Method), (ii) stem diameters (dendrometer) and (iii) plant architectures (derived from terrestrial laser scans), each of four maize plants, as well as (iv) latent heat flux (eddy covariance). A xylem flux model for trees (Janott et al., 2010) has been integrated into the modular model system Expert-N 5.0. This xylem flux model has been adapted to simulate water flow in single maize plants by using plant-specific parameters and by calculating a specific leaf area distribution (Heinlein, 2017). The model system provides simulations of soil water content, sap flow, transpiration, latent heat flux, and stem diameters as a function of plant water contents.

Results and Discussions

High daily maxima of measured sap flow rates and latent heat flux as well as large diurnal amplitudes of stem diameter change can be linked to high daily maxima of radiation and temperature and to low values of relative humidity. Soil water contents are well simulated, but some deviations between model and measurements occur due to preferential flow.

The simulated plant water potentials (Fig. 1) show higher negative values in the roots, and lower negative values at the plants' top and at the leaf tips. The statistics demonstrate good agreements between simulated and measured sap flow. The daily amplitudes of stem diameters could just be simulated with shortcomings due to the beginning of senescence. The daily maxima of the latent heat flux were often underestimated by the model, but simulations and measurements show good overall agreement (good model efficiency).

Conclusions

The xylem flux model can be applied to simulate water transport in maize plants. The model is able to simulate water uptake and transpiration in a mechanistic way (long-distance water flow within the plant). Thus, it has the potential to better describe impacts of extreme weather events on crop growth, but further testing is still needed. Since the xylem flux model is able to relate sap flow, latent heat flux and stem diameters, the model could also be used to better plan and control irrigation.

Acknowledgedments

This work was carried out in the framework of the DFG Research Unit FOR 1695 "Agricultural Landscapes under Global Climate Change – Processes and Feedbacks on a Regional Scale" as well as in the frameworks of BonaRes-SIGNAL "Sustainable intensification of agriculture through agroforestry" and the Client II project FarmImpact "Development of Sustainable Water and Energy Solutions for Farms in South Africa", both funded by the German Federal Ministry of Education and Research.

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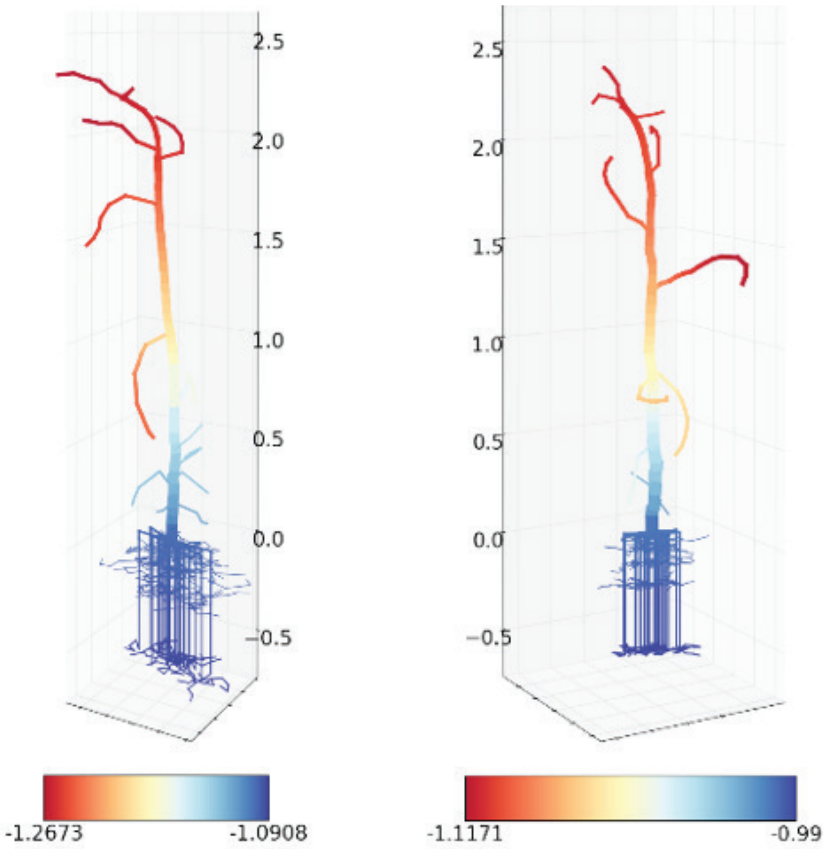

Figure 1. Laser scanned maize plants with simulated xylem water potential [MPa] at 15 July 2015 12:00.

Keywords: sap flow, eddy covariance, dendrometer, water flux.

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S1-P.08

Root descriptions of crop simulation models - do they serve studies of climate-smart agriculture?

Korhonen Panu[1] (panu.korhonen@luke.fi), Palosuo Taru[2]

[1] *Natural Resources Institute Finland, Kuopio, Finland*; [2] *Natural Resources Institute Finland, Helsinki, Finland*

Introduction

Climate-Smart Agriculture (CSA) is increasingly framing the studies that apply crop simulation models (CSMs). This approach that combines sustainable intensification of production, climate change adaptation and mitigation places new demands on the use of models and the processes and variables they describe. CSA-related model applications require both reliable estimates of crop responses to changing growing conditions and accurate estimates of rising number of variables and processes with variable management options. For example, soil carbon balances are increasingly important to be able to assess the CO_2 sequestration potential of agricultural soils. CSMs should thus cover carbon, water and nutrient cycles and their interconnections with sufficient accuracy.

Plant root growth and other root-related processes are in many ways central elements in CSMs. Roots take care of crop water and nutrient uptake and rhizodeposition is considered the main source of stabilised carbon input to soil. Due to the obvious challenges in observing roots and related below-ground processes, our knowledge on how they respond to environment and management is still very limited compared to what is known about the responses of above-ground biomass. It is important to identify and acknowledge the key limitations in the root descriptions, how they affect the reliability of CSM results in CSA studies and what are the most efficient ways to improve them.

Material and Methods

We reviewed altogether more than 30 CSMs and model versions for the approaches they apply for describing the root systems of crops and factors affecting them. Models ranged from detailed, site-specific agroecosystem models to large area vegetation models. The scientific papers describing the models, user manuals and other technical model documents were used as a primary source of information. Models were reviewed for the variables and factors affecting root growth, root mortality, rooting depth, assumptions on root density distributions, possible root exudates and root quality parameters.

Results and Discussion

Our results showed a wide range of approaches for root descriptions which varied from very simple assumptions to detailed descriptions of root 3d-architectures.

Root biomass is calculated as an explicit model variable in most of the CSMs. Root biomass growth is linked to the development of the above-ground biomass with crop or cultivar specific allocation factors that depend on the crop phenological state. In few models only the biomass allocation to roots responses to changes in temperature, soil water content or nutrient status. Root mortality descriptions were overall very rough and were mainly linked to crop phenology. Direct impacts of crop or soil management on root biomass were implemented only in a couple of models. Root exudates as a flow of carbon from plants to soil were explicitly considered in only one of the models.

Rooting depth is an important determinant of plant's access to water and nutrient reservoirs available in the soil profile. The maximum depth reached by root system was the most common factor used to describe roots in the models. It is in nearly all cases linked to accumulated temperature sums. In some models, low soil temperature hinders the root depth progression. Root depth development was also impacted by drought stress or excess of water in some models, but the responses were sometimes contradictory. Soil nutrient status affected the root depth progression directly only in couple of the models. Soil physical limitations for root penetrations is considered in nearly all of the models either with a soil-specific maximum rooting depth or with layer-specific factors describing physical conditions for root growth. Root distribution over the soil profile in the models was in most cases assumed exponential, linear or sigmoidal. There was in some models link from root biomass to root length, but in many models these two aspects were not explicitly linked.

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Increasing demands for accurate root descriptions are coming particularly from the need to find effective means for climate change mitigation and biodiversity conservation. For example, more diverse cropping systems including grasslands with high plant diversity and intercropping with species that have different rooting patterns will bring new demands to cover essential root processes effectively. In addition, covering the impacts of extreme weather events, such as droughts and heavy rains, on crop production will require more detailed descriptions of the responses of root growth processes to them.

Enhanced knowledge on roots and processes affecting their development is necessary for effectively and robustly supporting the development of solutions for CSA. New development in methods for studying roots, such as root-image analyses and DNA-based root quantification methods from small soil samples, may provide useful data also for model development in near future.

Keywords: root responses, process descriptions, model improvements, rhizodeposition, below-ground biomass.

S1-P.09

Modeling phenological responses of table grape cultivars

Rafique Rizwan[1] (rizwanrafiqueao@gmail.com), Ahmad Touqeer[2], Abbasi Nadeem[2], Ahmed Mukhtar[3]

[1] *Horticulture Department, Horticulture Department PMAS-AAUR, Rawalpindi, Pakistan, Pakistan*; [2] *Horticulture Department PMAS-AAUR, Rawalpindi, Pakistan*; [3] *Department of Agronomy PMAS-AAUR, Rawalpindi, Pakistan*

Introduction

Bud burst, blooming, berry set, verasion and harvest are the key phenological stages of grapevine and identification of these stages is of great economic value to enhance productivity by forecasting the effects of seasonal variations and timely vintage management. Crop modeling is a reliable and robust approach in assessing phenology, crop growth and yield. Chakwal and Rawalpindi/Islamabad districts are emerging as new clusters for commercial viticulture in Pothwar region of Pakistan where key phenological stages and physiological responses need to be identified. Therefore, the present study is designed to evaluate the pheno-physiological responses of table grape cultivars; Kings Ruby, Sugraone, Perlette, and NARC Black at Chakwal and Islamabad using Growing Degree Days (GDD) and STICS dynamic crop models.

Materials and Methods

Phenological obseravtions were made at two locations i.e. Islamabad (Sub-humid) and Chakwal (Semi-arid) with varying pedo-climatic conditions (see figure) in pothwar region in four table grape cultivars; Kings Ruby, Perlette, NARC Black Sugra One. Nine vines of uniform vigor trained on vertical positioning system (I Trellis system) with age 4-6 years were selected for recording observations. Phenology and growth data were recorded on weekly basis but at some stages such as bud burst, blooming and berry set frequent observations were made at both locations, some times even same day for better phenology projection. Initial soil conditions were determined and on site weather data collected while missing data were obtained fropm Pakistan Metrological Department.

Results and Discussion

The results show that there exists wide variability in the phenological timing of table grape cultivars. All the phenological stages i.e. bud burst, 5 leaf stage, start of bloom, full bloom, verasion and harvest reached earlier in Chakwal in comparison with Islamabad. Perlette and NARC Black have more variation in their timing of verasion and maturity at both locations. Full bloom stage was attained earlier in cv. NARC Black as it took 21 and 24 days, while cv. Sugra One took 38 and 41 days to attain this stage at Chakwal and Islamabad respectively. Days to reach maturity from bud burst were more in cv. Sugra One as it took 112 and 118 days at Chakwal and Islamabad respectively.
It is obvious that phenology is driven by temperature and phenological stages reach earlier in Chakwal with 1°C -1.5°C higher temperture than islamabad where phenological stages arrive later due to less heat unit accumulation. Bud burst is 3-4 days earlier while flowering is 6-7 days earlier in semi-arid conditions of Chakwal. Varietial heat requirements to switch to next phenophase also vary at different phenological satges.

Conclusion

There exist a variation of phenological responses due to tempereature fluctuations at both expermental vineyards. Varieties also have differences in phenological timings due to varaition in heat unit requiements of different cultivars. The findings of the present research are useful in developing a grapevine phenological model for eco-friendly, resilient and precision viticulture in this emerging region by predicting key phenological events.

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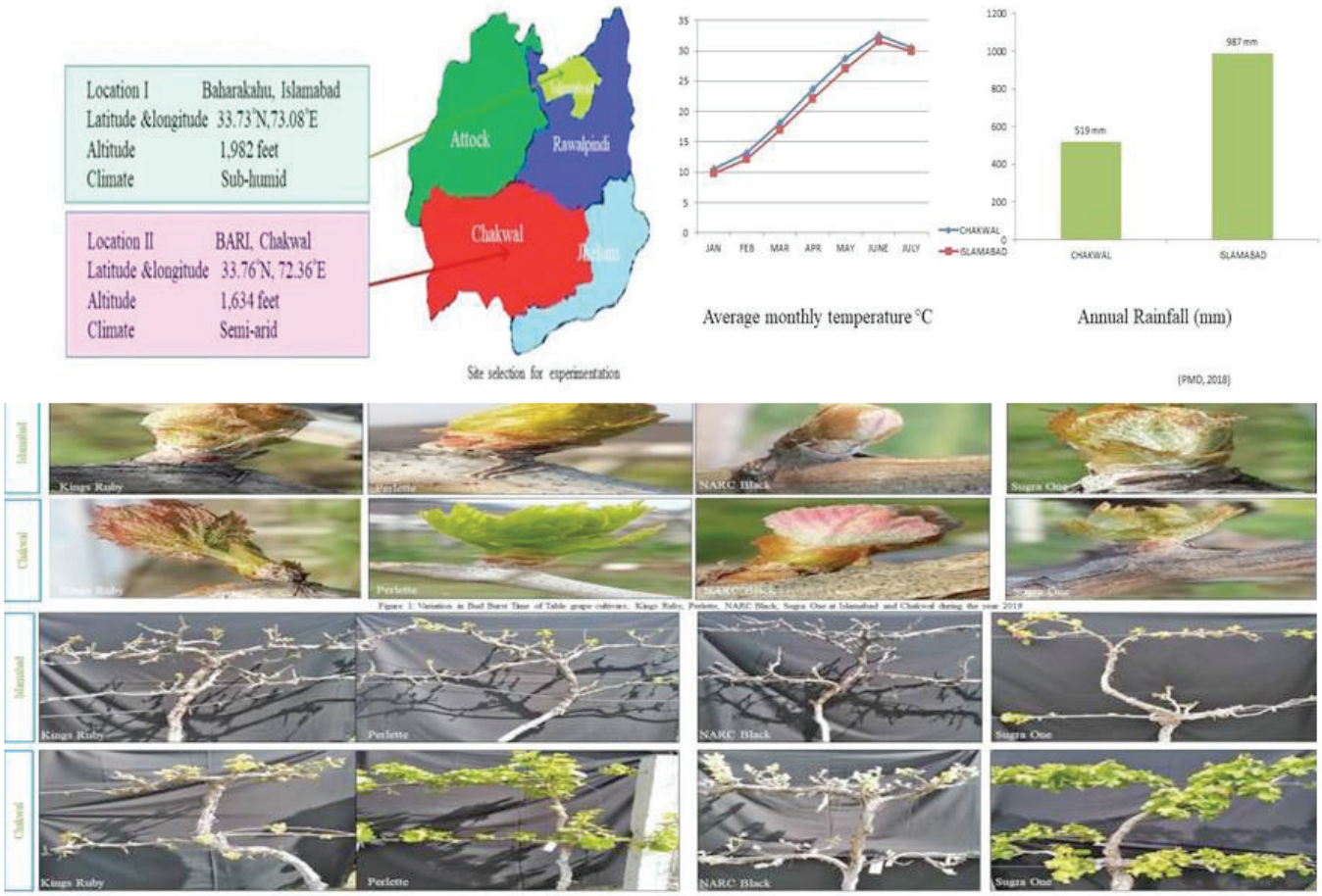

Figure: Vineyard locations, Variation in climatic conditions and phenological differences among varieties at both locations.

Keywords: Modeling, phenology, viticulture, GDD, Pothwar region.

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S1-P.10

Developing a mechanistic foliar stage model adapted to wheat diseases decision tools

Andrianasolo Fety[1] (f.andrianasolo@arvalis.fr), Deswarte Jean-Charles[2], Jorant Amaury[1]

[1] *Arvalis Institut du Végétal, Boigneville, France*; [2] *Arvalis Institut du Végétal, Villiers-le-Bâcle, France*

Introduction

Phenological stages are widely used in crop models as starting points for most processes based on leaf, biomass and yield growth. In soft wheat in particular, the appearance of the last leaf on the main shoot is a mandatory stage for crop protection strategy, since this stage alone, contributes to up to half of the carbon allocated to the grain. We propose to build a mechanistic model for simulating flag leaf appearance stage (FLAS) in soft wheat, consisting in three main steps ; (1) estimation of floral transition stage, that we assumed to be the stage corresponding to the moment when primordia are determined as future spikelets or leaves ; (2) computation of a dynamic phylochron along crop cycle, based on photoperiod and thermal time scales ; and (3) calculation of all leaf stages from pre-formed primordia to the last leaf to appear (FLAS).

Materials and Methods

This model was constructed using agronomic trials data, located in 53 sites in France and more than 20 years of experiments (+ 200 varieties), for floral transition stage, final leaf number and FLAS calibration and evaluation ; another database composed of regular leaf counts (Villiers-le-Bâcle, 2005 to 2016, France) was used for phylochron optimization. Cross-validation per year was carried out on both datasets, and indicators of error of prediction (RMSEP) and model efficiency (EF) were computed.

Results and Discussion

Results showed that the global error of the model was 5.9 days (EF = 0.6) (Figure 1). Adjusted mean value of phylochron was lower than those found in literature (90 versus 100 to 130 degrees-days per leaf respectively). There was likely a compensation phenomenon between overestimated floral transition date and underestimated final leaf number (compared to literature) ; nonetheless, these could neither be measured nor evaluated in the data we used. We discuss the potential of our approach compared to other existing leaf stage models in the context of crop protection and system decision tool usage.

Conclusions

Our newly phylochron-based soft wheat model provided similar predictive performance as compared to existing models, and could be further enriched with nitrogen and water stress effects for optimizing crop protection decisions.

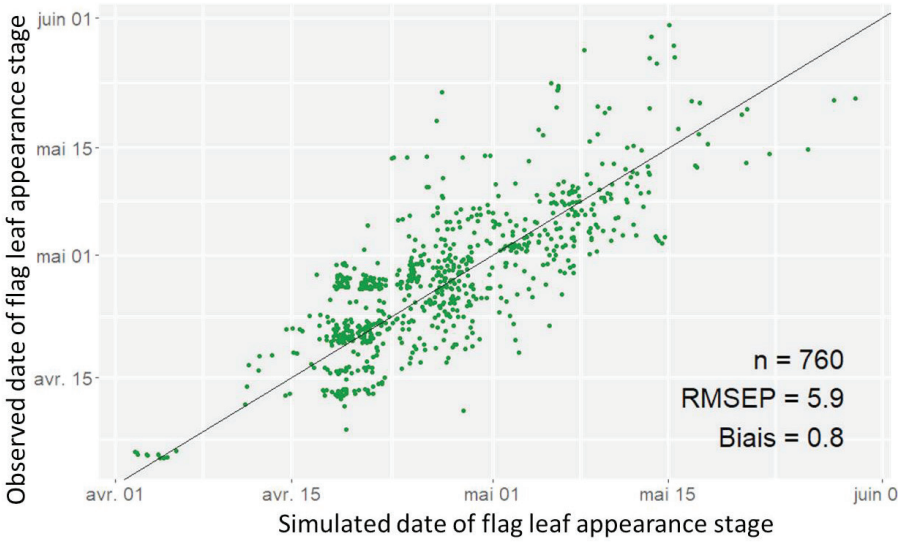

Figure 1. Comparison of observed and simulated dates of flag leaf appearance stage (FLAS) in soft wheat

Keywords: floral transition, phylochron, photoperiod, final leaf number, soft wheat.

S1-P.11

Predicting wheat yield and protein content at the plot scale with machine-learning and mechanistic models

Andrianasolo Fety*[1] (f.andrianasolo@arvalis.fr), Deswarte Jean-Charles[2], Garcia Cécile[2]

[1] *Arvalis Institut du Végétal, Boigneville, France*; [2] *Arvalis Institut du Végétal, Villiers-le-Bâcle, France*

Introduction

Providing the earliest reliable model predictions of crop production is of a major interest since it allows to optimize crop management and strategic positioning in the market. For wheat in particular, the recurrence of drought episodes due to climate change and variability challenges crop models on their ability to take into account genotype x environment effects at the plot scale.

Materials and Methods

Three yield component-based models were proposed to predict the grain number, grain weight and protein content respectively, for soft and durum wheat. These models were calibrated on historical database of field experiments conducted at plot scale (from 1996 to 2016), on more than 50 varieties and 40 sites in France. Models simulating grain number and protein content took into account varietal effects, agro-climatic indicators (e.g water stress and photothermal quotient around heading) and variables describing canopy state (nitrogen nutrition index, aboveground biomass) by the use of random forest methods. Grain weight model corresponded to a logistic curve describing the needs in temperatures (degree-days) of each variety, modulated by daily temperature, radiation and water stress effects during grain filling. Models were calibrated using indicators such as model efficiency, bias, and relative root mean squared error (RRMSE).

Results and Discussion

The models calibration results are illustrated in Figure 1. They were further evaluated on an independant dataset with very promising performances (relative error of 15% and 8%) for yield and proteins, respectively. Models highlighted differential varietal response to water stress between soft and durum wheat. These models will be soon deployed as part of a decision support tool, which combines the use of a dynamic crop model (CHN model) and LAI sensor data used to readjust model predictions during the campaign.

Conclusions

Based on this study, the combination of machine learning and mechanistic models appears to be a promising way for simulating wheat yield and protein at plot scale.

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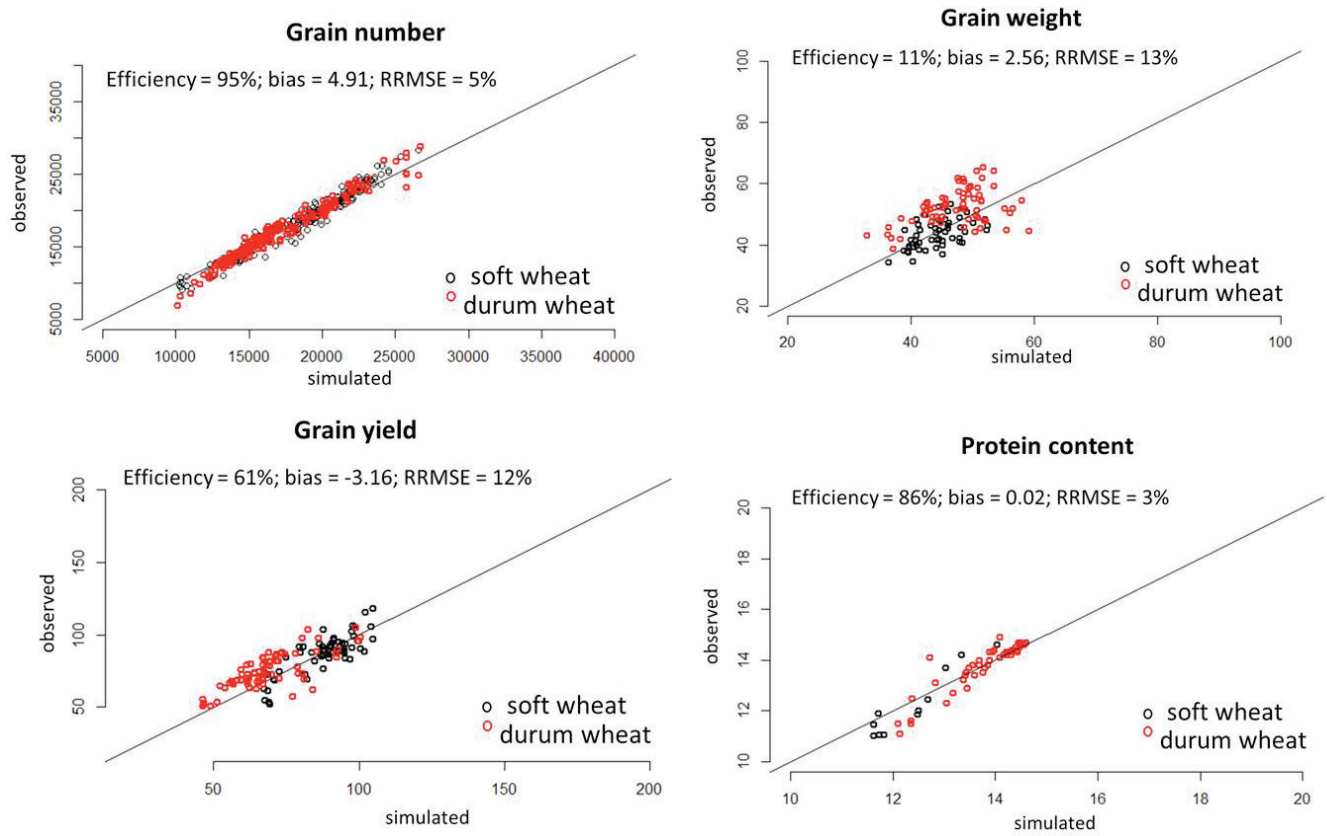

Figure 1. Results of wheat yield components model calibration (Grain number, grain weight, yield and protein content at harvest).

Keywords: wheat yield, random forest, logistic, water deficit, CHN crop model.

S1-P.12

New modelling methodology for improving crop model performance under stress conditions

Droutsas Ioannis[1] (eegdr@leeds.ac.uk), Challinor Andy[1], Arnold Steve[1], Swiderski Mikolaj[1], Semenov Mikhail[2], Mikkelsen Teis N.[3], Hansen Emilie[4]

[1] *School of Earth and Environment, University of Leeds, Leeds, United Kingdom*; [2] *Rothamsted Research, Harpenden, United Kingdom*; [3] *Department of Environmental Engineering, Technical University of Denmark, Lyngby, Denmark*; [4] *Department of People and Technology, Roskilde University, Roskilde, Denmark*

Introduction

Crop models exhibit large uncertainty in the quantification of risks imposed to food production by climate change (Asseng et al., 2013). A significant step towards reducing this uncertainty is to improve model structure (Tao et al., 2018). Here, we present a new modelling methodology for improving crop model structure based on simultaneous solution of model equations. The new technique is called SEMAC (Simultaneous Equation Modelling for Annual Crops) and is implemented into the GLAM crop model, resulting in a new model version GLAM-Parti (i.e. GLAM Partitioning). The new model has improved structure, it gives a better connection between the model processes and leads to higher internal consistency. The model skill is significantly increased when tested under different stress environments (i.e. water and ozone stress).

Materials and Methods

SEMAC develops a system of simultaneous equations which accounts for all above-ground crop growth and development processes. It uses allometric relationships to connect the masses of all plant compartments, which allows the expression of above-ground biomass as function of leaf mass. SLA and daily biomass growth are set as function of LAI. This forms a system of equations with equal unknown variables which is solved simultaneously to return the values of all unknown variables. A detailed description of SEMAC as well as its incorporation into the GLAM crop model is given in Droutsas et al., 2019. Here, SEMAC is tested for its ability to capture stress due to water and ozone in turn.

Results and Discussion

GLAM and GLAM-Parti were tested for wheat under various levels of water stress and GLAM-Parti exhibited higher skill in all experiments. The total RMSE of GLAM-Parti was reduced by 45% for grain yield in comparison with GLAM (Fig. 1A). We tested the relative contributions of the simultaneous equation system and the model improvements and found that the model which had both (i.e. GLAM-Parti) improved upon the same model with sequential solution methodology (i.e. GLAM-Partiseq). The model calibration (i.e. GLAM-Partiseq-cal) can only partially but not fully compensate for the inconsistencies of the sequential method. In addition, ozone stress was tested under CEMAC using a new parameterisation for wheat, including the acclimation mechanism under chronic exposure to the pollutant. The model successfully reproduced the observed yield reduction under variable duration of exposure to ozone (Fig 1B).

Conclusion

SEMAC is a new modelling technique for the simulation of crop growth and development. Applying the methodology into a crop model overcomes structural limitations. The step-by-step way of solving the model equations is replaced by simultaneous solution. This provides higher internal model consistency and increases the model skill. In this study, GLAM-Parti improved upon GLAM in the simulation of wheat growth and yield in all levels of water stress. The model was also successfully tested for the effect of ozone on wheat yield. SEMAC could be applied in other crop models to see if similar improvements in skill result.

Acknowledgements

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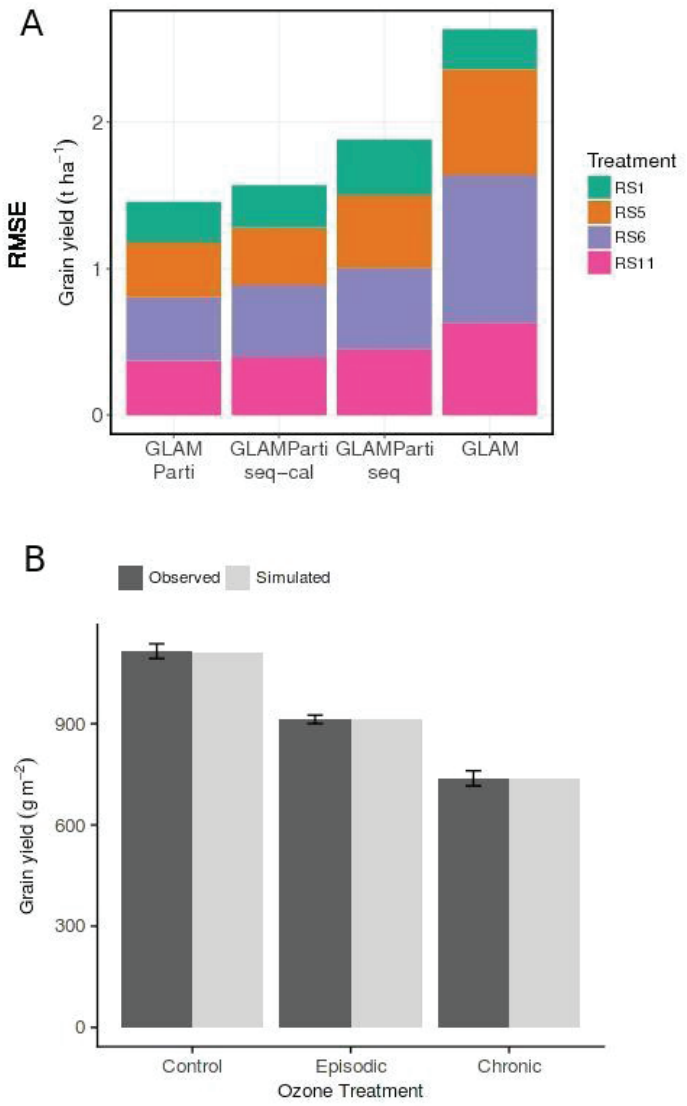

Fig. 1. A) Root mean square error (RMSE) between modelled and observed grain yield in the different water treatments: Control treatment (RS1), early drought treatment (RS5), late drought treatment (RS6), full drought treatment (RS11). Figure was extracted from Droutsas et al. 2019. B) Observed (wheat variety KWS Bittern) and simulated grain yield at harvest in Control, Chronic and Episodic O3 treatment. Error bars are standard errors of means in the observations.

Keywords: SEMAC, GLAM-Parti, Model improvement, Water stress, Ozone.

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S1-P.13

Analysis and modeling (STICS / L-egume) of crop growth under shading conditions in Agri-PV context

Edouard Sylvain[1] (sy.edouard@gmail.com), Van Iseghem Mike[2], Combes Didier[3]

[1] *Lab les renardières, EDF / INRA, Écuelles, France*; [2] *Lab les renardières, EDF, Écuelles, France*; [3] *URP3F, INRA, Lusignan, France*

Introduction

The Agri-PV concept refers to the combination of both agricultural and electrical productions on the same area. The presence of photovoltaic panels above a crop implies sharing of sunlight. The panels create shading on the crop and thus reduce the light available for plants. Previous studies has already been done to evaluate this association. The results are conclusive but optimization still needs to be done. It is essential to define strategies in order to determine the optimum orientation of the PV modules that are favourable for crop growth. First, a modelling approach is done in order to understand the interaction between the plant and the irradiation. Indeed, in order to adapt plant growth models, it is necessary to define new formalisms.

Context

This work is supported by the quite new installation of a demonstrator on the EDF Lab les Renardières site (Seine-et-Marne, 60 km south of Paris). It consists of a structure equipped with photovoltaic panels located 4.5m above the ground on a surface area of 3000 m², half of which is in the control zone. In addition, the panels are located on trackers that allow them to be oriented along two axes of rotation. This demonstrator will serve as an experimental support to test the hypotheses put forward.

Our study based on three models

The study seeks to estimate electricity and agricultural production in this context and for different crops. The aim is to optimize these two types of production. To do this, the simulations are based on three models:
- L-egume is an individual based model on fodder crops. This model simulates the dynamics of grassland communities but accurately computes the interception of radiation by the plant. This model will thus be used to understand the changes observed experimentally in shade situations.
- The second model used is the STICS crop model. It is widely used and can simulate a large number of crops. This more simplified model of radiation interception will allow optimization between the power generation and the crop production.
- Both crop growing models are coupled with a ray-tracing model (PVarray) that allows to determine the irradiation on top and below the PV panels at any time during the whole year.
The way the input variables are couples with the modelling bricks is shown in the illustration below (Figure 1). From the irradiation below the panels, the local microclimate is calculated, which allows to predict crop growth.

Future investigation of the study

In the rest of the work, the objective is to calibrate and adapt the model by conducting experiments on different crops in the Agri-PV context. To do this, it will be essential to take into account the interception of radiation at the height of the vegetation cover in the presence of the panels and their inclinations. Infraday dynamics will also be studied to determine a photosynthesis threshold to control shading. From an operational point of view, the interest will be to provide the most efficient panel orientation algorithm for the association.

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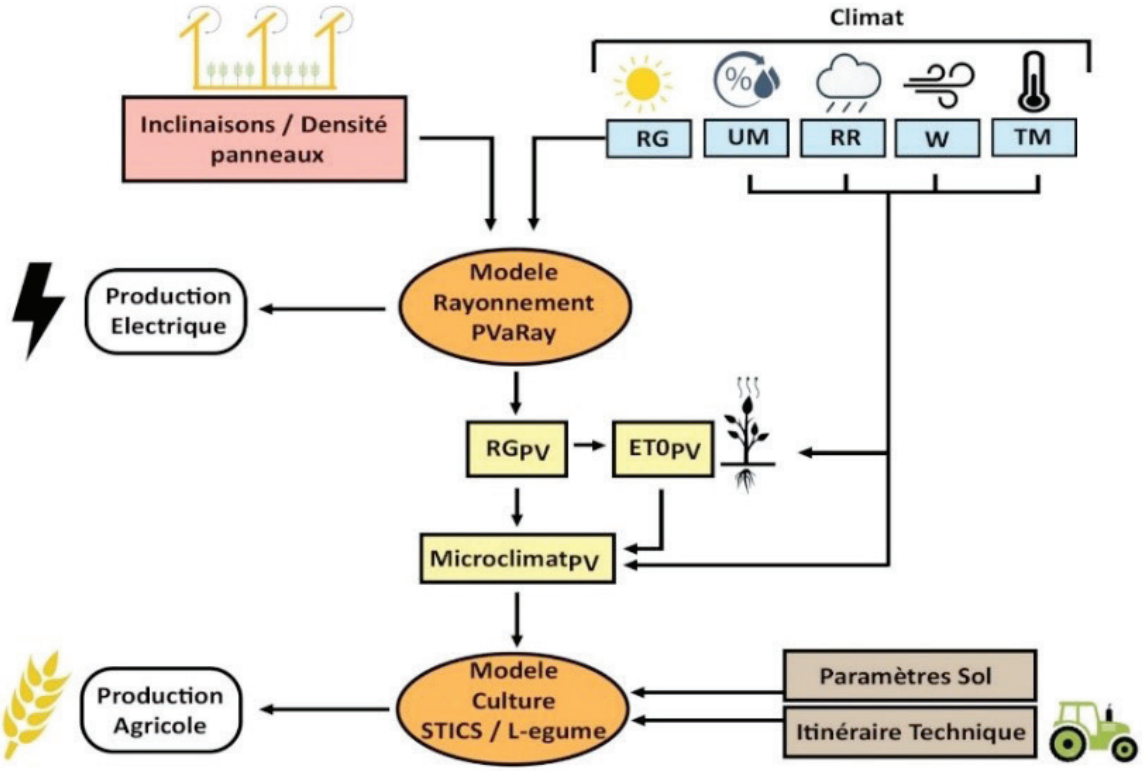

Agri-PV simulation block diagram.

Keywords: agrivoltaic, shade, modelling, crop.

References:

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S1-P.14

Assimilating leaf area index into a simple crop model to predict soybean yield and maximum root depth at field scale

Gaso Deborah[1] (deborah.gasomelgar@wur.nl), Berger Andres[2], Kooistra Lammert[1], de Wit Allard[3]

[1] *Laboratory of Geo-Information Science, Wageningen University, Wageningen, Wageningen, the Netherlands*; [2] *La Estanzuela, Instituto Nacional de Investigación Agro, Colonia, Colonia, Uruguay*; [3] *Wageningen Environmental Research, Wageningen University, Wageningen, Wageningen, the Netherlands*

Introduction

Yield forecasting has been extensively tackled by the use of crop growth models, however its implementation at field scale still faces numerous constrains due to the lack of input data required and uncertainties in parameter value. Current accessibility of remote sensing data with global coverage and free access offers a great opportunity to enhance crop model predictions throughout retrieval biophysical parameters to link with model, such as leaf are index (LAI). Among methods available to assimilate LAI into the model, calibration has been successfully applied for wheat (Gaso, et al., 2019). Therefore, the aim of this study was to predict spatial variability of soybean grain yield and maximum root depth (RDmax) at field scale by assimilating temporal series of Sentinel-2.

Materials and Methods

Study area and field data

The study area was located in southern part of Uruguay during 2017-2018 growing season. A field was planted with soybean in early December and harvested in May. Flowering and maturity dates are required by the model as input parameters but this information is not available for the site. Therefore this information was derived from official variety trails at a nearby location (INIA-INASE Trials). Weather data was downloaded from the closest meteorological weather station. Yield was measured using standard yield monitor mounted on harvesting machines.

Crop growth model inversion

The model described by Campbell and Diaz, (1988) was implemented in Python language. This model is based on soil water budget and biomass is calculated through the link between carbon assimilation and water transpiration. A total of 20 parameters are included in the model.

Time series of LAI derived from Sentinel 2 was used to estimate the parameters driving the model through the optimization of the predicted vs observed LAI. The estimation of maximum root depth (RDmax) was optimized by the use of inversion method of LAI curves. In a following step, forward running was executed using parameter values assigned through the optimization process for the whole growing season, including grain filling.

Results and Discussion

Rainfed soybean system performance is determined by water availability and WHC plays a crucial role on water supply for rainfed crops. Through the approach of inverting model, a value for RDmax was obtained for each pixel and yield prediction was enhanced by means of adjusting RDmax. Calibrated values for RDmax have agronomic meaning and their values were between the expected range for this property, but it is not feasible to validate these values with field data. The rooting depth is a property hard to measure because, there is no sharp value for this feature, and root presence is not necessarily related to root activity in water extraction which makes validation even more complex. After the calibration procedure, yield predictions were successfully achieved (Figure 1). Although predicted yield by the model presented a wider range than observed yield, spatial distribution of the observed yield was accordingly with the distribution of estimated yield (RMSE= 507 kg ha-1).

Conclusion

Spatial variability of grain yield could be accurately predicted by means of using the methodology proposed. Valuable results were obtained from the calibration procedure of RDmax. Parameter values of RDmax provided useful information to improve field characterization and detect limitations for summer crop production.

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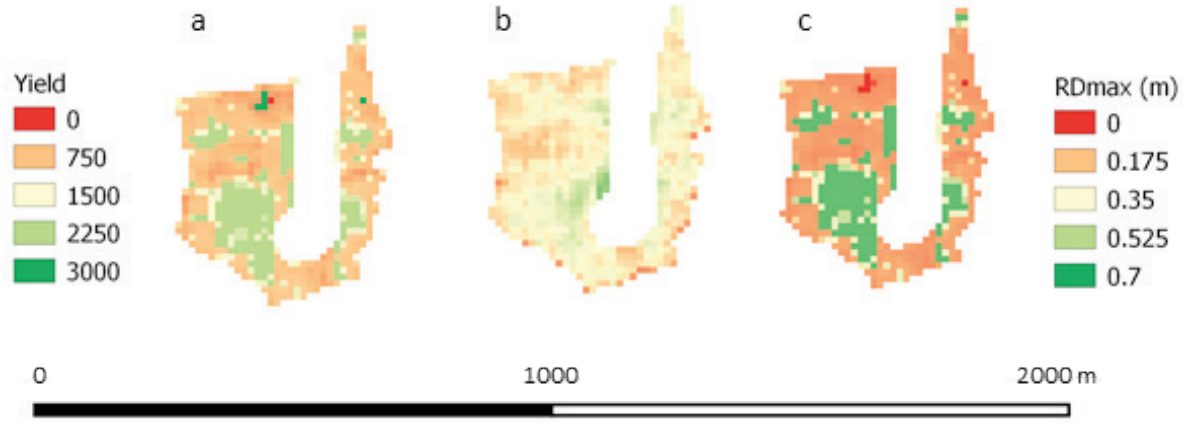

Figure 1. Spatial distribution of yield (kg ha-1) for the field study: (a) predicted yield, (b) observed yield and (c) calibrated value for RDmax (m).

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S1-P.15

What can crop modelers learn from machine learning models about corn, sorghum and soybean?

Kemanian Armen[1] (kxa15@psu.edu), Hoffman Alexis[2], Chris Forest[2]

[1] *Plant Science, The Pennsylvania State University, University Park, PA, US*; [2] *Meteorology, The Pennsylvania State University, University Park, PA, US*

Background

An ingenious statistical analysis by Schlenker and Roberts (2009) of the county-level grain yield of cotton, corn and soybean in response to climate showed that these non-controlled experiments contain valuable and somewhat hidden information. Critically, these authors identified a temperature range over which grain yields increase (≈10 to 29°C for corn for corn) after which grain yields decrease sharply. Analogous analyses have been presented by Lobell et al. (2014) and Hoffman et al. (2017).

Our goal was to apply machine learning (ML) tools to data panels like those used by Schlenker and Roberts (2009) to reveal the relationship between grain yield and climate variables for specific phases of the crop cycle. We analyzed the rainfed yield of corn, sorghum and soybean in response to climate in the US using Random Forest (RF), a non-parametric machine learning (ML) tool (Breiman, 2001). Unlike other ML tools, RF allows gleaning the functional form between predicted and predictor variables.

Methods

For the period 1980-2016, we extracted county-level yield for corn, sorghum and soybean (≈30,000, 18,000 and 27,000 records, respectively) from the USDA-NASS database for 1631 US Great Plains counties. This data was paired with the 4-km resolution grid from MetData (Abatzoglou, 2011). We computed climate predictors (temperature = T, solar radiation = SR, precipitation = PP, vapor pressure deficit = D) for three growth phases and for the entire crop cycle for each species. The crop phases were establishment, critical window pre-post flowering and grain filling. Planting dates were based on temperature and varied by year and county. Each crop yield was modeled using RF with year and all climate variables in each phase and in the growing season as predictors.

Results and Discussion

The RF models captured 86%, 71% and 81% of the variance in yield for corn, sorghum, and soybean. The yield dependence on time was linear (90 kg ha-1 y-1 for corn and 29 kg ha-1 y-1 for sorghum and soybean). T, PP and D related to yield; the magnitude and thresholds varied by crop. Minimum T affected yield positively roughly until 19°C but decreased quickly below 14°C for sorghum. Maximum T thresholds after which yield decreased were ≈29, 32 and 29 for corn, sorghum and soybean. The cumulative precipitation levels that maximized yield were 628, 420 and 494 mm; corn was responsive to cumulative precipitation than to precipitation in any given phase, while sorghum and soybean responded mostly to precipitation in the grain filling phase. All crops responded negatively to the D, but the most striking response was that of corn, whose yield decreased sharply as the D increased during flowering. This response was likely independent of soil moisture as precipitation already accounted for the water supply.

Conclusion

This analysis provides a benchmark against which process-based models can be compared: were we to create yield x climate panels based on simulation models for the same region, the results of an RF analysis should be similar to those presented here. The RF allowed identifying critical T and D threshold that can guide research in this area. The sharp response to D of corn during grain filling and the positive response of sorghum to minimum T increases as well as a higher tolerance to high T provide clear food for thought for modelers. It remains to be seen if ML can provide information on expected production outputs in a changing climate.

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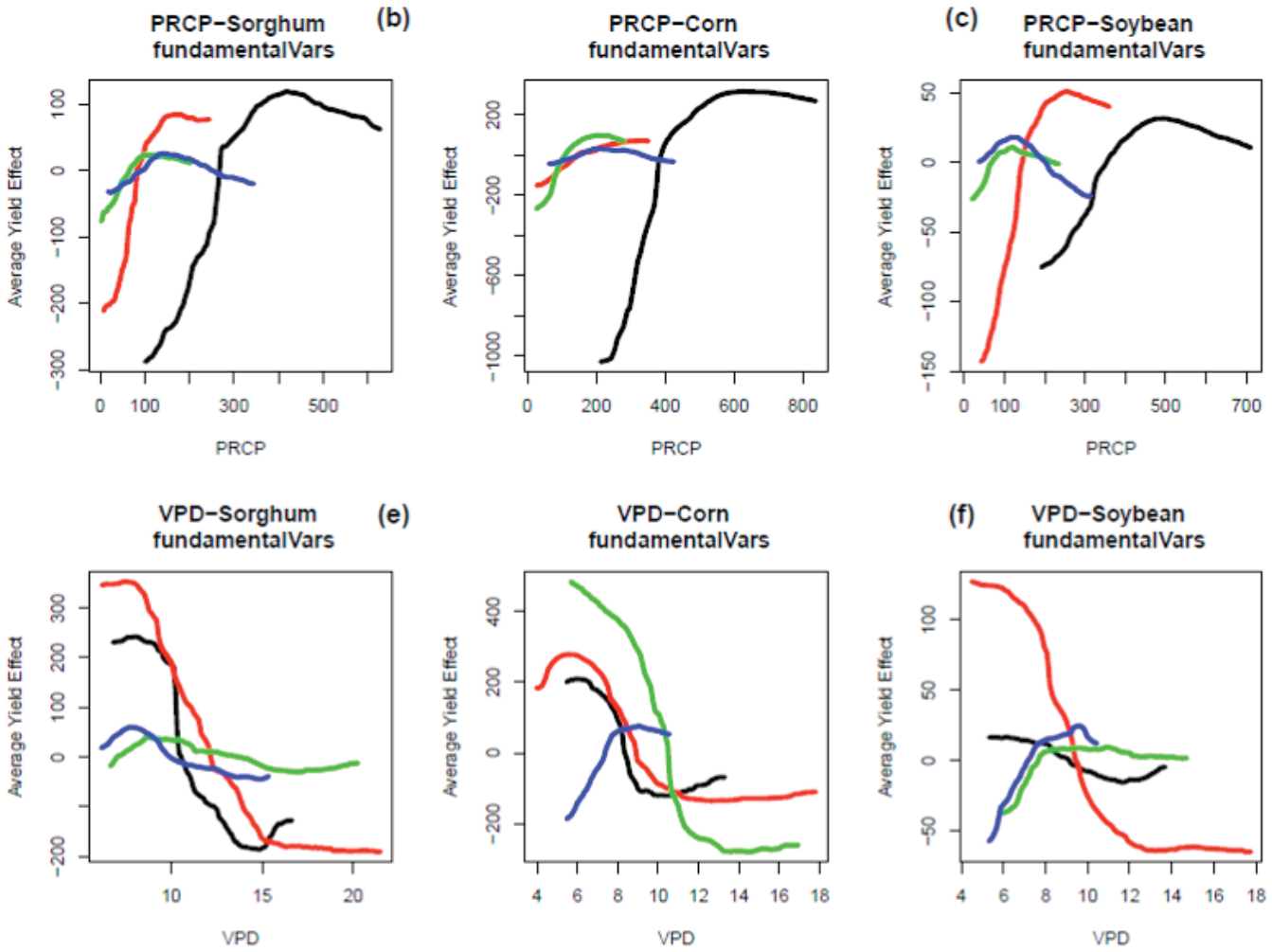

Figure 1. Partial dependence plot of the yield versus precipitation and vapor pressure deficit for sorghum (a, d), corn (b, e) and soybean (c, f). Line color code: blue = establishment, green = flowering, red = grain filling, black = growing season.

Keywords: machine learning, climate, corn, sorghum, soybean.

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S1-P.16

Potential yield simulated by Global Gridded Crop Models: what explains their difference

Ringeval Bruno[1] (bruno.ringeval@inra.fr), Müller Christoph[2], Pugh Thomas[3], Mueller Nathaniel[4], Ciais Philippe[5], Folberth Christian[6], Pellerin Sylvain[7], Debaecke Philippe[8], Liu Wenfeng[5]

[1] *ISPA, INRA, Villenave d'Ornon, France*; [2] *Institute for Climate Impact Research, Potsdam, Germany*; [3] *University of Birmingham, Birmingham, United Kingdom*; [4] *University of California, Irvine, United States*; [5] *LSCE, Gif-sur-Yvette, France*; [6] *IIASA, Vienna, Austria*; [7] *INRA, Villenave d'Ornon, France*; [8] *UMR AGIR, INRA, Castanet-Tolosan, France*

Introduction

Yield gap analysis are based on the difference between potential and actual yields. Such analysis tend to be used at regional to global scales to investigate questions about global food security, management of resources with global perspective, etc. (van Ittersum et al., 2013). However, while crop models used at local scale to compute potential yield can be tuned to account for local specificities, it is much more complicated at the global scale as Global Gridded Crop Models (GGCMs) have difficulties to account for genotype x environment x management interactions. The GGCM Intercomparison (GGCMI, phase I) provides a framework relevant to understand the difference among GGCMs (Müller et al., 2019) and we aimed here to investigate the differences in simulated potential yield between GGCMs.

Methods

To do so, we built a very simple model (called SIM in the following) based on well-known formalisms such as the sum of growing degree days, canopy-integration of Beer-Lambert law, constant light-use efficiency (*LUE*) to simulate the final aboveground biomass (*biom* in the following). We then calibrated SIM independently against each GGCM. For each GGCM, we used the so-called "harmon" (harmonized growing season and no nutrient limitation) and "irrigated" simulations from GGCMI for maize. The calibration of SIM concerns the *LUE* and one parameter related to the heat requirements (called GGD_{1leaf} hereafter). A globally-constant *LUE* has been tuned for each GGCM while GGD_{1leaf} varies in space to mimic the procedure given to GGCM modellers in the GGCMI protocol (in which GGCM modellers tuned heat requirements to match the growing season provided by global datasets). Besides, the calibration of SIM concerns also two additional parameters related to the computation of the final yield: one parameter related to the start of the grain filling (*thresh*) and the fraction of the productivity filling the grains (*frac*, constant in time). SIM was forced by daily radiation, daily temperature, as well as by begin/end of the growing season simulated by each GGCM.

Results

$biom_{GGCM}$ strongly varies between GGCMs (1st column of Figure). We showed that once a global *LUE* and a spatially varying GGD_{1leaf} are calibrated in SIM, this latter is able to reproduce $biom_{GGCM}$ simulated by most GGCMs (2nd and 3rd columns of Figure). Some mismatch exists between SIM and EPIC models and we found that this mismatch is explained by the existence of a heat stress in EPIC models. Investigations to understand why SIM cannot reproduce *biom* simulated by CLM and PEGASUS are in progress. We found that the calibration of two other parameters (*thresh* and *frac*) allows SIM to mimic the relationship *biom* vs *grain* simulated by each GGCM. A spatial variability in *frac* is nevertheless required to reproduce EPIC models as these models consider a cultivar diversity.

Conclusions

Differences in few parameters explained most of the difference in simulated potential yield between GGCMs. In purpose to simulate potential yield at the global scale, our proposed set of equations (feed by daily temperature, daily radiation and begin/end of the growing season) is an interesting alternative to complex GGCMs as they are easier to manipulate and allow much faster uncertainty analysis.

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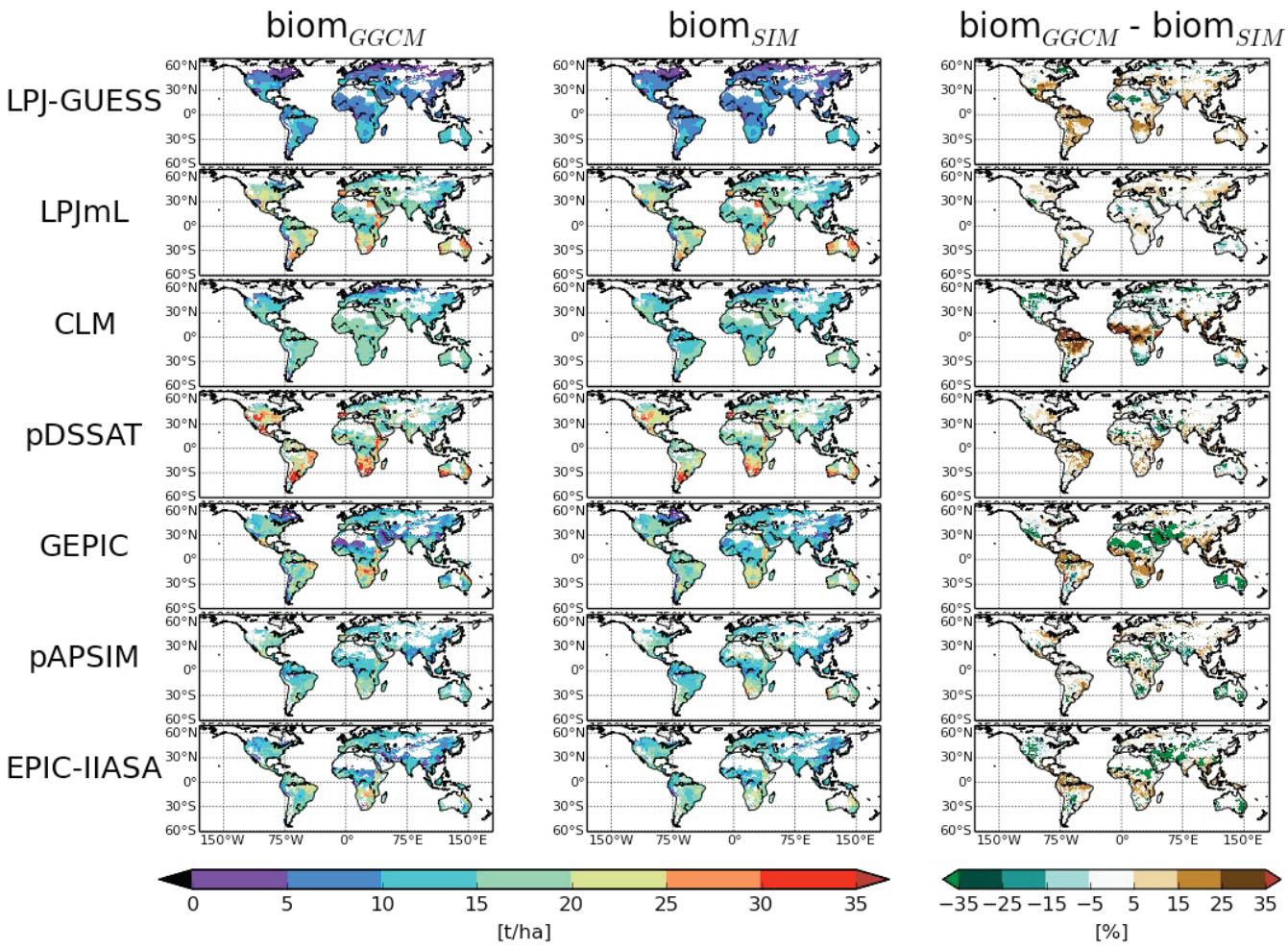

Figure: Comparison between biomGGCM (1st column) and biomSIM (2nd column) for few GGCMs involved in the GGCM intercomparison. Last column shows the difference (biomGGCM - biomSIM) (in % of biomSIM). biomSIM varies between lines as the SIM calibration is GGCM-dependent.

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S1-P.17

Potential for using low-cost spectral sensors to predict yield in small-scale rice fields in northwest Cambodia

Onwuchekwa-Henry Chinaza*1 (conw5681@sydney.edu.au), Van Ogtrop Floris 1, Martin Robert 1, Tan Daniel 1

Faculty of Science, University of Sydney, Sydney, NSW, Australia

Introduction

Smart technology is playing a vital role in making crop management decisions (Awan et al., 2018). However, advanced high throughput technologies may be a significant adoption challenge for small-scale rice growers in Cambodia due to cost and accessibility. Hence, developing algorithm to predict yield in-season using cost-effective technologies is a better intervention to support Cambodian rice growers.

GreenSeeker-NDVI and Canopeo are potentially emerging affordable tools that can produce a working algorithm to support small-scale rice growers. Thus, we hypothesized that low-cost sensors can predict yield in small-sale rice fields. Therefore, the objective of the study is to calibrate a working algorithm for predicting yield in small-scale rice fields in northwest Cambodia.

Materials and Methods

Spectra data were collected from different field experiments at Battambang and Banteay Meanchey Provinces in 2018 Cambodian wet season. GreenSeeker-NDVI and Canopeo were scanned 70 cm above crop canopy in transect at varying growth stages simulteneously. A total number of 720 sample size of individual spectral data was collected. Data were analysed using simple linear regression (SLR) model to determine a better predictor of rice yield between both spectral sensors. While multiple linear regression (MLR) was used to develop a model to rice predict yield at harvest using the spectral indices as well as easy to measure climatic variables; cumulative rainfall, average temperature including insect and disease counts.

Data were split into 80:20 % for training and testing of the model respectively. Model accuracy was evaluated using the coefficient of determination (r^2), Lin's concordance correlation coefficient (LCCC) and root mean square error (RMSE).

Results and Discussion

The result indicates that NDVI had a higher coefficient of determination (r^2 = 0.36) in predicting yield at panicle differentiation (PD) stage in the early wet season and r^2 of 0.4 at grain filling (GF) stage in the main wet season than Canopeo index (CI) using SLR model. When data was pooled across locations, NDVI explained 30 % of the variability in yield at GF stage than CI. This explains that each spectral index showed limited capability in estimating yield which could be attributed to environmental heterogeneity in rice ecosystems with soil increasing saturation effects or higher concentration of plant pigments at visible wavelength (Ali et al., 2014).

Alternatively, the MLR model indicates that combination of cumulative rainfall, insect counts and CI explained 66 % of variation in yield at PD stage. The results of the validation model indicate the model performs reasonably well (r^2 = 0.53, LCCC = 0.7 and RMSE= 0.46) at PD stage than GF stage (Figure 1). Thus, model performance was improved by integrating environmental variables with spectral sensors indicating the usefulness of environmental variables to develop a robust model for yield prediction.

Conclusions

The MLR model clearly showed the potential for using spectral sensors in combination with environmental variables to predict yield in small-scale rice fields. More spectra data collection are underway on the rice fields with varying conditions to validate model robustness.

Acknowledgements

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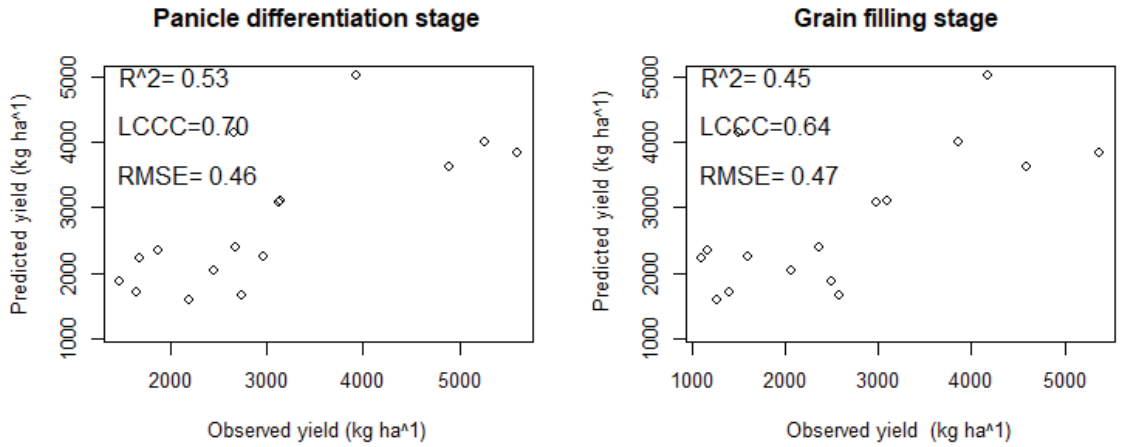

Figure 1. Cross-validation between observed yield and predicted yield across both locations in 2018 planting season

Keywords: Spectral indices, Rice paddy, Yield prediction.

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S1-P.18

Potential maize yields in a Mediterranean environment depend on conditions around flowering

Bassu Simona[1] (simona.bassu@ec.europa.eu), Fumagalli Davide[1], Toreti Andrea[1], Ceglar Andrej[1], Giunta Francesco[2], Motzo Rosella[2], Niemeyer Stefan[1]

[1] *Joint Research Centre, Ispra, Italy*; [2] *University of Sassari, Sassari, Italy*

Introduction

Understanding the effects of different combinations of sowing dates and cultivars on maize yield is essential to develop appropriate climate change adaptation strategies. Thus, modelling ability in reproducing the observed response of maize yield to sowing dates and cultivars needs to be assessed. In particular, whether crop conditions around flowering can entirely explain the variability of potential yields across sowing dates and cultivars in climatic conditions such as the Mediterranean ones (where high temperatures may occur during the grain filling period) needs to be explored. Otherwise, also assimilation during grain filling and its duration should be taken into account.

Materials and Methods

Here we test in potential conditions the WOFOST model, based on the partitioning approach, and a simpler model, based on physiological crop conditions around flowering, built combining WOFOST-simulated above-ground biomass, LAI, anthesis date with the yield estimation method proposed by Otegui et al. (1998) and Gambín et al. (2006), hereafter Otegui-Gambín. The latter calculates kernel number on the base of the amount of intercepted photosynthetically active radiation during the critical period of ear elongation, i.e. around flowering, and kernel weight on the assimilate availability close to flowering, which includes the period of early grain development. Models evaluation was based on a 2-year field experiment conducted in a Mediterranean environment under fully irrigated conditions.

Results and Discussion

Both modelling approaches reveal good performance in simulating average maize yield under irrigated conditions. However, the simpler one based on the conditions around flowering outperforms the WOFOST model in the responsiveness to changes in sowing date and cultivar, with a RMSD (root mean square difference) reduction and a higher model efficiency (Willmott, 1982). The yield variability across the six sowing dates, calculated using the variation coefficient *per* year and cultivar, was higher in the Otegui-Gambín approach than in WOFOST, as shown in Figure 1.

Our analyses reveals that crop conditions around flowering time can explain alone maize yield variation through different sowing dates and cultivars under irrigated conditions. This is because in an environment where crop can fully take advantage of the growing season, in absence of environmental constraints, such as water shortage, frost or heat stress, yield is solely determined by radiation and temperature during the yield critical period (Andrade et al., 2010) Thus, higher temperatures during grain filling may change grain filling duration but not necessarily yields if they are compensated by high incident daily radiation supporting the findings of Muchow (1990). Therefore, the variation in duration of the grain filling, the main yield determinant in the partitioning modelling approach, may produce a simulated yield variability that is different from the one determined by biomass production and intercepted radiation around flowering.

Conclusions

Our findings show that the partitioning approach achieves less accurate estimates of yields across different sowing dates, whereas an approach mainly based on anthesis conditions performs better.

Acknowledgements

The authors thank Paola Fenu, Roberto Leri and Paolo Manca for their technical assistance and Matteo Serusi for the supply of 1 year of field data used in the calibration of WOFOST model.

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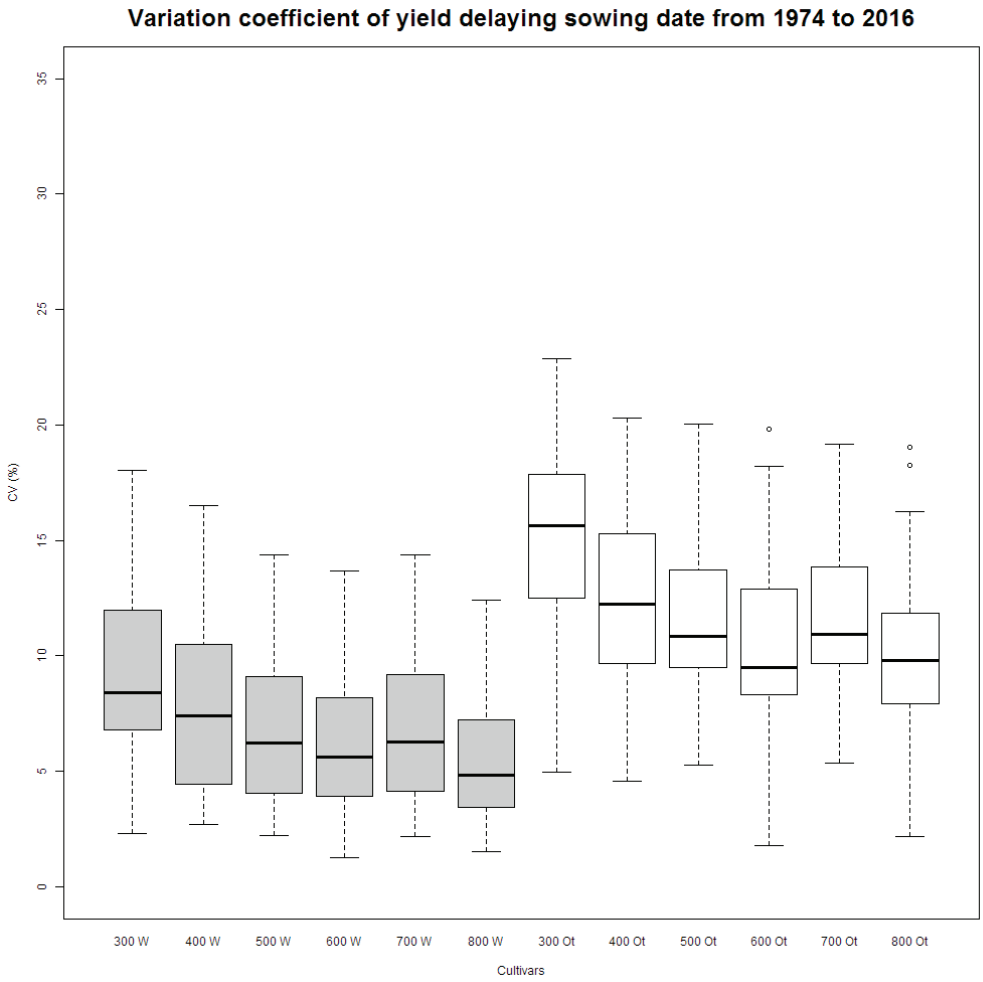

Figure 1. Variation coefficients of predicted maize yields through six different sowing dates (15th and 30th of each month from April to June) for each cultivar type (300, 400, 500, 600, 700, 800) during the 1974-2016 period. Grey and white boxplots correspond to the variation coefficients of the yields simulated by WOFOST (W) and Otegui- Gambín (Ot), respectively.

Keywords: sowing date, cultivar, maize, modelling, potential grain yield variability.

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S1-P.19

Performance of CSM-DSSAT-CROPGRO model for soybean plant density in low latitude in Brazil

Battisti Rafael[1] (battisti@ufg.br), Sampaio Leila Sobral[2], Lana Marcos A.[3]

[1] *Escola de Agronomia, Universidade Federal de Goiás, Goiânia, GO, Brazil*; [2] *Instituto de Ciências Agrárias, Universidade Federal Rural da Amazônia, Belém, PA, Brazil*; [3] *Swedish University of Agricultural Scien, Uppsala, Sweden*

Introduction

Sowing dates, maturity group and climate conditions associated with plant density can lead to different effects on soybean (Battisti et al., 2017). Light interception explains responses to plant density among different maturity groups and environments (Edwards et al., 2005). Decisions concerning sowing density need to take into account two main factors: the lowest possible sowing density to reduce seed costs, and the optimum possible interception of solar radiation. Crop models can help to evaluate the interaction between these factors, but studies about plant density are very scarce, especially for soybean. In order to better explore this knowledge gap, this study aims to evaluate the CSM-DSSAT-CROPGRO-Soybean regarding plant development and yield in response to plant density for two distinct soybean maturity groups (7.7 and 8.8) in low latitudes, Brazil.

Materials and Methods

Fields experiment were conducted in Paragominas, PA, Brazil (Lat -3.37°; Long -47.42°; 176 m a.s.l; Aw climate, Yellow Latosol, very clayey). The cultivars M7739 IPRO (MG 7.7, quasi-determinate,) and M8808 IPRO (MG 8.8, determinate) were sowed on 06 Jan (Sowing date 1(S1)), 19 Jan (S2), and 16 Feb (S3) in 2018, and 12 Jan (S4) for 2019. Sowing densities were 10 (MG 7.7 – S1, S2 and S4; MG 8.8 – all S), 20 (MG 7.7 – all S; MG 8.8 – S1, S2 and S4), 30 (MG 7.7 – all S; MG 8.8 – S1 and S4) and 40 (MG 7.7 – S1 and S4; MG 8.8 – S3 and S4) plants m-2. Field measurements included phenology, grain yield, leaf area index, and aboveground (total, leaf, stem, and pod) dry biomass. S1, S2, and S3 data were used for model calibration and S4 for model evaluation. Calibration started with default parameters from CROPGRO, following Hunt and Boote (1998) calibration steps. The relative root mean square error (RRMSE) and Willmott index (d) were used to evaluate crop model performance.

Results and Discussion

The model calibration was able to adequately simulate phenology, reducing the initial RRMSE from 25% (uncalibrated) to less than 4% after calibration. MG 7.7 grain yield had an RRMSE of 12% and 3.5%, respectively, for calibration and evaluation, with d above 0.83 (Figure 1a). MG 8.8 had similar result for calibration (RRMSE = 10%; d = 0.76). However, the crop model outputs showed yield variability associated to plant density in the evaluation, contradicting field observations of MG 8.8 S4 (Figure 1b). As consequence, the MG 8.8 yield RRMSE increased to 32%. The yield response for MG 8.8 S4 was associated with a reduction of leaf area index and biomass at the field, with the crop model overestimating these results. For the leaf area index, the calculated RMSE was 0.12, 0.46, 0.68 and 1.10 for 10, 20, 30 and 40 plants m-2, respectively. The same tendency was observed for MG 8.8 during calibration.

Conclusions

In most cases, the model was able to simulate yield, leaf area index and biomass in response to plant density. The limitation was observed for the MG 8.8 in the evaluation step. Our hypothesis is that other limitations particular to MG 8.8 features, or even environmental limitations in N fixation (due soil saturation after extreme precipitation events) or solar radiation quality are not captured by the model. While the model was able to correctly mimic the MG 7.7 cultivar, further analysis needs to be done to clarify the source of limiting yield and crop model performance for MG 8.8.

Acknowledgments

We gratefully acknowledge support from the Juparanã Agrícola.

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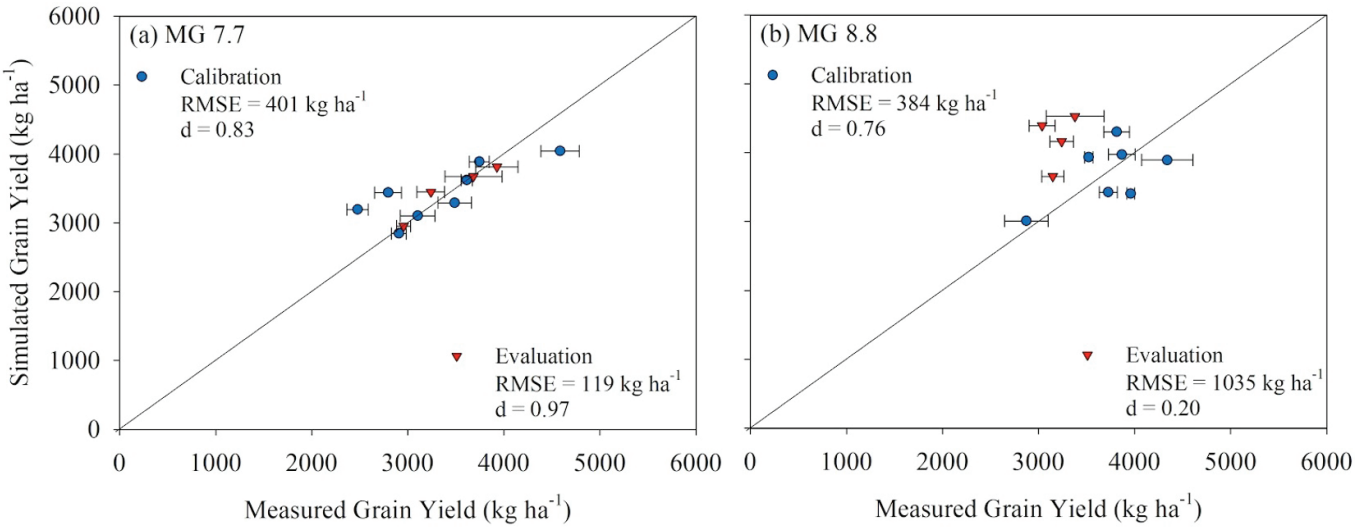

Figure 1. Relationship between measured and simulated soybean grain yield for calibration and evaluation phase for maturity group 7.7 (MG 7.7) (a) and MG 8.8 (b). RMSE is the root mean square error and d is the Willmott index.

Keywords: Crop modeling, crop management, maturity group, potential yield.

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S1-P.20

Potential and challenges of long term uninterrupted field crop rotations modelling: case study from Czech Republic

Bednařík Martin[1] (Bednarik.Mart@gmail.com), Pohanková Eva[1], Hlavinka Petr[1], Kersebaum Kurt Christian[1], Madaras Mikuláš[2], Jan Balek[1], Dubrovský Martin[3], Trnka Miroslav[1]

[1] *Global Change Research Institute CAS, Brno, Czech Republic*; [2] *Crop Research Institute, Prague, Czech Republic*; [3] *Institute of Atmospheric Physics, Prague, Czech Republic*

Crop rotation composition, fertilization strategy and residue management could have long term effects on soil properties and crop production. Due to system complexity and unceasing changes (e.g. the development climatic conditions) exact quantification of various factors is relatively complicated. Crop growth models are available tools for assessment of interactions and processes (crop development, biomass production, soil processes, flow of matters etc.) at various levels of agrosystems. This makes such tools very useful aside field experiment which has limited range of options and conditions. The aim of this study is to demonstrate functionality of HERMES crop model for simulations of long term uninterrupted crop rotations. The evaluation of the model behavior within recent period is described for selected soil-climatic conditions (examples for representative locations within Czech Republic) with focus both on crop production aspects and soil processes (including organic matter balance). Moreover the examples of the simulated processes by HERMES model under selected set of future climatic conditions during this century is presented. Based on acquired knowledges the challenges for further progress is described (e.g. crops mixtures modelling, new crop implementation, effect of tillage intensity). The ambition is to have the complex and reliable modelling procedure as a tool for possible adaptation measures design and assessment both for current and future climatic condition. The study and contribution was funded through SustES - Adaptation strategies for sustainable ecosystem services and food security under adverse environmental conditions“ project no. CZ.02.1.01/0.0/0.0/16_019/0000797.

S1-P.21

From point to field scale: How consistent are agro-ecosystem models in terms of changes in soil texture?

Kersebaum Kurt-Christian[1] (ckersebaum@zalf.de), Wallor Evelyn[1], Coucheney Elsa[2], Hoffmann Munir[3], Neira Anuschka[1], Lewan Elisabet[2]

[1] *Research Platform Models and Simulation, Leibniz Centre for Agric Landsc Research, Muencheberg, Germany*; [2] *Department of Soil and Environment, Swedish University of Agric Science, Uppsala, Sweden*; [3] *Research Area Landscape Synthesis, Leibniz Centre for Agric Landsc Research, Muencheberg, Germany*

Introduction

Field scale variability of soil texture contributes to the site-specific performance of water dynamics, nitrogen turnover and crop development in the soil-plant-atmosphere system. In agricultural practice, management recommendations that operate on the basis of spatially and temporally variable soil states are rarely considered, even though, having knowledge about it could help to avoid unwanted environmental impact and waste of resources (Fowler et al., 2013). Agro-ecosystem models are able to derive spatially and temporally high resolution state variables considering both, soil and crop processes. To assess selected models for future application in agricultural practice (e.g. precision farming), this study examines the consistency of yield simulation in relation to soil texture changes at the field scale.

Materials and Methods

The data set used in the present study results from intensive mapping and sampling activities at a 20 ha large agricultural field in north western Germany. Data is extensively described in Wallor et al. (2018) and includes three years of on-the-go measured yields and results of soil analysis at 60 sampling points arranged as a regular grid. The soil inventory of the field consists of seven homogeneous soil zones that show increasing clay contents from 5% to 45%. Winter wheat yields of the years 2000 and 2001 show a clear response to these changing soil conditions. We exemplarily tested the models APSIM (AS; Keating et al., 2003), COUP (CO; Jansson, 2012), and HERMES (HE; Kersebaum, 2007) regarding their consistency in yield simulation with respect to changes in clay content and hence, soil water contents. A four-year period is simulated including one spin-up year and one year for model calibration.

Results and Discussion

When comparing the mean deviation of simulated and observed yields with the mean deviation of simulated and observed soil water contents for each model, AS showed highly variable deviations in yield predictions although water deviations were only slightly biased (cf. Figure 1). Especially for sampling points that have less than 25% clay the response of yield formation to soil water is over-predicted. HE produced the most consistent results showing a relative small band of deviations for water and yields, independently from soil texture. CO's simulation was similarly consistent in this sense, but showed larger deviations for yield predictions. The overestimation of yields was accompanied by over-predicted water contents without showing a clear relation to soil texture.

Conclusions

In terms of the highly sufficient depiction of heterogeneous soil water contents, which mainly affect yield performance in this field, the assessed models performed mostly consistent. This suggests that the cause for the deviations between simulation and observation can be found in the model-specific structure and equations, as the influence of model inherent estimation of soil hydrological parameters was excluded before.

Acknowledgements

This work was conducted within the Project I4S which is part of the BonaRes programme funded by the German Federal Ministry of Education and Research (BMBF), Grant Number 031B0513I. It is an in-depth evaluation of a modeling exercise that was carried out within the framework of FACCE JPI MACSUR2. The contributing authors thank the National Ministries and the European Union for funding the projects (grant 0339740 and 031B0039C).

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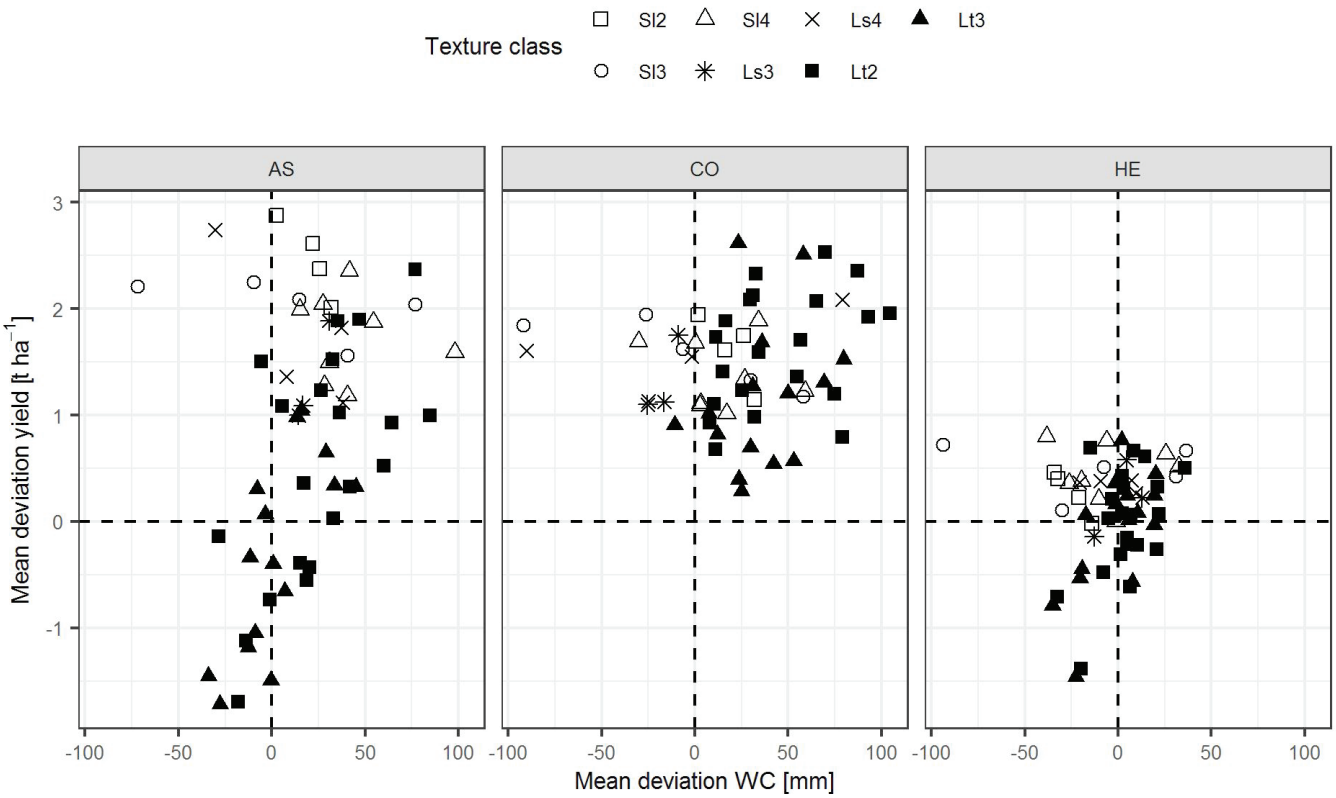

Figure 1. Model-based relation between the mean deviation of simulated and observed yields and the mean deviation of simulated and observed soil water contents (WC) grouped by soil texture class (Sl2, Sl3, Sl4 = 5 to 17% clay; Ls3, Ls4 = 17 to 25% clay; Lt2, Lt3 = 25 to 45% clay); mean deviation was calculated based on all observations per sampling point of the entire simulation period

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S1-P.22

Prediction of Evapotranspiration and Yields of Maize: An Inter-comparison among 29 Maize Models and Future Plans

Kimball Bruce[1] (bruce.kimball@usda.gov), Boote Kenneth[2], Hatfield Jerry[3], Ahuja Laj[4], Stockle Claudio[5], Archontoulis Sotirios[6], Baron Christian[7], Basso Bruno[8], Bertuzzi Patrick[9], Constantin Julie[10], Deryng Delphine[11], Dumont Benjamin[12], Durand Jean-Louis[13], Ewert Frank[11], Gaiser Thomas[14], Gayler Sebastian[15], Hoffman Munir[16], Jiang Qianjing[17], Kim Soo-Hyung[18], Lizaso Jon[19], Moulin Sophie[20], Nendel Claas[11], Parker Philip[21], Palosuo Taru[22], Priesack Eckart[23], Qi Zhiming[24], Srivastava Amit[14], Stella Tommaso[11], Tao Fulu[24], Thorp Kelly[1], Timlin Dennis[25], Twine Tracy[26], Webber Heidi[11], Willaume Magali[27], Williams Karina[28], Suyker Andrew[29], Evett Steven[30]

[1] *U.S. Arid-Land Agricultural Res. Center, USDA, Agricultural Research Service, Maricopa, Arizona, United States*; [2] *University of Florida, Gainesville, Florida, United States*; [3] *Nat. Lab. for Agr. and Environ., USDA, Agricultural Research Service, Ames, Iowa, United States*; [4] *Agric. Systems Res. Unit, USDA, Agricultural Research Service, Ft. Collins, Colorado, United States*; [5] *Biological System Engineering, Washington State University, Pullman, Washington, United States*; [6] *Department of Agronomy, Iowa State University, Ames, Iowa, United States*; [7] *CIRAD UMR TETIS, Maison de la Télédétect, Montpellier, France*; [8] *Dept. Geological Sciences, Michigan State University, East Lansing, Michigan, United States*; [9] *US1116 AgroClim, INRA centre de recherch, Avignon, France*; [10] *AGIR, Université de Toulouse, INRA, INP, CastanetTolosan, France*; [11] *Leibniz Centre for Agr. Landscape Res., Mucheberg, Germany*; [12] *Department of Agronomy, ULg-GxABT, University of Liege, Gembloux, Belgium*; [13] *Unité de Rec. Pluridisciplinaire Prairie, INRA, Lusignan, France*; [14] *Inst. of Crop Sci. and Resource Conserva, University of Bonn, Bonn, Germany*; [15] *Institute of Soil Science and Land Evalu, Universitat Hohenheim, Stuttgart, Germany*; [16] *Crop Production Systems in the Tropics, Georg-August-Universität, Göttingen, Germany*; [17] *Department of Bioresource Engineering, McGill University, Sanite-Anne-de-Bellevue, Quebec, Canada*; [18] *Center for Urban Horticulture, University of Washington, Seattle, Washington, United States*; [19] *Dept. Producción Agraria-CEIGRAM, Technical University of Madrid (UPM), Madrid, Spain*; [20] *centre de recherche Provence-Alpes-Côte, INRA, Avignon, France*; [21] *Spatial Business Integration, Darmstadt, Germany*; [22] *Natural Resources Inst. Finland (Luke), Vantaa, Finland*; [23] *Institute of Biochemical Plant Pathology, Helmholtz Center Munich, Neuherberg, Germany*; [24] *Inst. of Geographic Sci. and Nat. Resour, Chinese Academy of Science, Beijing, China*; [25] *Crop Systems and Global Change Research, USDA, Agricultural Research Service, Beltsville, Maryland, United States*; [26] *Department of Soil, Water, and Climate, University of Minnesota, St. Paul, Minnesota, United States*; [27] *AGIR, Université de Toulouse, INRA, CastanetTolosan, France*; [28] *Hadley Centre, Devon, United Kingdom*; [29] *School of Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska, United States*; [30] *Conservation and Production Laboratory, USDA, Agricultural Research Service, Bushland, Texas, United States*

Introduction

Crop yield can be affected by crop water use (evapotranspiration, ET) and vice versa, so when trying to simulate one or the other, it can be important to simulate both well.

Method: To determine how well 29 maize growth models can simulate ET, an inter-comparison study was initiated under the umbrella of AgMIP (Agricultural Model Inter-Comparison and Improvement Project) using eddy covariance data from Ames, IA as the standard for comparison (Kimball et al., 2019).

Results

In the first "blind" phase for which only weather, soils, phenology, and management information were provided to the modelers, estimates of seasonal ET varied from about 200 to about 700 mm (Fig. 1), and even after receiving all information, ET estimates still varied by a factor of two or more. Much of the variability among the models was due to differing estimates of potential evapotranspiration. The ensemble median values were generally close to the observations, but a few of the models sometimes performed better. The best models varied widely in complexity in spite of having similar prediction accuracies. Models that are widely used tended to perform better, leading us to speculate that a larger number of users testing these models over a wider range of conditions likely has led to improvement. User experience and skill were also a factor in determining the accuracy of model predictions. In several cases, different versions of a model were better, such as an older soil evaporation routine was better than a newer default routine in the DSSAT family.

Future plans

However, there were several issues with the observed data, so a second round of inter-comparisons was initiated and is underway using eddy covariance data from Mead, NE and lysimeter data from Bushland, TX. Besides the ET data, these datasets feature several within-season observations of growth and soil moisture measurements at several depths.

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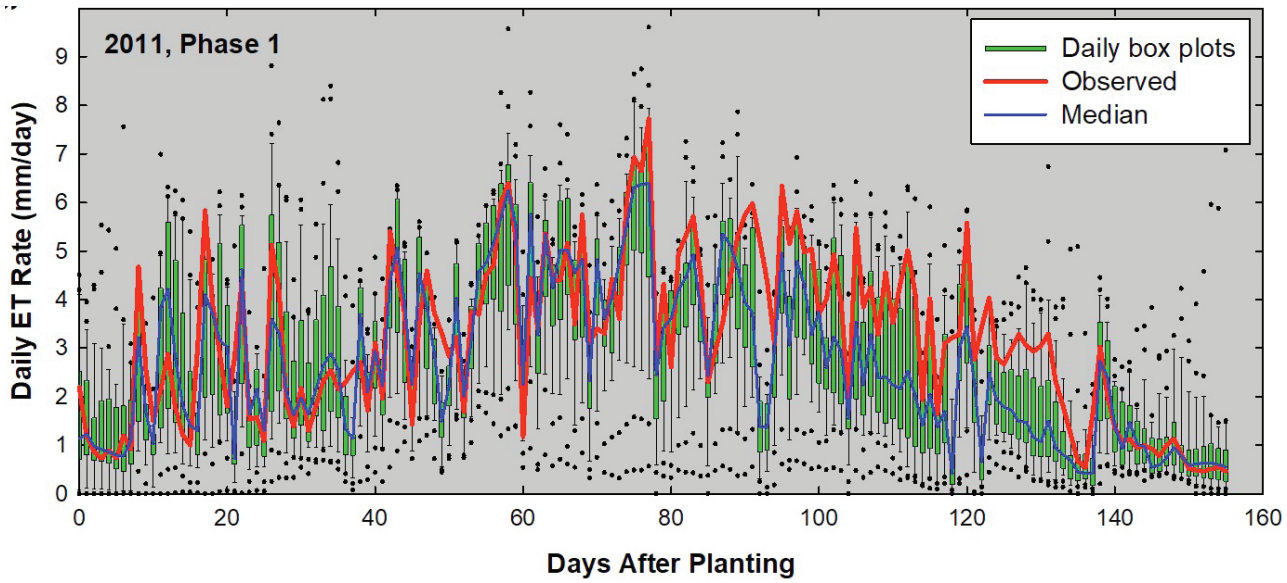

Figure 1. Box plots of daily evapotranspiration (ET) where the lower and upper limits of the box indicate the 25th and 75th percentile of ET values simulated by 29 maize growth models, respectively, the lower and upper whiskers indicate the 10th and 90th percentiles, and the points are outliers. Observed values and the median values from the 29 models are also shown. The simulated values in this plot came from Phase 1, a "blind" test whereby the modellers were only given weather, phenology, management, and soils information, but no crop response data.

Keywords: Water Use, growth, yield.

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S1-P.23

First Soybean Multi-model Sensitivity Analysis to CO_2, Temperature, Water, and Nitrogen

Kothari Kritika[1] (kritikakothari@uky.edu), Salmeron Montserrat[1], Battisti Rafael[2], Boote Kenneth J[3], Archontoulis Sotirios[4], Confalone Adriana[5], Constantin Julie[6], Cuadra Sanatiago Vianna[7], Debaeke Philippe[6], Faye Babacar[8], Grant Brian[9], Hoogenboom Gerrit[3], Jing Qi[9], Laan Michael van der[10], Macena Fernando[7], Marin Fabio[11], Nehbandani Alireza[12], Nendel Class[13], Purcell Larry[14], Qian Budong[9], Ruane Alex[15], Silva Evandro da[11], Smith Ward[9], Soltani Afshin[12], Srivastava Amit[8], Vieira Nilson Aparecido[11]

[1] *Plant and Soil Sciences, University of Kentucky, Lexington, KY, United States*; [2] *Escola de Agronomia, Universidade Federal de Goiás, Goiânia, Brazil*; [3] *Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States*; [4] *Department of Agronomy, Iowa State University, Ames, IA, United States*; [5] *Facultad de Agronomía, Universidad Nacional del Centro, Buenos Aires, Argentina*; [6] *Agrosystèmes et Agricultures, National Institute for Agricultural Res., Tolosan, France*; [7] *Empresa Brasileira de Pesquisa Agropecuá, São Paulo, Brazil*; [8] *Crop Science and Resource Conservation, University of Bonn, Bonn, Germany*; [9] *Agriculture and Agri-Food Canada, Ottawa Research and Development Centre, Ottawa, Canada*; [10] *University of Pretoria, Pretoria, South Africa*; [11] *Biosystems Engineering Department, University of São Paulo, São Paulo, Brazil*; [12] *Agronomy Group, Gorgan University of Agricultural Scienc, Gorgan, Iran*; [13] *Ecosystem Modelling, Leibniz Centre for Agricultural Landscap, Müncheberg, Germany*; [14] *Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR, United States*; [15] *NASA Goddard Institute for Space Studies, New York, NY, United States*

Introduction

Crop model responses to changes in climatic and management factors could be highly variable due to variation in model coding and prior calibration with limited observed data, thus introducing high uncertainty in food projections. Coordinated multi-model comparison studies play a crucial role in evaluating model uncertainty and improving existing models. The present study is the first model intercomparison effort on a legume, soybean (*Glycine max* L. (Merr.)), with special emphasis on the crop N processes. Previous multi-model studies in cereal grain crops identified the value of model ensembles to reduce uncertainties in yield projections (Bassu *et al.*, 2014; Martre *et al.*, 2015). Interestingly, model responses to changes in temperature and atmospheric carbon dioxide concentration [CO_2] were not affected by the level of observed data available for calibration (Bassu *et al.*, 2014). We propose to test: 1) whether soybean multi-model ensembles are better estimators of yield, crop growth and grain nitrogen concentration (grain N%) than individual models; and 2) whether the level of observed data available during calibration influences model responses to variation in climatic and N fertilization factors ([CO_2], Temperature, Water, and Nitrogen; CTWN sensitivity analysis).

Materials and Methods

Field experimental data from five environments (Azul, Argentina; Auzeville, France; Brasilia, Brazil; Ames, IA, and Fayetteville, AR, United States) were used to calibrate models under baseline conditions. Each experiment included different years, planting dates (early and late) and/or water levels (irrigated and rainfed). We evaluated two types of calibrations: (1) with phenology data only (blind calibration), and (2) with high intensity observed data including seasonal plant growth and N composition (full calibration). After each calibration, a CTWN sensitivity analysis was conducted, consisting of 30-yr simulations (1980–2009) for 124 combinations of [CO_2] (360 ppm to 720 ppm), temperature (−3 to +9 oC), water (−30% to +30% rainfall, and irrigated), and nitrogen (0 and 400 kg N/ha). By the time of this submission, a total of nine soybean models had been calibrated against phenology data (blind calibration).

Results and Discussion

Preliminary results after the blind calibration indicate a median root mean square error (RMSE) in simulating grain yield, biomass, and grain N% of 29, 25, and 17%, respectively, when individual model outputs were compared with the measured data. However, when individual model outputs were averaged and compared with the measured data (model ensemble), estimation of grain yield and biomass improved with RMSEs of 24 and 24%, respectively. In contrast, the estimation of grain N% worsened (RMSE 27%) compared to the median from individual models. The CTWN sensitivity analysis after the blind calibration showed negative effects on yield of increasing temperature, and positive effects of increasing [CO_2] on yield. Increasing water level typically increased crop production. The yield response to nitrogen levels was more variable across models.

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Conclusions

Our preliminary data suggests that the ensemble of models was a better predictor of grain yield, but not of grain N%. On a next step we will evaluate CTWN responses after a full calibration with high intensity observed data. The uncertainty in soybean model projections across different CTWN levels after a full and blind calibration will be presented.

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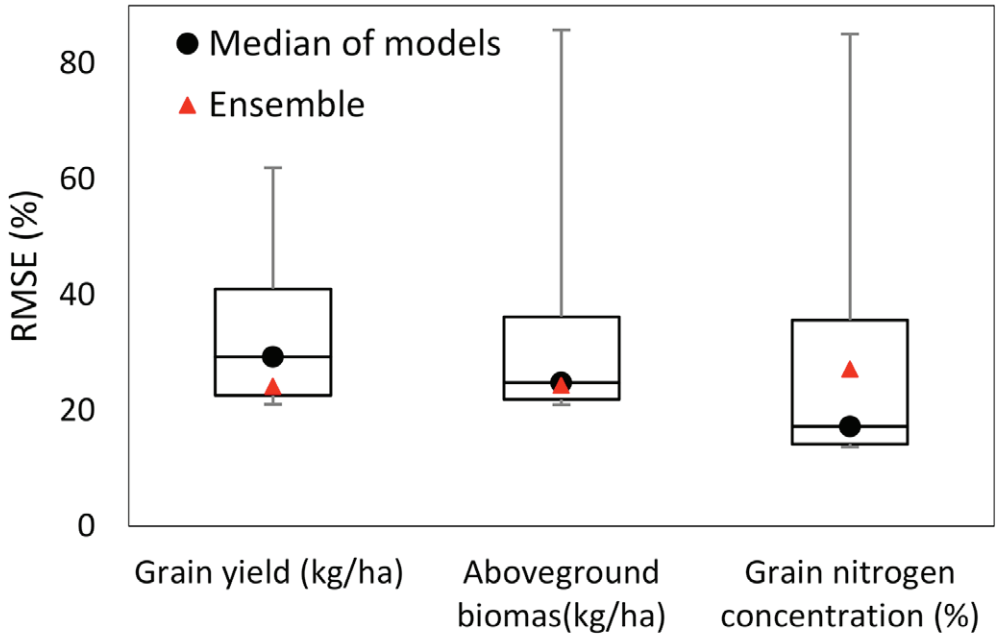

Figure 1. Boxplot of normalized root mean square error (RMSE, %) for grain yield, aboveground biomass, and grain nitrogen concentration simulated by nine soybean models after a blind calibration. The RMSE obtained using the ensemble of models as a predictor is shown by red triangles.

Keywords: AgMIP-Soybean, Blind Calibration, Full Calibration, CTWN response.

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S1-P.24

Modelling floodplain grasslands to explore the impact of changing hydrological conditions on vegetation productivity

Leauthaud Crystele[1] (crystele.leauthaud@cirad.fr), Kergoat Laurent[2], Hiernaux Pierre[3], Grippa Manuela[4], Musila Winfred[5], Duvail Stéphanie[6], Albergel Jean[7]

[1] *G-eau, Cirad, Montpellier, France*; [2] *Géosciences Environnement Toulouse, CNRS, Toulouse, France*; [3] *Pastoralisme Conseil, Caylus, France*; [4] *CNRS, Toulouse, France*; [5] *Kenya Water Towers Agency, Nairobi, Kenya*; [6] *IRD, Paris, France*; [7] *IRD, Montpellier, France*

This study (i) presents a coupled vegetation-soil model adapted to perennial C4 seasonally flooded semi-arid grasslands; and (ii) applies the model to evaluate changes in the annual productivity of the grasslands of the Tana River Delta, Kenya, under changing flooding conditions. Main plant growth processes are modelled within coupled plant carbon balance and soil water budget modules: photosynthesis, allocation of photosynthates, respiration, translocation of root phytomass to aerial phytomass, senescence and litter production. Aerial phytomass can also be subtracted from the system, to simulate grazing or cutting. New features concern the inclusion of effects of floods on energy conversion efficiency, photosynthate allocation, senescence and litter production. The vegetation model, composed of four phytomass compartments (leaves, stems, roots, aerial dead matter), simulates three main growth phases related to flooding: floods, a post-flood phase and a non-flooded phase. It was designed to be used with limited climatic data. Data collected during a 14-month experiment (2010–2012) in the Tana River Delta, Kenya, in which different irrigation and cutting treatments and flood events were recorded, were used for calibration and validation purposes. Fourteen parameters, selected through a sensitivity analysis, were calibrated on half of these treatments. Uncertainty in parameter estimation was expressed through a stochastic ensemble of simulations. The remaining independent data were used for model validation. Overall, the model predictions are in good agreement with the experimental data. This model can be used to assess the impact of rain variability, grazing or flooding patterns on the annual primary productivity of Sub-Saharan floodplain grasslands composed mainly of *Echinochloa stagnina* (Retz) P. Beauv. In particular, simulations for the Tana River Delta suggest that past changes in the hydrological regime of the river, as well as future changes due to the construction of hydroelectric infrastructure, have led and will certainly lead to an important decrease of the floodplain grassland productivity. As local and regional livestock keeping activities rely heavily on the dry seasons' grazing resources available within the wetland, future development plans should seriously consider the negative effects of these changes on local activities and livelihoods. This presentation results from a publication in Ecological Modelling: https://doi.org/10.1016/j.ecolmodel.2018.09.015

Keywords: Echinochloa stagnina (Retz) P. Beauv., plant growth model, floodplains, Tana River Delta, Kenya.

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S1-P.26

Modelling of drought stress in field crops by crop growth model DAISY

Pohanková Eva[1] (Eva.Pohankova@seznam.cz), Hlavinka Petr[2], Takáč Jozef[3], Bednařík Martin[2], Trnka Miroslav[4]

[1] *Department of Climate Change Impacts, Global Change Research Institute CAS, Brno, Česká republika, Czech Republic*; [2] *Department of Climate Change Impacts, Global Change Research Institute CAS, Brno, Czech Republic*; [3] *Soil Science and Conservation Research I, Bratislava, Slovakia*; [4] *Department of Climate Change Impacts on, Global Change Research Institute CAS, Brno, Czech Republic*

The field experiment with rain-out shelters for precipitation reduction was established in Bohemian-Moravian highlands (Domanínek experimental station, 49°31'42»N, 16°14'13»E, altitude 560 m) in 2014. The purpose of this field experiment is to gather sufficient data for modelling the crop's response to the climatic conditions expected in the future, in this case drought stress. Winter wheat and spring barley are the most widely grown cereals in the Czech Republic. The main aim of this study was evaluate a drought stress effect on winter wheat (cultivar Bohemia) and spring barley (cultivar Bojos). At the same time the ability of crop model DAISY to simulate drought stress response was tested. The monitored parameters were development, grain yield and soil moisture on two growth seasons (2017/2018 and 2018/2019) for two experimental variants with three repetitions in each crops (the first variant = natural climatic conditions; the second variant = drought stress is induced using the mobile rain-out shelters made of corrugated clear polycarbonate material and installed in the crop canopy). In each variant were sensors TDR (time domain reflectometry, CS 616, Campbell Scientifi c Inc., Shepshed, UK) to measure the soil water content placed vertically to monitor the soil water content from the surface to a depth of 30 cm. Observed and measured parameters such as terms of phenological phases, soil moisture and grain yields were compared with modelled data. The simulation results with respect to the phenological phase of flowering/maturity showed a slight deviation from the observations, from +3/-1 to -3/+1 days for winter wheat and -6/-2 to +5/+1 days for spring barley. The precipitation was reduced during the growth season. A reduction of precipitation by 138,2 mm and 203,8 mm for winter wheat 2018 and 2019 and a reduction of precipitation by 87,6 mm and 102,2 mm for spring barley 2018 and 2019, led to decrease in grain yields. Grain yield for winter wheat/spring barley decreased from 7.43 /4.97 t/ha (natural climatic conditions) to 4.19/3.70 t/ha (drought stress was induced using the rain-out shelters) in 2018 and from 6.72/6.12 t/ha to 4.99/4.44 t/ha in 2019. The results of this study showed that the crop model DAISY relatively satisfactorily simulates the main feature soil water content dynamics as measured by TRD sensors in 2018 and 2019 and reproduce the drought stress for crop yields of winter wheat and spring barley to a certain extent. The crop model DAISY simulated the movement of soil water based on the numerical solution of Richards' equation. The decrease in the simulated grain yield after precipitation reduction is obvious. The simulation results for winter wheat/spring barley grain yield in natural climatic conditions were 8.04/3.98 t / ha in 2018 and 8.01/6.12 t/ha in 2019. The simulation results for winter wheat/spring barley grain yield in drought stress were 4.42/2.54 t/ha in 2018 and 4.40/4.20 t/ha in 2019. When rain-out shelters were used, real winter wheat/spring barley grain yields were reduced by 3.24/1.27 t/ha in 2018 and by 1.73/1.68 t/ha in 2019. The model underestimated the yields of winter wheat/spring barley for the sheltered variant by 3.62/1.44 t/ha in 2018 and by 3.61/1.92 t/ha in 2019. The study and contribution was funded through SustES - Adaptation strategies for sustainable ecosystem services and food security under adverse environmental conditions" project no. CZ.02.1.01/0.0/0.0/16_019/0000797.

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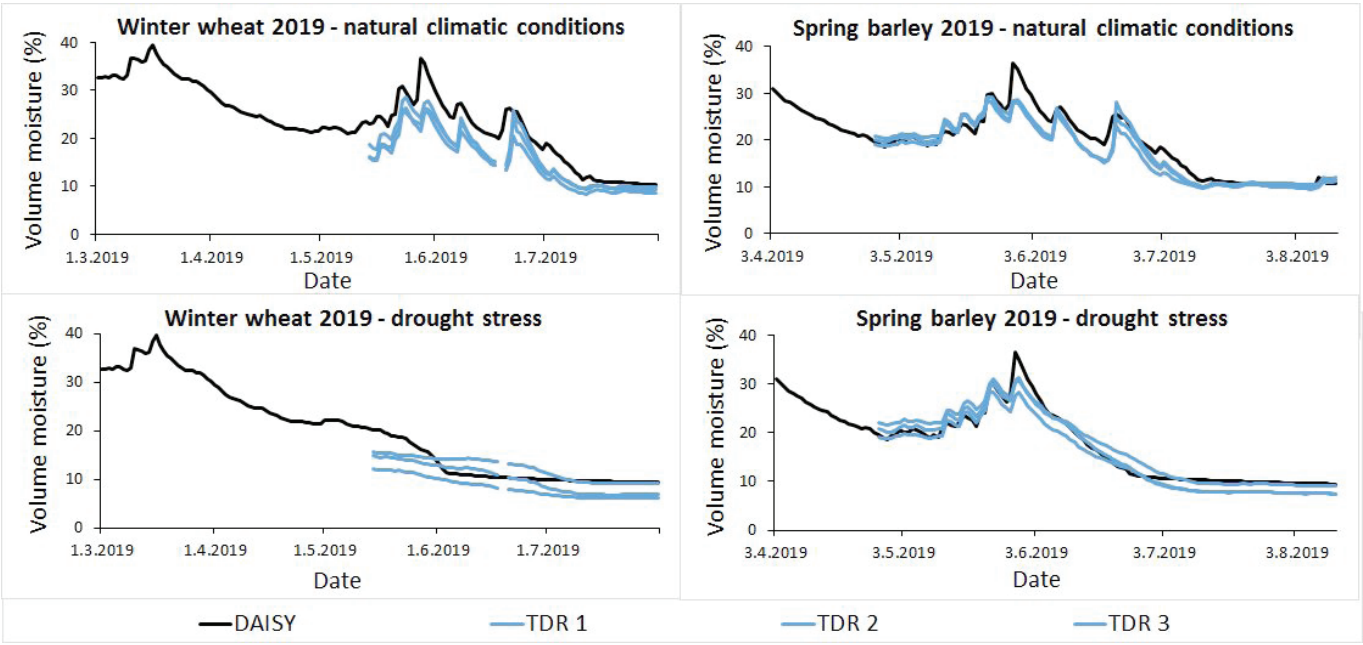

Comparisons between the simulated (DAISY) and measured (by sensors TDR, under the rain-out shelters as drought stress and outside as natural climatic conditions) soil water content from 0.0 to 30 cm.

Keywords: crop development, soil moisture, grain yields, DAISY crop model.

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S1-P.27

Predicting grass growth: The MoSt GG model

Ruelle Elodie[1] (elodie.ruelle@teagasc.ie), Delaby Luc[2], Hennessy Deirdre[1]

[1] *Moorepark, Teagasc, Fermoy, Ireland*; [2] *INRA, St Gilles, France*

Introduction

PastureBase Ireland (PBI - Hanrahan et al., 2017) is a grassland management tool for farmers. PBI helps farmers to manage the grass on their farm, identify grass supply surpluses or deficits and to take appropriate action. However, currently within PBI farmer can only make decisions based on historical information. The incorporation of a predictive model within PBI such as the MoSt GG (Ruelle et al., 2018) would allow farmer to get information on the future growth of their farm. And help to facilitate anticipation and improve decision making.

Materials and Methods

The MoSt GG model (Ruelle et al., 2018) is a dynamic model developed in C++ describing the grass growth and the nitrogen (N) and water fluxes of a paddock. The model is run with a daily time step simulating soil N mineralisation, immobilisation and water balance, grass growth, N uptake and grass N content. The model is driven by a daily potential growth depending on the radiation and the total green biomass. To calculate the actual daily growth, this potential growth is then multiplied by parameters depending on environmental conditions (temperature, water in the soil and radiation) and a parameter depending on the availability of the mineral N in the soil compared to the N demand associated with the potential grass growth. Animal depositions of N from dung and urine are also separately represented by the model. The main inputs of the model are the soil type (% sand and clay, organic matter and soil mineral N content), the weather (temperature, rainfall and solar radiation) and paddock management (fertilisation, grazing and cutting). The MoSt GG model was evaluated using experimental data for 2013-2018 from three Teagasc experimental farms - Ballyhaise, Clonakilty and Curtins in Ireland.

Results and Discussion

Overall the model showed a similar accuracy across the three farms. The accuracy at the paddock level with RMSE of between 27 (Curtins 2018) to 31.7 kg DM/ha day (Ballyhaise 2014) is quite poor, however the accuracy at the farm level of between 11.5 (Ballyhaise 2015) to 17.9 kg DM/ha/day (Clonakilty 2016) is quite promising. The Figure 1 presents the simulated and recorded growth during two contrasting years.

Since February 2019 the model is being used to predict grass growth on 40 farms across Ireland. The farms are representative of the soil type and geographic variability of Ireland. Historical and forecast weather data is provided for each individual farm by Met Éireann, the Irish Meteorological Service. Information about N fertiliser and grazing and cutting events are entered weekly by the farmer in to PBI. The weekly grass growth is communicated to farmers involved in the pilot study in the form of a map sent to the farmers on a Tuesdays. The feedback from the farm managers is very positive, and the farmers consider the predictions are very useful aids to decision making and help to be more confident.

Conclusion

The MoSt GG model is a mechanistic model developed for both research and farmer use. The initial evaluation indicates that the model is capable of adapting to differences in farm and in weather conditions. The pilot study currently on-going will provide a true indication of the MoSt GG model's ability to provide useful grass growth prediction across soil types, regions and management conditions. If the pilot study is successful, and the accuracy of the model is sufficient across the different farms, the model will be integrated into PBI.

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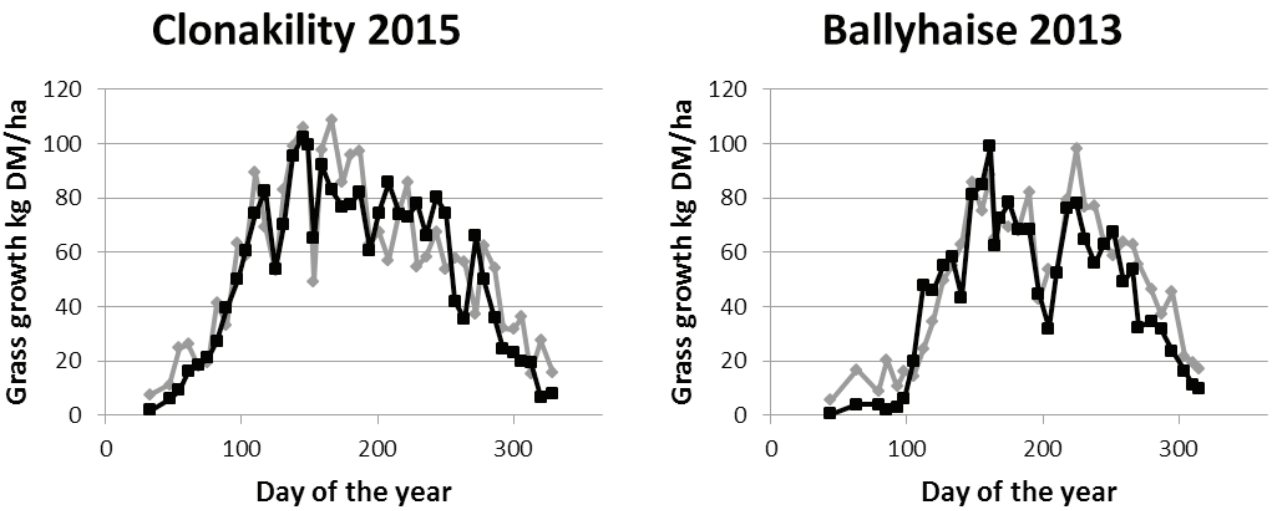

Left Clonakility 2015, RMSE 13.8 kg DM/ha, CCC 0.89 Right Ballyhaise 2013, RMSE 12.0 kg DM/ha, CCC 0.90
Figure 1: Comparison between the growths recorded in PBI (grey) and predicted by the MoSt model (black) for two contracting years in two contrasting farms.

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S1-P.28

Comparison of DSSAT wheat models performances with different regions and cultivars

Fallah Mohammad Hassan[1] (mhfallah65@mail.um.ac.ir), Zare Hossein[2], Nezami Ahmad[1], Khazaie Hamid Reza[1], Nassiri Mahallati Mehdi[1], Hoogenboom Gerrit[3]

[1] *Department of Agrotechnology, Ferdowsi University of Mashhad, Mashhad, Iran*; [2] *Soil Science and Land Evaluation, University of Hohenheim, Stuttgart, Germany*; [3] *Institute for Sustainable Food Systems, University of Florida, Gainesville, Florida, United States*

Introduction

Process-based crop models can integrate the complex interactions of soil properties, climatic conditions, management practices, and crop genetic characteristics. They differ in the way they simulate soil-plant-atmosphere processes, in detail of describing crop growth, water use and soil water balances, also in the number of parameters and inputs required (Rötter et al., 2012). The prediction uncertainty of crop models not only differs from one model to the other but also through different environmental conditions (Ramirez-Villegas et al., 2017). In fact, crop models response differently and nonlinearly to different environmental conditions. In addition to the model structure, the number of environments using for the model calibration also impact on the model response to the different environmental condition (Kassie et al., 2016). This paper aims to compare the response of DSSAT v.4.7 wheat models (CERES-Wheat, CROPSIM-Wheat and N-Wheat) with different climates using different cultivars.

Materials and Methods

Experimental data include 26 locations that categorized into four different climates in Iran. Concerning yield level and season length, we classified the locations from as high yielding and long seasons in the northwest of Iran, and short seasons as low yielding in south of Iran. Cultivars were Shahriyar, Pishtaz, Tajan, and Chamran cultivated in cold, temperate, humid and tropical regions of Iran, respectively. Planting time varied from October (in the northwest) to December (in the south), depending on the planting window for each experimental site. A limited measured data including planting, anthesis and maturity dates, and yield was used to calibrate and validate the models. Applying a local sensitivity analysis, we selected the most sensitive parameters for first the phenology, then growth and yield. All the models are executed for potential and attainable conditions.

Results and Discussion

All three models were very robust in simulating the critical phenological growth stages (anthesis and maturity) of the wheat cultivars (Table 1). RMSE for grain yield varied from 341 kg ha-1 to 933 kg ha-1 (Table 1). Nwheat underestimated grain yield of Chamran cultivar for low-yielding locations. The response of the crop models to heat stress varied significantly in the simulation of grain filling duration, biomass production, and grain yield. Biomass simulated by Nwheat model were more sensitive to heat stress effects than CERES-Wheat and CROPSIM-Wheat. CERES-Wheat simulated the higher biological yield than other models. In the Nwheat model, the specific heat stress function accelerated leaf senescence with Tmax>34 °C, explains heat stress effects during grain filling on grain yield in cultivars (Liu et al., 2016). Because the cultivars differ regarding resistance to the end season heat stress, crop models need to consider cultivar-specific tolerance to heat stress for better simulation of temperature effects on wheat cropping systems.

In the CROPSIM-Wheat model, the proportion between grain number and weight was better and the grain weight was more accurate than the other two models, but totally grain weight was not very accurate. In the Nwheat model, the grain number was highly dependent on plant population, and the model seems to be sensitive to plant density. So that in low plant population, the model cannot compensate for the tiller number and grain number.

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Table 1.
Statistical indices of evaluating comparative performance of CERES-Wheat, CROPSIM-Wheat and Nwheat models for predicting anthesis and maturity days and grain yield for four wheat cultivars.

Variable	Models Performance index	Shahriyar			Pishtaz			Tajan			Chamran		
		CSCER	CSCRP	WHAPS	CSCER	CSCRP	WHAPS	CSCER	CSCRP	WHAPS	CSCER	CSCRP	WHAPS
Anthesis day	RMSE	2.43	2.30	3.15	2.41	2.52	1.78	2.57	2.48	2.33	3.86	2.97	3.51
	CV (%)	1.14	1.08	1.48	1.36	1.42	1.00	1.75	1.69	1.59	3.55	2.73	3.23
	d	1.00	1.00	0.99	0.99	0.99	0.99	1.00	1.00	1.00	0.99	1.00	0.99
	ME	0.98	0.98	0.97	0.95	0.95	0.98	0.99	0.99	0.99	0.97	0.98	0.98
	R2	0.98	0.98	0.98	0.99	0.99	0.98	0.99	0.99	0.99	0.98	0.99	0.98
Maturity day	RMSE	2.46	3.01	2.38	2.97	3.43	2.73	2.36	2.68	2.25	3.48	3.42	3.26
	CV (%)	0.96	1.17	0.92	1.33	1.54	1.23	1.25	1.42	1.19	2.29	2.25	2.15
	d	1.00	0.99	1.00	0.98	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
	ME	0.98	0.98	0.99	0.93	0.91	0.94	0.99	0.98	0.99	0.98	0.98	0.98
	R2	0.98	0.98	0.99	0.94	0.96	0.95	0.99	0.99	0.99	0.99	0.99	0.98
Grain yield	RMSE	619	711	702	609	546	627	341	515	568	716	591	933
	CV (%)	10.8	12.4	12.2	10.8	9.7	11.2	7.8	11.8	13.0	14.4	11.9	18.7
	d	0.89	0.87	0.83	0.86	0.90	0.84	0.93	0.80	0.85	0.84	0.91	0.83
	ME	0.61	0.48	0.50	0.47	0.63	0.51	0.76	0.46	0.34	0.48	0.65	0.12
	R2	0.65	0.59	0.51	0.56	0.65	0.53	0.78	0.47	0.59	0.50	0.68	0.56

Keywords: Multi-Model ensemble, CERES-Wheat, CROPSIM-Wheat, Nwheat, Uncertainty.

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S1-P.29

APSIM Next Generation to Model Red Clover Under Nordic Climate

Ahmed Mukhtar[1] (mukhtar.ahmed@slu.se), Parsons David[1], Morel Julien[1], Kumar Uttam[1], Sandström Boel[1], Lanna Marcos[2], Wallsten Johanna[1]

[1] *Agricultural Research forNorthern Sweden, Swedish University of Agric Scinces, Umeå, Sweden*; [2] *Plant Production Ecology, Swedish University of Agric Scinces, Uppsala, Sweden*

Introduction

Cool climate and shorter growing season are the main feature of northern part of Sweden. These features poses a serious challenges to have crops which can survive under low thermal units, and grow well at higher latitudes with longer day length and higher radiation use efficiency. Red clover (*Tri-folium pratense* L.) is an important deep rooted perennial forage legume crop famous for its high protein feed (Marshall *et al.*, 2017) and high rate of biological nitrogen fixation. Red clover is a native of Sweden and have been cultivated in Sweden from at least 200 years. Management practices, study sites and climatic conditions have significant impact on the quantity and quality of forage. Climate change in the form of increased CO_2 concentration and temperature and changes in rainfall patterns have quite significant differential influences on crop yield and product quality. The effect of mangements, genotypes and environments on red clover in northern Sweden could be studied by the use of crop model such as Agricultural Production Systems sIMulator (APSIM) next generation. This model have not been tested and calibrated for northern part of the world. Therfore, the purpose of this study is to calibrate and evalaute APSIM next geneartion for red clover crop production under nordic conditions and to see how this model can capture effect of radiation use effeciency on drymatter production of red clover crop.

Materials and Methods

Data regarding crop, soil and weather for four study sites i.e. Röbäcksdalen (63◦81'N, 20◦24' E), Öjebyn (65° 34'° N, 21° 39' E), Lännäs (63°11' N, 17°74' E) and Ås (63◦24'N, 14◦56'E) were collected from Nordic field trail System (NFTS). One red clover cultivar i.e Torun (4n) drymatter data was considered only (Table 1) to calibrate the model. Afterwards, four year (2015-2018) simulation was conducted in which first year was cosnidered as establishment year while in the next three years, defoliation command was initiated to have three cuts in each year.

Results and Discussion

Above dry matter accumulation by APSIM next generation was simulated in close agreements with observed data but variation was higher during establishment year where it was under simulated as initially default cultivar coefficients were used. However, if we modify leaf radiation use efficiency (RUE) parameter then increase in dry matter was observed. Therefore, in order to get accurate estimation from APSIM next generation it is important to focus on parameters which can capture effect of higher RUE in northern part of Sweden. Similarly, to improve model performance at higher latitude light extinction coefficient was also changed but still it has been observed that proper phenotypic data should be made available to implement APSIM next generation with true spirit at ground scale.

Conclusions

Field scale data is required to calibrate the APSIM next generation at higher latitudes of Nordic regions so that it can effectively capture the effect of higher radiation use efficiency. Our results can help to see the performance of APSIM next generation at higher latitudes and help to improve the model performance on ground scale.

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Table 1. Sowing and harvesting date of Red Clover during 2015-2018 at four sites

Years	2015-18			
	Sowing	Harvests		
		H1	H2	H3
Establishment Year (Y1)	21/05/2015	21-06-2015	-	-
2016		21-06-2016	10/8/2016	10/9/2016
2017		21-07-2017	10/7/2017	28/8/2017
2018		17-06-2018	26/07/2018	5/9/2018

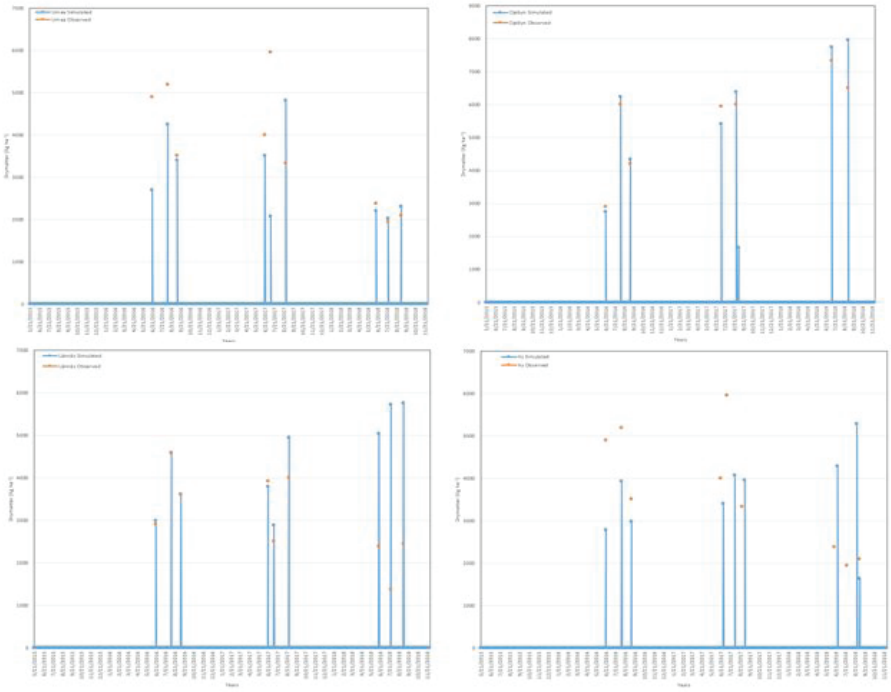

Figure 1. Red Clover Drymatter accumulation at four different study sites

Keywords: APSIM Next Generation, Red Clover, Nordic Climate, radiation use efficiency, Drymatter.

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S1-P.30

Extraction of FAO Growth Model in a Fuzzy Control Hydroponic Greenhouse

Banakar Ahmad[1] (ah_banakar@modares.ac.ir), Khafajeh Hamid[1], Minaei Saeid[1], Delavar Majid[2]

[1] *Biosytems Engineering, Tarbiat Modares University, Tehran, Iran*; [2] *Department of Water Engineering, Tarbiat Modares University, Tehran, Iran*

Introduction

Greenhouse is an environment where variables such as: climate, nutritional and biological conditions can be controlled. Therefore, the greenhouse allows horticultural crops to grow in the off-season and also affect plant growth to achieve optimal conditions for different stages of crop growth (Janoudi., 1993). The purpose of a greenhouse construction is to achieve the maximum amount of a product with the highest quality and minimum cost. Multiple factors and relationships inside the greenhouse have made it a complex system in which energy, mass transfer and genetic factors. Greenhouse production is affected by various variables, such as changes in environmental conditions (temperature, humidity, carbon dioxide and plant photosynthesis), plant nutrition (water and nutrients), biological factors (pests, diseases, viruses, bacteria and weeds) and plant breeding management (pruning) (Ali *et al.*, 2018). These variables are associated with a high level of complexity. Therefore, all of these variables need to be identified and investigated to calculate the growth model (Raes *et al*., 2010).

Materials and Methods

Water management in agricultural sector is impossible notwithstanding to water, soil and plant relationships. Models and software in soil and water relationships have been develop because the field research need to spend time, money and energy(Momeni *et al*., 2016). AquaCrop is one of the plant models developed by Food and Agriculture Organization (FAO) (Steduto *et al*., 2009). In this model, due to evapotranspiration in the greenhouse, the amount of water consumption along with increasing the crop yield has been considered. In this study, a fuzzy control was initially designed and constructed for a research hydroponic cucumber cultivation greenhouse**.**

Results and Discussion

The greenhouse system consists of several sensors, several operators, and a data collection and recording system. Operators include heating, cooling, fogging, ventilation and greenhouse lighting, and sensors include temperature, humidity, carbon dioxide gas, oxygen and light inside and outside the greenhouse. By sending and receiving environmental information from the sensors, the central controller maintains the environmental conditions inside the greenhouse within the optimal range of the FAO-2009 performance model. Plant growth parameters (consumption of water, leaf area evapotranspiration, chlorophyll content) and greenhouse energy consumption (electricity, gas) were also measured. Using these data, the plant growth model was extracted to use in optimization of control system. Fig1. Shows leaf area relation with yield. It certify by increasing the leaf area the production also has been increased.

Conclusions

The results of this study showed that it is possible to estimate the relative evapotranspiration of the reference cucumber by four variables including radiation, temperature, humidity and daily water intake in the greenhouse. The results showed that the FOA model is able to estimate the reference evapotranspiration-cucumber with the lowest error in greenhouse conditions**.**

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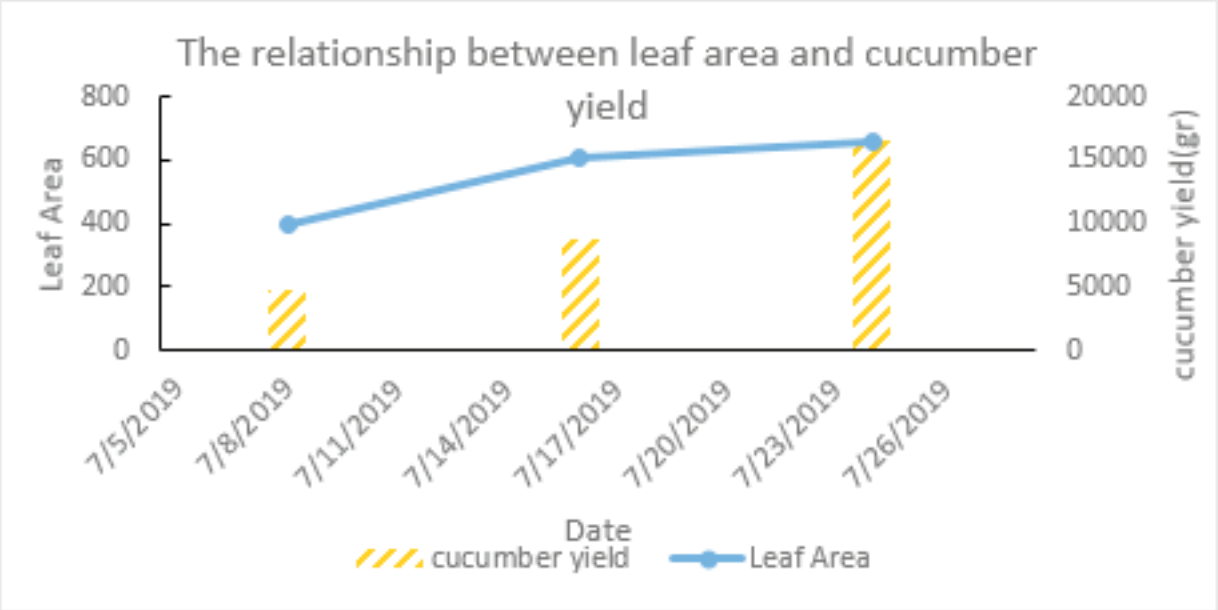

Fig1: relationship between net photosynthesis and crop yield.

Keywords: AquaCrop, Fuzzy Control, Hydroponic, Greenhouse.

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S1-P.31

Development of a global crop growth simulation model for simulating long-term trends in rice yields: Global MATCRO-Rice

Masutomi Yuji (yuji.masutomi@gmail.com)

Graduate School of Agriculture, Ibaraki University, Ami, Ibaraki, Japan

Introduction

Crop growth simulation models, CGSM, are a useful tool for analysis of crop growth and assessment of climate change impacts. A lot of CGSMs have been developed and used for a range of objectives so far. The author has developed a crop growth simulation model called MATCRO (Masutomi et al. 2016a,b). A feature of MATCRO is that detailed processes of photosynthesis in leaf and canopy are implemented. MATCRO have been validated in simulating rice yields in Japan.

CGSMs at a global scale are suitable for understanding global pictures of historical productivity and future climate change impacts. Although a large number of global CGSMs have been developed, few have been validated for globally simulating long-term changes in crop yields for countries. The objective of the present study is to develop a global CGSM for simulating long-term changes in rice yields by improving and upscaling MATCRO.

Materials and Methods

For the goal, two processes related to nitrogen were introduced. First, leaf nitrogen content depends on development stages (DVS) and the amount of nitrogen inputs (Nin) as fertilizer. Second, maximum Rubisco capacity (Vcmax), which affects photosynthesis rate, is changed by leaf nitrogen content. The dependency of leaf nitrogen content on DVS and Nin was determined by field data globally collected. The relationship between Vcmax and leaf nitrogen content followed Hasegawa et al. (2016). Global gridded data on historical nitrogen inputs developed by Lu and Tian (2017) was used for nitrogen input as fertilizer.

Results and Discussion

Figure 1 shows comparisons of rice yields from 1981 to 2010 between observations and simulations for global and top 3 rice producing countries including China, India, and Indonesia. It can be seen from Fig. 1 that the improved MATCRO can reproduce the increasing trends of rice yields. On the other hand, the original MATCRO could not reproduce them. Therefore, it can be concluded that the nitrogen processes introduced are key factors on the long-term increasing trends of crop yields.

Acknowledgements

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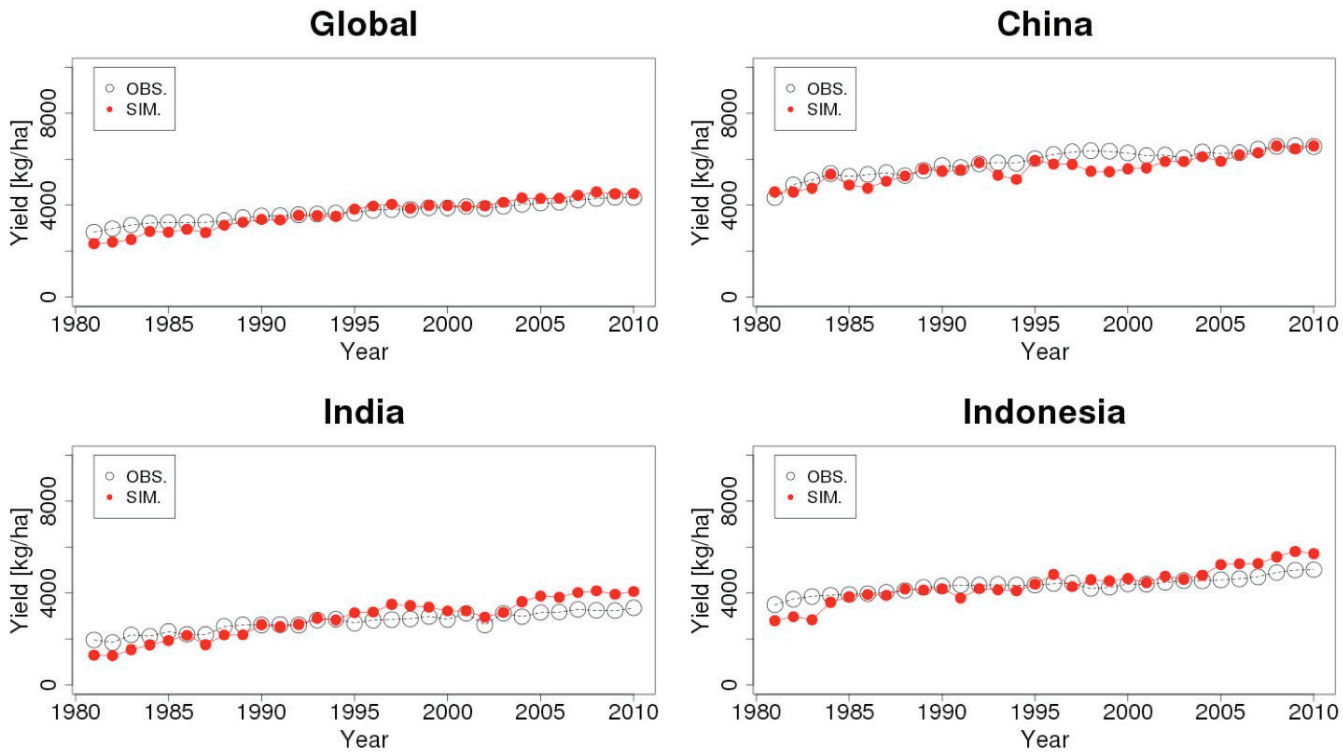

Figure 1 Comparison of rice yields from 1981 to 2010 for global and top 3 rice producing countries.

Keywords: crop model, long-term trends in crop yields, global, nitrogen, rice.

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S1-P.32

Winter wheat development and growth in The Netherlands: Using a detailed field trial to update crop parameters in WOFOST

Silva J.V.[1] (joao.silva@wur.nl), de Wit A.J.W.[2], Rijk B.[3], Supit I.[4], Reidsma P.[3], van Ittersum M.K.[3]

[1] *Centre for Crop Systems Analysis, Wageningen University, Wageningen, The Netherlands*; [2] *Earth Obs. and Environmental Informatics, Wageningen Environmental Research, Wageningen, The Ne*; [3] *Plant Production Systems, Wageningen University, Wageningen, The Netherlands*; [4] *Water Systems and Global Change, Wageningen University, Wageningen, The Netherlands*

Introduction

Crop models are key tools for agricultural research (van Ittersum et al., 2003). Despite the wide range of model applications, little attention has been paid to model calibration (Seidel et al., 2018). Detailed field trials are needed for this purpose but these are costly and barely conducted, and thus model parameters tend to become outdated. This study aims to present the results of field trials conducted in The Netherlands alongside a re-parametrization of WOFOST for relatively old and new wheat varieties. We deem this important given the genetic yield progress of wheat in The Netherlands (Rijk et al., 2013).

Materials and Methods

Two field trials were conducted in Wageningen to estimate the potential yield of winter wheat. The first was harvested in the summer 2014 and the second in 2015. The trials included three varieties (one old variety 'Ritmo' (released in 1992) and two recent varieties 'Tabasco' (2009) and 'Julius' (2010)) and three N levels (180, 240 and 300 kg N/ha) laid out in a split-plot design in four replicates. Ten intermediate samples were taken during the growing season to measure leaf area index (LAI), aboveground biomass of leaf (LVB), stem (STB) and grain (GRB) and yield components. Crop development was also recorded, including anthesis and maturity dates .

Data from 2014 were used for model calibration and from 2015 for model evaluation. Calibration consisted of: 1) optimization of thermal times to anthesis and maturity using observed phenological dates, 2) optimization of six parameters controlling leaf and biomass dynamics using measured LAI and total aboveground biomass (TAGP) and, 3) manual calibration of partitioning coefficients to approximate final yield. A non-linear optimization algorithm minimizing the RMSE between simulated and observed data was used for calibration. Simulations were done with WOFOST (de Wit et al., 2018), which was modified to include reallocation of leaf and stem biomass to grain after anthesis.

Results

Measured yields were between 10.31 and 12.52 t DM/ha in 2014 and between 10.53 and 13.06 t DM/ha in 2015. Wheat yields increased with N level and these effects were significant across years and varieties. In 2014, there were no significant yield differences between Julius and Tabasco and both outperformed Ritmo. In 2015, Tabasco obtained the greatest yield followed by Ritmo and Julius with differences between varieties being statistically significant.

WOFOST reproduced the observations of development stage, TAGP, LAI, LVB, STB and grain yield fairly well for the old variety (Figure 1). This was particularly true prior to anthesis (DVS value of 1) but values of TAGP and grain yield were slightly underestimated towards the end of the season. First results indicate that crop parameters and model performance for the new varieties were similar to those reported here for the old variety, but detailed results will be presented.

Conclusion

Detailed field trials under potential growth conditions are needed for proper calibration of crop models. This study builds upon these to re-parametrize WOFOST for winter wheat in The Netherlands. Preliminary results indicate the model can reproduce the measured data fairly well and that there are no major differences in crop parameters between the old and new varieties. Next steps will focus on improving model calibration regarding partitioning coefficients and on documenting differences in crop parameters between old and recent wheat varieties.

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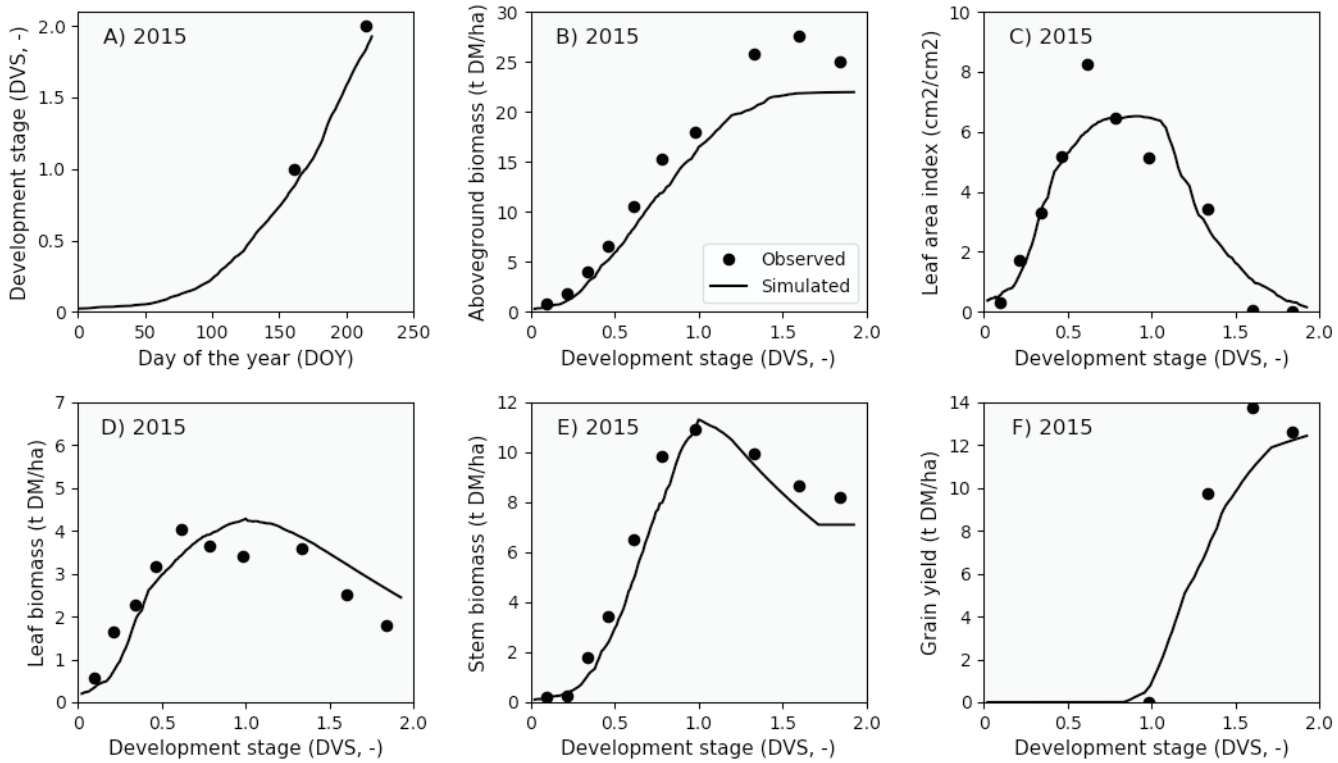

Figure 1. Simulated and observed data on A) development stage, B) aboveground biomass, C) leaf area index, D) leaf biomass, E) stem biomass and F) grain yield for an old winter wheat variety 'Ritmo' with 300 kg N ha-1 in year 2015 (used for model evaluation only).

Keywords: Yield potential, Model calibration, Wheat varieties, Genetic progress.

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S1-P.33

The effect of potato cultivar differences on parameters in WOFOST

ten Den Tamara[1] (tamara.tenden@wur.nl), van de Wiel Inge[1], de Wit Allard[2], van Evert Frits[3], van Ittersum Martin[1], Reidsma Pytrik[1]

[1] *Department of Plant Sciences, Wageningen University & Research, Wageningen, The Netherlands*; [2] *Environmental Research, Wageningen University & Research, Wageningen, The Netherlands*; [3] *Agrosystems Research, Wageningen University & Research, Wageningen, The Netherlands*

Introduction

WOFOST is a generic crop model which has been applied for many crops including potatoes (de Wit *et al.*, 2018). However, some of the crop parameter sets require revision as they are outdated. For example, for potato the values for important parameters were derived from cultivar Bintje (Wang *et al.*, 2018). Bintje was popular in the 1960s to 1980s but has now largely been replaced by modern cultivars. Therefore, the objectives of this study are to update the model parameters for potato in WOFOST and consider if these differences matter for model calibration using data from new experimental trials. This should provide farmers, industry and researchers with an improved cultivar-specific model results that can be used for estimating yield potentials, impact of water and nitrogen management, and impacts of climate variability and change.

Our focus is on parameters related to photosynthesis and biomass allocation. It is expected that there will be differences between modern cultivars and the current model values, most apparent in biomass allocation, less so for photosynthesis.

Materials and Methods

To explore the effect of different cultivars, irrigation and soil, two experiments were designed in the Netherlands, one on a clayey soil in Lelystad and one on a sandy soil in Vredepeel. Cultivars were selected for their differing lateness. In Lelystad, these were 'Innovator' (lateness: mid-early), 'Fontane' (mid-late) and 'Markies' (late) were used and in Vredepeel 'Premiere' (early), 'Fontane' and 'Festien' (late). Two irrigation and three nitrogen fertilisation treatments (Figure 1A) were used to allow for calibration of potential, water-limited and water-and-nutrient limited yield.

Measurements ran from June until final harvest. The dry weight of the stems, leaves and tubers was measured to estimate the fraction of biomass partitioned to stems (FSTB), leaves (FLTB) and tubers (FOTB). Combined with leaf area data the dry weight was used to estimate the Leaf Area Index (LAI) and the specific leaf area as a function of the development stage (SLATB). Chlorophyll and light interception (from June until crop senescence) and photosynthesis (around the time of maximal LAI) were done to allow for calibration of the maximum leaf CO_2 assimilation rate (AMAXTB, EFFTB) and intercepted light (Fint). All measurements were done on all treatment combinations, except for CO_2 assimilation, which was only done on well irrigated well fertilized plots.

Results and discussion

At the time of writing, leaf senescence is still ongoing in some plots (Figure 1B). Therefore, data collection is still ongoing and data analysis has not been completed. So far, there are large differences in aboveground biomass, yield and chlorophyll between the cultivars, between treatments for the same cultivars the differences are smaller. The nitrogen application had a stronger effect than the water treatments, especially on the clayey soils in Lelystad with more abundant rainfall resulting in smaller differences between the irrigation treatments. Differences in AMAXTB between the cultivars were small.

Conclusion

The data analysed so far indicates that AMAXTB does not differ much between cultivars around maximum LAI. Therefore, AMAXTB at this date is of less interest in model calibration than phenology, FSTB and FLTB. Data collected during the season suggests that yield potentials and impact of water and nitrogen management, differ per cultivar, which is relevant when using WOFOST.

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A

Fontane N0 37	Premiere N1 38	Festien N0 39	Premiere N2 40	Fontane N1 41	Festien N1 42
Premiere N1 31	Festien N2 32	Fontane N1 33	Festien N2 34	Premiere N2 35	Fontane N1 36
Festien N2 25	Fontane N1 26	Premiere N2 27	Fontane N1 28	Festien N1 29	Premiere N2 30
Fontane N1 18	Premiere N2 19	Festien N1 20	Premiere N0 21	Fontane N2 22	Festien N2 23
Premiere N2 13	Festien N1 14	Fontane N2 15	Festien N1 16	Premiere N1 17	Fontane N2 18
Festien N1 7	Fontane N2 8	Premiere N1 9	Fontane N2 10	Festien N2 11	Premiere N1 12
Fontane N2 1	Premiere N0 2	Festien N2 3	Premiere N1 4	Fontane N0 5	Festien N0 6
⬆ W2	⬆ W1	⬆ W1	⬆ W2	⬆ W1	⬆ W2

B



Figure 1: Experimental field in Vredepeel. In A) the plot layout. Cultivar names are written out. W indicates irrigation treatments. W2 was kept at a pF of 2.4 and W1 between 3.2 and 3.4. N indicates fertilisation with N0 being no nitrogen applied, N1 30 percent of advised nitrogen and N2 130 percent of advised nitrogen applied. In B) the field as on the 2nd of September, 2019.

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S1-P.34

Modelling water and carbon balances of date palm trees under different salinity conditions

Zhen Jingbo[1] (jingbozhen@gmail.com), Lazarovitch Naftali[1], Jansson Per-Erik[2], Tripler Effi[3]

[1] *Wyler Department of Dryland Agriculture, Ben Gurion University of the Negev, Beer Sheva, Israel*; [2] *Dept of Land and Water Resources Engrg, KTH-Royal Institute of Technology, Stockholm, Sweden*; [3] *Central and Northern Arava R&D, Sapir Center, Central Arava, Israel*

Introduction

The cultivation of date palm trees in Israel's hyper-arid Arava Valley exclusively relies on irrigation using saline water. Salinity effects on date palm have been well studied (Tripler et al., 2011; Sperling et al., 2014). Recently, a field study of Zhen et al. (2019) has found an interaction between crop load and water uptake of date palms. This study was aimed to improve our understanding with respect to water and carbon fluxes and distribution within the soil-plant-atmosphere continuum (SPAC) of date palms, by numerical ecosystem model.

Materials and Methods

We used CoupModel, a transient one-dimensional process-based ecosystem model simulating heat, water, solutes, carbon and nitrogen balances in various SPAC ecosystems (Jansson and Karlberg, 2010). The model simulated date palm trees early investigated in weighting lysimeters irrigated with three different salinity treatments (EC = 1.8, 4 and 8 $dS \cdot m^{-1}$) since 2001. Daily transpiration within 2006-2007 was calculated based on water balance in lysimeter. Temporal tree properties, such as canopy size and height, yearly new leaf number and yield each tree, were recorded. Additionally, soil property and agronomic management for the experiment were documented in previous research (Ben-Gal and Shani, 2002; Tripler et al., 2011). In the CoupModel, initial tree condition (*e.g.,* LAI and carbon content of different organs), soil property and salinity stress were set. Meteorological data and daily irrigation were input as the driving variables for the simulation. Radiation use efficiency approach was selected for leaf assimilation, which is affected by leaf temperature and nitrogen content, soil water content and salinity stress. The simulation was calibrated and validated by daily transpiration and yield. Parameter sensitivity and uncertainty analysis were also performed in order to improve the confidence of model simulation.

Results and Discussion

The results showed that the CoupModel well captured the daily transpiration and yearly yield of date palm ecosystem under different salinity treatments. High salinity level led to high respiration and lower leaf assimilation rate by reducing radiation use efficiency. Hence, less carbon was allocated to fruit sink due to maintenance demand. In addition, the simulation is sensitive to maintenance respiration coefficients and carbon allocation parameters.

Conclusion

We conclude that the CoupModel is feasible to simulate the water and carbon balances in date palm ecosystem under different salinity treatments. More field measurements coupled with calibration made with General Likelihood Uncertainty Estimation (GLUE), are needed to make the model robust. Future work will focus on modelling water and carbon balances in date palm ecosystem under combined treatments of fruit load intensity and irrigation level with local saline water.

Acknowledgements

The work of the team at Southern Arava Research and Development in Yotvata is deeply appreciated.

Keywords: Date palm, Salinity, Transpiration, Yield, CoupModel.

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S1-P.35

TADA, a mechanistic model for carbon, nitrogen and water cycle in cropland and grassland ecosystems

Delhez Laura[1] (laura.delhez@uliege.be), Dumont Clément[2], Vandewattyne Félix[2], Longdoz Bernard[2]

[1] *Gembloux Agro-Bio Tech, University of Liège, Gembloux, Belgium*; [2] *University of Liège, Gembloux, Belgium*

A process-based model which simulates carbon, nitrogen and water cycle at a plot scale has been recently developed at Gembloux Agro-Bio Tech. Adapted to different agroecosystems, this model is mainly oriented towards the estimation of greenhouse gas exchanges. The model, named TADA (Terrestrial Agroecosystems Dynamics Analysis), is based on the mechanistic 1D model ASPECTS developed for forests and was adapted to cropland and grassland ecosystems by including specific phenology, allocation scheme, management and grazing modules proposed in literature.
Some processes simulated in TADA (such as photosynthesis, soil evaporation, nitrification, etc.) were calibrated against a large dataset obtained on two Walloon ICOS (or ICOS candidate) flux tower sites: a winter wheat crop which is part of a 4-year crop rotation at Lonzee and an intensively grazed grassland at Dorinne.
The model will be presented and the improvements that could be made to improve the processes description will be highlighted, together with the measurements needed for a better calibration of these processes, as this is a long-term project.

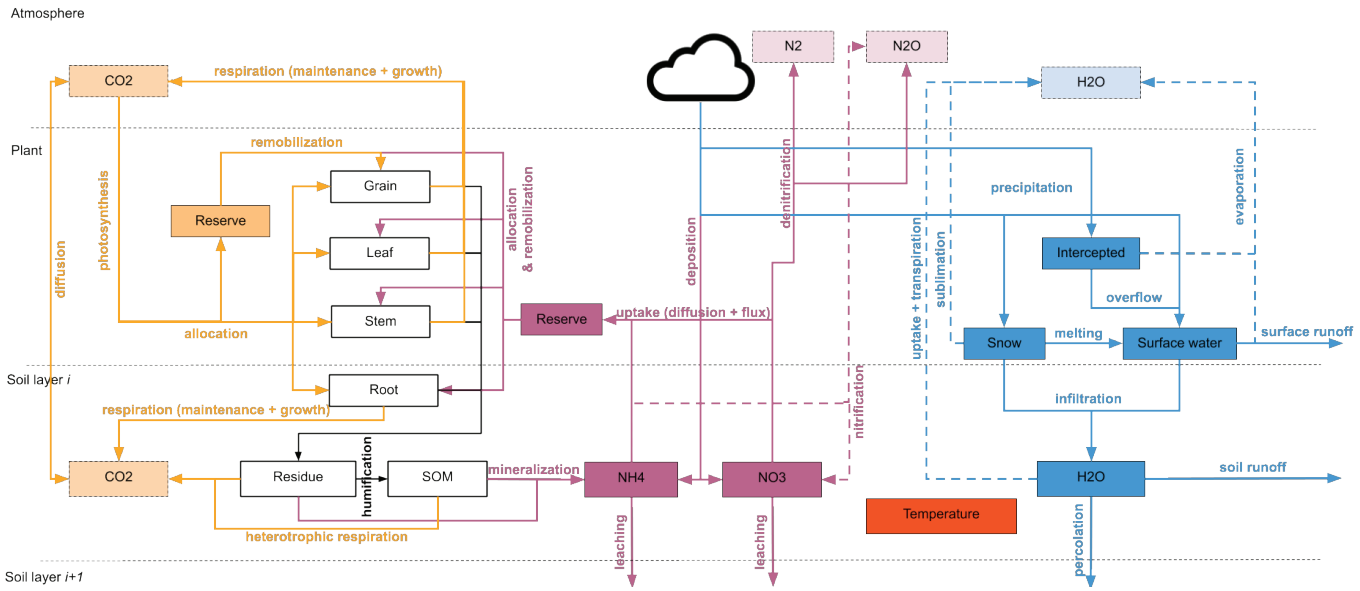

Figure 1: Diagram of the reservoirs simulated by the TADA model.

Keywords: Mechanistic modelling, grassland, winter wheat crop.

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ABSTRACTS POSTERS

SESSION II

CROP MODELLING FOR ECOLOGICAL INTENSIFICATION

S2-P.01

Modelling Climate Change Impact on Wheat Production in South Africa using GCM Projections and DSSAT model

Ajilogba Caroline Fadeke (ajilogbac@arc.agric.za), Walker Sue

Agrometeorology, Agricultural Research Council-ISCW, Pretoria, Gauteng, South Africa

Introduction

Climate change is observed to affect global agricultural sector generally and global food productivity in particular. The impact of climate change on food production in South Africa is enormous because with the lack of rainfall and drought, South Africa is likely to face food insecurity in the future (Masipa 2017). In order to mitigate the impact of climate change, it is imperative to use crop models with projected data. Using a crop model to simulate the response of crops to variation in weather would be effective in giving advisories to farmers based on the potential effect of climate change on crop yields (Waffa and Benoit 2015). Different crop models have been used to predict crop yield using observed data.

Materials and Methods

DSSAT model was used to simulate and to estimate wheat yield prediction using global climate model (GCM) data projection in Swellendam and Bethlehem areas of South Africa for adaptation measures and mitigation.

Results and Discussion

The result from this study showed that DSSAT was able to efficiently model the impact of climate change on wheat production.

Conclusions

Adaptation measures to mitigate the potential impact of climate change included possible changes in planting dates and irrigation selection.

Acknowledgements

The authors want to thank the National Research Foundation for the grant to the first author and the Agricultural Research Council-Institute of Soil, Climate, Water (ARC-ISCW) for logistics.

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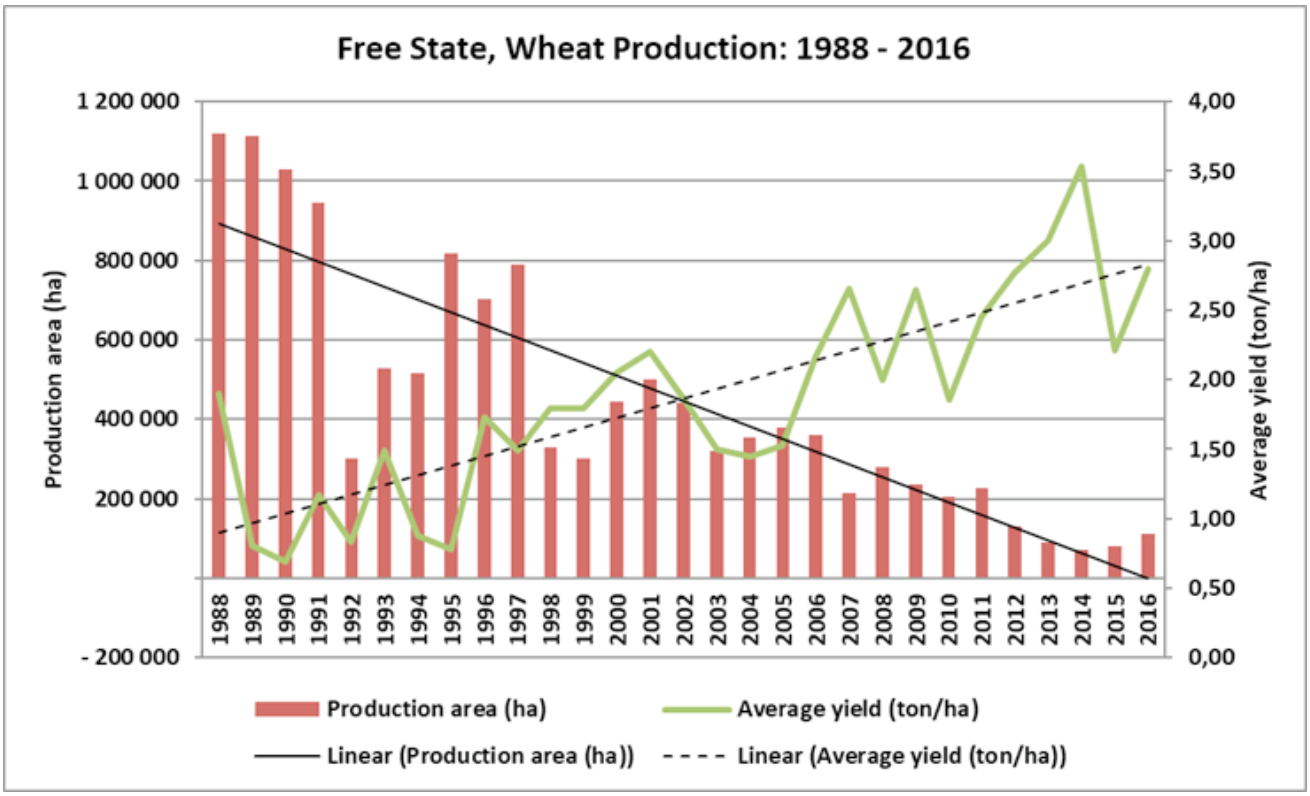

Figure 1. Wheat production in Free state, South Africa.

Keywords: Climate change, DSSAT, South Africa, Wheat production.

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S2-P.02

How does climate change impacts and adaptation alter the intensification potential of future cropping systems?

Minoli Sara (sara.minoli@pik-potsdam.de), Lutz Femke, Müller Christoph

PIK, Potsdam, Brandenburg, Germany

Introduction

Global food demand is expected to strongly rise in future decades, pushing farming systems to increase their crop productivity. Increasing total crop production by further expanding cropland is not seen as a viable option as land availability for cultivation is becoming scarce. Instead, enhancing productivity per unit of land through intensification is a widely proposed strategy to meet future crop demands, because yields in many world regions are much below their potential. This is mainly a consequence of deficits in soil water and macronutrients. Agricultural management (e.g. irrigation and nitrogen fertilization) could thus be employed for increasing yields (Mueller et al., 2012). Yet, the rapid changes in atmospheric composition (CO_2) and climate (temperature and precipitation) are also modifying the environmental conditions of global agricultural systems, resulting in variable effects on crop yields and demanding for adaptation strategies. Recent findings indicate that the implementation of relatively simple adaptive management (e.g. sowing dates and cultivars) could partially compensate for negative impacts of climate change on yields and could help exploiting the benefits due to e.g. CO_2 fertilization (Minoli, submitted). Overall, climate change is expected to modify yields of future cropping systems, but how this could affect their intensification potential remains unexplored.

Materials and Methods

Here we use a global modelling framework to study climate change impacts and adaptation of crops under different management intensities. We apply the LPJmL global gridded crop model (von Bloh et al., 2018) for simulating yields at 0.5 degrees spatial resolution. In order to simulate historical yield levels, we run the model with observed weather data for the period 1996-2005 and observation based management datasets for irrigated area, nitrogen fertilization rates and crop growing periods. We then use climate scenarios from the ISIMIP2b protocol to assess impacts of climate change on the yield intensification potential. We compute sowing dates and cultivars adapted to both historical and future climate by applying previously published rule based approaches from Waha et al. (2012), Minoli et al. (2018) and Jägermeyr & Frieler (2018).

Results and Discussion

First, we show estimates of potential yields, assuming no limitations in agricultural management, as well as yields limited by either irrigation, fertilization, or both. We analyze how current intensification potentials of major crops would be impacted under future climate, if there was no change in agricultural management. In a second step, we test the effect of adaptation strategies by adjusting crop growing periods under climate change and whether these affect global patterns of intensification potential.

Conclusions

The results will help identifying, across the different world regions, which strategically should be prioritized between intensification and adaptation, in order to increase global crop production.

Acknowledgements

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Keywords: Global Gridded Crop Model, Nitrogen fertilization, Irrigation, Sowing dates, Cultivars.

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S2-P.03

DSSAT modelling for best irrigation management practices assessment under Mediterranean conditions

Dechmi Farida (fdechmi@aragon.es), Malik Wafa

Soil and Irrigation Department, Agrifood Research and Technology Centre, Zaragoza, Spain

Introduction

Sustainable water management in agriculture aims to match water availability and water needs in terms of quantity and quality and in space and time with acceptable environmental impact, especially in arid and semi-arid regions, where irrigation is required to reach a competitive and profitable agriculture. The objectives of this research were to (1) calibrate and validate the DSSAT model for the main crops of a modernized irrigation district located in the Ebro Valley (Spain) after irrigation performance characterization at the farm-field scale and (2) determine the best management irrigation practices under different soil types and crop requirements.

Materials and Methods

This work is performed in the Violada Irrigation District (VID), located in the Ebro River basin (northeast Spain). The VID (5231 ha) was recently modernized (2008-2009) from traditional irrigation systems to pressured irrigation systems. The DSSAT V4.7 software (Hoogenboom et al., 2017) was used to calibrate and validate the main crops in the VID. Data from 54 plots of farmers' fields were used for model calibration and evaluation during two cropping seasons for barley, wheat, maize long season (maize-LS) and maize short season (maize-SS) and sunflower. In the case of alfalfa, the field experiment described by Malik et al. (2018) was used. Two irrigation scenarios were evaluated in the eight principal soil types for both seasons (the current irrigation practices and the irrigation dose adjusted to crop requirement and soil properties).

Results and Discussion

Both DSSAT calibration and validation demonstrated a good performance for all crops. The evaluation of the current irrigation system showed that farmers were not managing their modern irrigation systems adequately. Consequently, yields losses due to drought stress were identified, especially for wheat, barley and alfalfa. In contrast, an excessive irrigation water depth was applied for maize-LS, maize-SS and sunflower. The optimal irrigation schedule can improve the water use efficiency by 22.5%, 22.0%, 86.0%, 35.0% and 26.0% for maize-SS, maize-LS, sunflower, barley and alfalfa, respectively. The reduction in the seasonal irrigation depth was 27% for maize-SS, 18% for maize-LS and 16% for sunflower. In a broader context, adjusted irrigation practices could reduce the amount of deep percolation and leached N losses by 34% (1.2 hm3) and 31% (4.48 T), respectively, considering the all cultivated crop area in the VID. The spatial distribution of water lost by deep percolation and Leached N under the current and optimal irrigation schedules is presented in Figure 1.

Conclusions

The DSSAT model demonstrated good performance for simulating the main crops in intensive cropping systems under Mediterranean conditions. The water management scenarios considered in this study indicated that the optimal irrigation management significantly improved the irrigation water use by adjusting the irrigation water applied according the actual evapotranspiration needs and the soil holding capacity.

Acknowledgements

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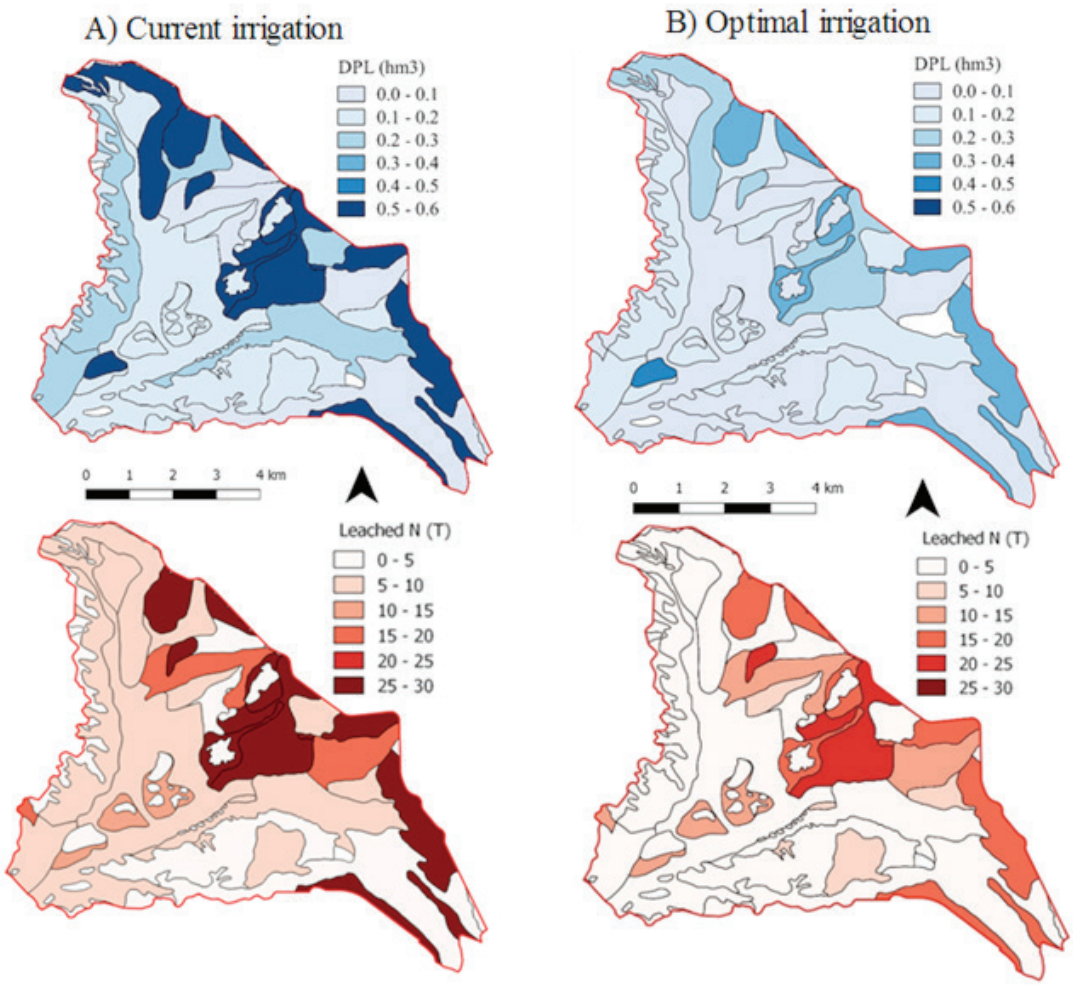

Figure 1. Spatial distribution of average total deep percolation losses (DPL, hm3) and leached N (T) under current irrigation (A) and optimal irrigation (B) in the VID.

Keywords: Current irrigation, Optimum irrigation, Deep percolation losses, N leaching, Scenarios.

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S2-P.04

Characterization of the Groundnut Production Systems in India to guide the crop improvement efforts

Hajjarpoor Amir[1] (amiragro65@gmail.com), Kholova Jana[2], Pasupuleti Janila[2], Soltani Afshin[3], Vadez Vincent[1]

[1] *IRD -UMR DIADE- Univ. de Montpellier, MONTPELLIER, France*; [2] *ICRISAT, Patancheru, India*; [3] *Agronomy Group, GUASNR, Gorgan, Iran*

Introduction

Groundnut is an important source of income for farming communities in many developing countries like China, India, Nigeria and Myanmar. The groundnut production improvement is expected to have a significant impact on food and income security especially in these countries where food supplies are in deficit (Anderson et al., 2016). Currently, China produces ~35% while India produces about a 15% of global groundnut produce (FAO, 2016). Despite, India has much larger area under groundnut cultivation compared to China and this sole fact points out to large yield gaps in groundnut production on this sub-continent. In the presented work we will build up on the methodology for yield gap analysis using the mechanistic crop-growth modelling tools (Hajjarpoor et al., 2018) and try to map and dissect the groundnut yield variability and its causes in India.

Methods

Information on bio-geo-physical properties (weather, soil, crop, management) of these regions was collated and the SSM model used to reproduce seasonal variability and potential yield for the major groundnut producing districts. The difference between potential yield and water-limited potential yield mimicked the effect of drought in that district. Further, we estimated the difference between the weighted yield potential (according to the irrigation portion) and the currently achieved yields; i.e. yield-gap. Observed geo-bio-physical properties of the districts and simulation results of yield gap analysis were used to cluster groundnut-growing districts into units with higher degrees of similarities; i.e. homogeneous system units (HSU).

Results and Discussion

The results showed that India has the capacity of doubling the groundnut production -just by reaching 70% of the achievable yield- compared to the current production status (yield gap ~65%). Actual yields vastly fluctuate between the seasons and regions (~450-2000 kg ha^{-1}). Even though groundnut grows mostly in the rainy season (82% in Kharif season) but crop production in rainfed systems is largely limited by water availability during the season (~40%) with large variability in the drought stress effect on yields between the investigated districts.

Groundnut growing areas in India are divided into five agro-climatic zones according to some old map (Witcombe et al., 1998; Rathnakumar et al., 2013). However according to the results, the border between the old zone I and II is shifting to the Gujarat because of more water scarcely in the north than in the past. Now, Rajasthan is in the separate HSU #1 (Figure 1), characteristics with high drought effect (73%). Gujarat is in HSU #2, where low radiation is limiting yield potentials, although it shows low yield gaps, indicative of proper management practices. Old Zone III is expanded now in the center of India (HSU #3). HSU #3 is also under radiation-limitation production but has high yield gap, which indicates mismanagement and likely effect of diseases. Old zone V is now divided across three HSUs with different constraints, e.g. drought effects, rainfall amount, radiation and definitely different yield gaps. HSU #4 characteristics with high rainfall amount and the highest yield gap could be mostly constrained by diseases. HSU #5 has the lowest actual yield and the most groundnut area among the rest which could be a good target for breeders. The identified HSUs are proposed as authentic breeding units in crop improvement programs (target population of environments) in India.

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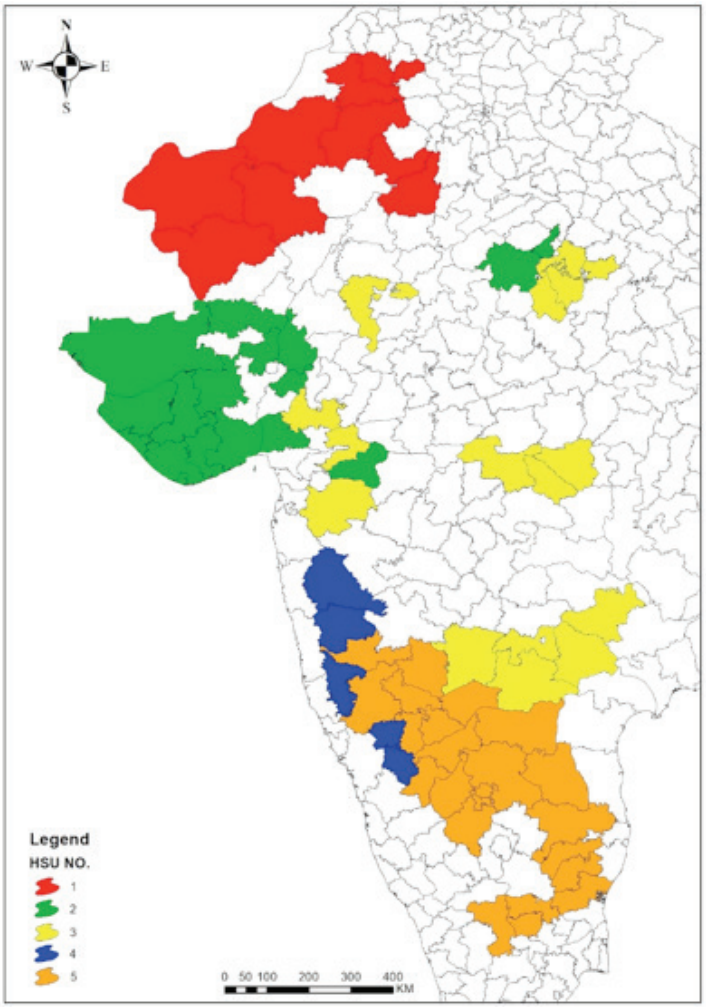

Figure. 1. Results of clustering analysis which separated districts within the main production tract in India (highlighted with colors) into five Homogenous System Units (HSUs) with higher degree of similarities in their observed and modelled bio-geo-physical characteristics. The highlighted districts encompass more than 85% of groundnut production area in India.

Keywords: Potential Yield, Yield Gap, Homogeneous System Unit, SSM Model.

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S2-P.05

Assessing the sustainability of new olive farming in the Mediterranean region using the process-based model OliveCan

Mairech Hanene[1] (mairech.hanene@gmail.com), López-Bernal Álvaro[2], Moriondo Marco[3], Dibari Camilla[4], Regni Luca[5], Proietti Primo[5], Villalobos Francisco J.[6], Testi Luca[7]

[1] *DSA3, University of Perugia, Italy & IAS-CSIC, Cordoba, Spain*; [2] *ETSIAM, University of Cordoba & IAS-CSIC, Cordoba, Spain*; [3] *Institute of BioEconomy, Florence, Italy*; [4] *DAGRI, University of Florence, Florence, Italy*; [5] *DSA3, University of Perugia, Perugia, Italy*; [6] *ETSIAM, University of Cordoba, Cordoba, Spain*; [7] *Department of Agronomy, Institute for Sustainable Agriculture, Cordoba, Spain*

Introduction

Olive (*Olea europaea* L.) is a widely spread tree species in the Mediterranean. In the last decades, olive farming has known major management changes with high economic and environmental impacts. The fast track expansion of this modern olive farming in these recent years casts doubts on the sustainability of such important tree plantation across the Mediterranean.

Materials and Methods

In this work, we performed a spatial modelling analysis to investigate the implications of climate variability and farming management on the productivity and environmental performances of olive orchards around the Mediterranean. Implementation of this research is based on the use of OliveCan; a process-based model able to illustrate responses of water and carbon balances to weather variables, soil characteristics and management techniques enabling the comprehension of olive orchard dynamics under heterogeneous conditions of climate and agricultural practices (López-Bernal et al. (2018)). Four main intensification levels were adopted to reflect the main olive grove types from traditional to new intensive plantations: low density LD (100 trees ha^{-1}), medium density MD (200 trees ha^{-1}), high density HD (400 trees ha^{-1}) and super high density SHD (1650 trees ha^{-1}). Managements tested were intensification and water supply (rainfed, deficit and full irrigated). Two cases studies in two of the main Mediterranean olive-growing regions with contrasting environmental conditions, Tuscany and Jaen regions, focused on mitigation alternative managements for carbon sequestration.

Results and Discussion

Results showed that olive orchards responses in terms of yield and Net Ecosystem Productivity (NEP=Gross Primary Productivity - Total Ecosystem Respiration) are highly responsive to climate variability. Assessment of impact surface responses of yield showed that the increase in yield is not driven by water inputs only but depends also on evaporative demand (Figure 1). The C sequestration potential of olive orchards was confirmed. Implications of management innovations on olive farming sustainability was quantified. In fact, irrigation and increasing the level of intensification have positive impacts on olive groves carbon sequestration potential due to the increase in biomass production and thus the higher input for the carbon pool accumulation.

Conclusions

Findings of this research enabled the identification of the main drivers influencing the productive and environmental performance of olive groves in the different Mediterranean sub-climates. Impacts of management innovations on olive farming sustainability were also quantified. This increases the knowledge about the environmental role of olive production and its potential implication in mitigating climate change.

Acknowledgements

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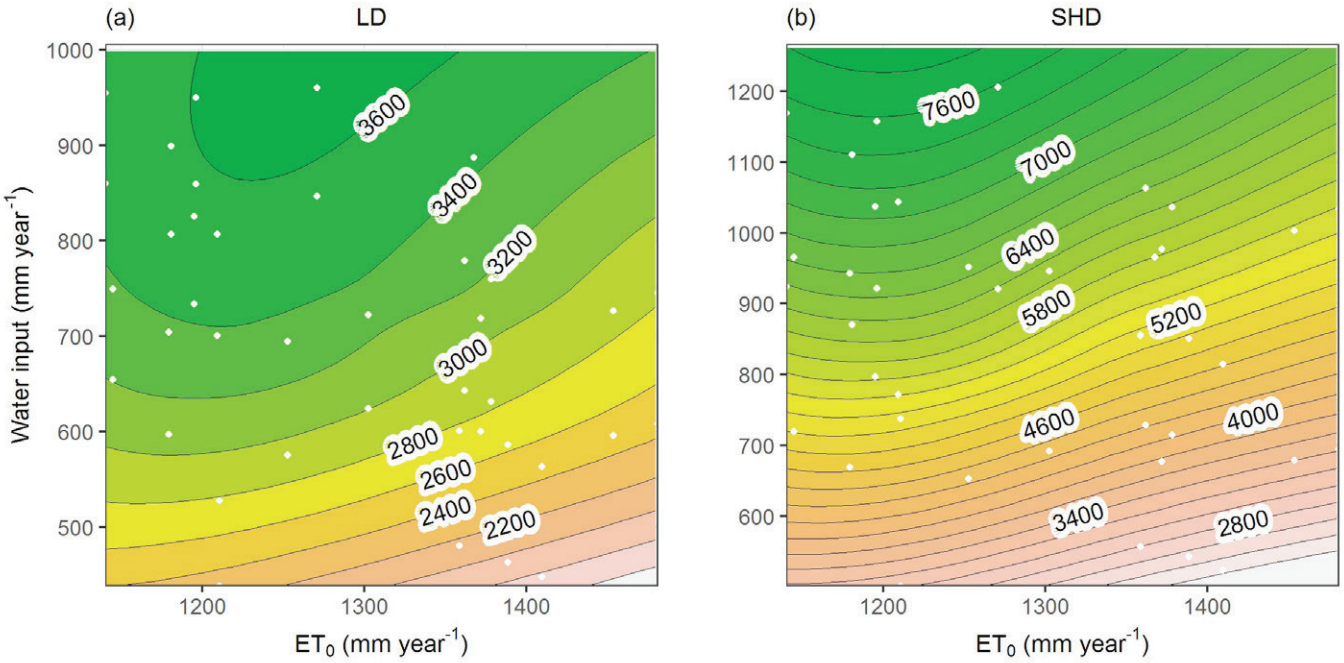

Figure 1: Impact surface response of dry yield (kg ha-1) to variation in ET0 and total water inputs for LD and SHD orchards

Keywords: Olea europaea, Climate, Agricultural management, OliveCan, Carbon sequestration.

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S2-P.06

Assessment of nitrogen fertilizer release half-life using crop modelling based experiments in tropical soils

Mehmandoost Kotlar Ali[1] (aliko@usp.br), Turek Maria Eliza[2], de Jong van Lier Quirijn[1]

[1] *University of Sao Paulo, Piracicaba, São Paulo, Brazil*; [2] *Universidade Federal do Paraná, Curitiba, Parana, Brazil*

Abstract

This numerical study uses SWAP- N module crop model to assess the effect of hypothetical slow release fertilizer with different half-lives 10, 20, 30 and 40 days. The soil hydraulic parameters of typical layered profiles nearby Piracicaba under cultivation of summer maize and the recommended 180 kg N ha-1 was considered as major input of the model. A typical manure fertilization to provide 180 kg N ha-1 was simulated and then SRFs were applied in two different ways first when the 180 kg N ha-1 was added on the sowing data and secondly we assumed the application of alleviated weight of SRFs to provide plant with 180 kg N ha-1 during cropping period. Yield of maize under application of SRFs with half-lives of 30 and 40 days can increase up to 200 kg N ha-1 and leaching of nitrogen diminished by 30 to 40 kg ha-1, unless bottom layers of the soil profile are very permeable. In both scenarios of SRF application and in all soils, SRF with half-life of 10 days resulted in more leaching and less uptake by plant compared to typical fertilization scenario.

Results and Discussion

The uptake and leaching of nitrogen besides grain yield of simulated maize are plotted in Figure 2. Generally, increase in half-life resulted in increase in nitrogen uptake and yield, however leaching of nitrogen was reduced, regardless of inherent 25 and 50 kg nitrogen loss of slow release fertilizers with half-life of 30 and 40 days. Nitrogen uptake increased more by increasing half-lives for soils (II) and (III) where 7 and 10 kg ha - 1 rise in N uptake was observed in using SRF with 40 days' half-life compared to typical urea fertilizer. However, in soil (I), no improvement in nitrogen uptake between SRF with half-life of 20, 30 and 40 days occurred. A very permeable layer in soil (III) can affect in a way that no more nitrogen is taken up by plant due to increasing half-life. This simulated maize has 60 cm rooting depth on average within the first 30 days and in this depth soil hydraulic conductivity is extremely large in this soil, thus movement of water in lower depths are faster than root uptake. Therefore, soils with permeable layers at the bottom could entirely react in a different way with SRFs. In soil (III), no significant change between nitrogen leaching and yield were observed along with half-life increasing, confirming that during plant growth extension of half-life will. In soil (II) and (III), using SRF with longer half-lives can reduce nitrate leaching by more 10 kg ha – 1, however SRF with half-life of 10 days resulted in increase in leaching by 10 and 6 kg ha - 1 compared to the typical fertilizer (half-life of zero). In these soils (II and III), SRF with 40 days' half-life led to 350 and 400 kg ha - 1 yield increase in comparison to application of typical fertilizer.

Conclusion

In this study, we demonstrated that using numerical experiments the fate of nitrogen from hypothetical slow release fertilizers with half-life of 10, 20, 30 and 40 days can be traced within the media. Short time slow release fertilizer did not provide required amount of nitrogen for maize, however, SRF with longer half-life increased nitrogen uptake by plant. Using slow release fertilizer with half-life between 20 to 40 days for maize cultivation in Sao Paulo, Brazil, 200 to 400 kg ha - 1 yield increase and 10 kg ha - 1 nitrogen leaching reduction can be expected.

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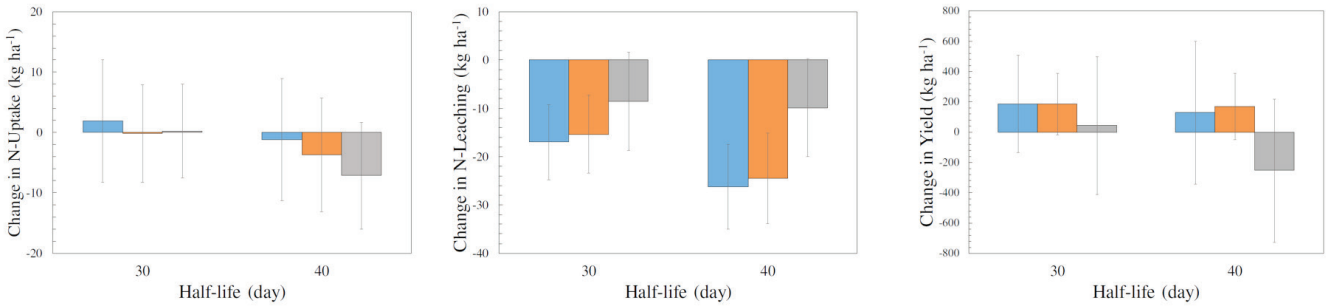

changes in crop yield (maize), nitrogen uptake and leaching under application of nitrogen slow release fertilizer with 30 and 40 days half life.

Keywords: slow release fertilizer, layered soil profiles, nitrogen leaching, nitrogen uptake, half life.

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S2-P.07

Modeling of nitrous oxide emissions from no-tillage systems in the Cerrado of central Brazil

da Silva Fernando A. Macena[1] (fernando.macena@embrapa.br), de Oliveira Alexsandra Duarte[1], Justes Eric[2], Naudin Krishna[2], Muller Artur Gustavo[1], de Sá Marcos Aurélio Carolino[1], Malaquias Juaci Vitória[1], de Carvalho Arminda Moreira[1]

[1] *Cerrados, EMBRAPA, Planaltina, DF, Brazil*; [2] *PERSYST, CIRAD, Montpellier, France*

Introduction

The prediction of the effects of land-use changes on soil carbon dynamics and GHG emissions is an essential condition underlying the formulation and analysis of effective policies. In the last 20 years, not only analytical methods, but also computer simulators have been recommended for this purpose (Plaza-Bonilla et al, 2018).

These simulators are known as powerful tools to assess the effects of interactions between management practices, soil and climate on the agricultural production environment. To this end, the modeling of N20 emissions, the greenhouse gas with the largest contribution from agricultural activities and the highest global warming potential (Figueiredo et al., 2018), can be an important evaluation tool of the adaptability and mitigation capacity of agricultural production systems under different soil management systems in the Cerrado.

The main objective of this study was to evaluate the capacity of the STICS (French acronym for "multidisciplinary simulator for standard crops") model (Brisson et al., 2002) to simulate soil N_2O fluxes in no-tillage systems, under the soil-climatic conditions of the Cerrado.

Material and Methods

The date used in this study were obtained from October 2013 to September 2014, on a long-term experiment (initiated in 1996) at Embrapa Cerrados research station, Brazil (15 ° 33'33.99 «S, 47 ° 44'12.32 «W; 1035 m asl). The climate is seasonal, classified as Aw-tropical rainy (Köppen), with two well-defined seasons (dry and rainy). The soil of the experimental area is classified as "Latossolo Vermelho distrófico" and has a clayey texture (50% clay) (Santos et. al., 2013. The climatic variables were recorded by an automatic weather station (®Campbell Scientific), installed near the experimental plots. The N_2O fluxes were measured by the static closed chamber method. The total N_2O fluxes were determined in 88 evaluation events. One static chambers was installed for each of the three replicate of the soil management system modality.

Results and Discussion

The observed and simulated values of cumulative N_2O emissions were fitted as a function of the parameter optimization related to the potential denitrification rate of the model (vpotdenit = 0.1386) at a soil depth of 10 cm (0-10 cm layer). As can be seen in Figure 1, the dynamics of N_2O emissions are well simulated by the model. By adjusting the potential rate of denitrification cumulative values of N_2O simulated were close to observed values.

Conclusions

The results indicated that under the soil-climatic conditions of the Cerrado in the central region of Brazil, STICS proved to be a well-adapted model to simulate cumulative N_2O emissions in no-tillage systems. Consequently, it is promising for future contributions to the formulation and analysis of environmental, agricultural, social and economic policies, in particular with regard to global climate changes.

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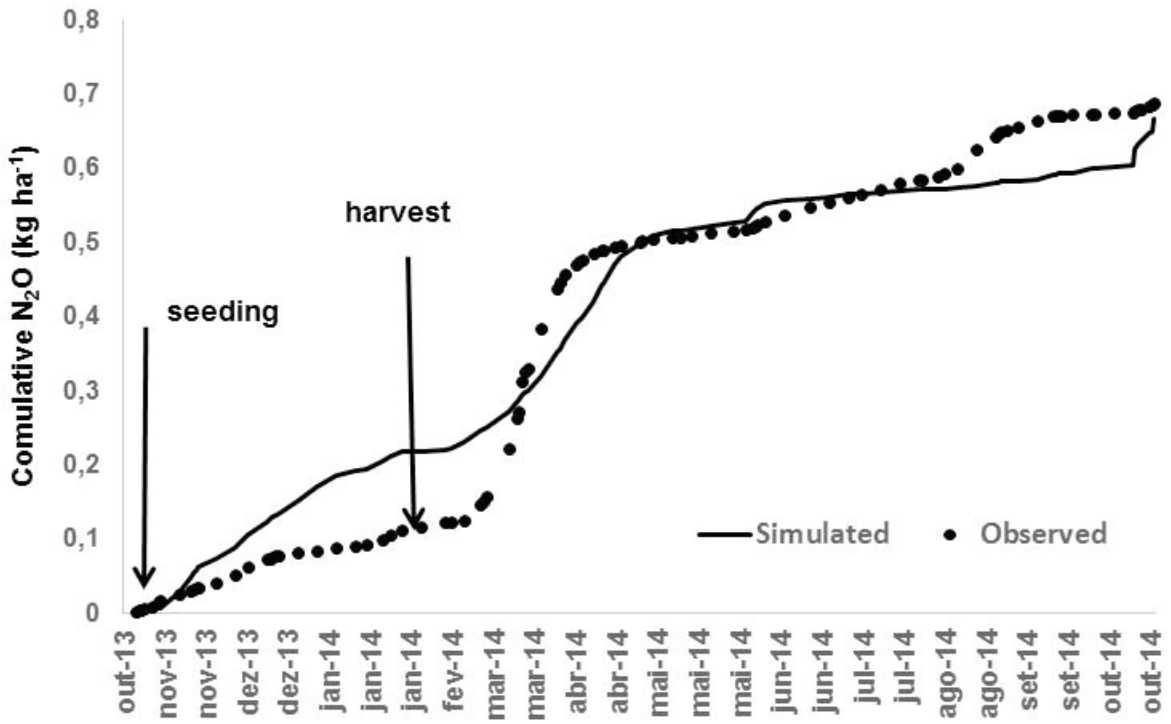

Observed and simulated values of cumulative N_2O losses for no-till soybean, between 10/22/2013 and 10/30/2014.

Keywords: GHGs, STICS, soil management, soybean, tropical climate.

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S2-P.08

Do cover crops increase or decrease spatiotemporal variability in maize yield?

Poffenbarger Hanna (hanna.poffenbarger@uky.edu), Leuthold Sam, Salmeron Montserrat, Wendroth Ole, Haramoto Erin

Plant and Soil Sciences, University of Kentucky, Lexington, KY, United States

Introduction

Complex rolling-hill terrain is a common feature of agricultural landscapes. Topographic complexity causes downslope movement of soil, water, and nutrients, leading to a mosaic of high- and low-productivity zones throughout a particular field. These high- and low-productivity zones can shift from one year to the next due to different weather conditions (Maestrini and Basso, 2018), making optimum rates of inputs challenging to predict and increasing the risk of low economic returns to inputs. One approach to addressing this challenge is to stabilize crop yield and input requirements over space and time using cover crops, which protect topsoil against erosion, enhance plant-available soil water, retain excess nutrients, and release nutrients gradually (Kaye and Quemada, 2017). The objectives of this study were to: 1) determine the effect of a winter cover crop on spatial variability in maize (*Zea mays* L.) yield using a field study, and 2) determine the effect of the cover crop on yield spatial variability under different weather conditions using model simulations.

Materials and Methods

In fall of 2018, we initiated a field experiment that included two cover crop treatments [cereal rye (*Secale cereale* L.) and no cover] applied on summit, backslope, and toeslope positions of a rolling field in Lexington, Kentucky, USA. In the following spring, the cover crop was terminated, maize was planted, and the plots were split into four N fertilizer rates (0, 90, 180, 270 kg N ha-1). We characterized soil physical and chemical properties at each landscape position and measured cover crop biomass and N content, soil inorganic N and moisture content during the maize growing season, maize plant N content at silking and maturity, and grain yield. We used data collected in the field study to calibrate and validate the Decision Support System for Agrotechnology Transfer to predict maize yield at each landscape position. We then performed simulations of maize yield at each position for a range of weather conditions.

Results and Discussion

The three landscape positions differed in elevation (274, 276, and 270 m above sea level for backslope, summit, and toeslope, respectively), slope (5.1, 2.1, and 1.4 degrees for backslope, summit, and toeslope, respectively), and depth to bedrock (~25 cm for backslope and >100 cm for summit and toeslope). Cover crop growth differed by landscape position, with 3140, 3430, and 2580 kg ha-1 aboveground biomass produced on the backslope, summit, and toeslope, respectively. The 2019 growing season was relatively dry and maize yield responded strongly to landscape position: yield was lowest on the backslope, intermediate on the summit, and greatest on the toeslope (Figure 1). At the optimum N rate, the winter cover crop decreased yield by 25% on the backslope but did not affect yield on the other two landscape positions (Figure 1).

Conclusions

Our preliminary results suggest that the cover crop increased spatial variability in maize yield by increasing maize water stress in the backslope position, where soil was shallow and water stress was high. Model simulations will be performed to better understand the interactive effects of landscape position, cover crop, and weather on maize grain yield.

Acknowledgements

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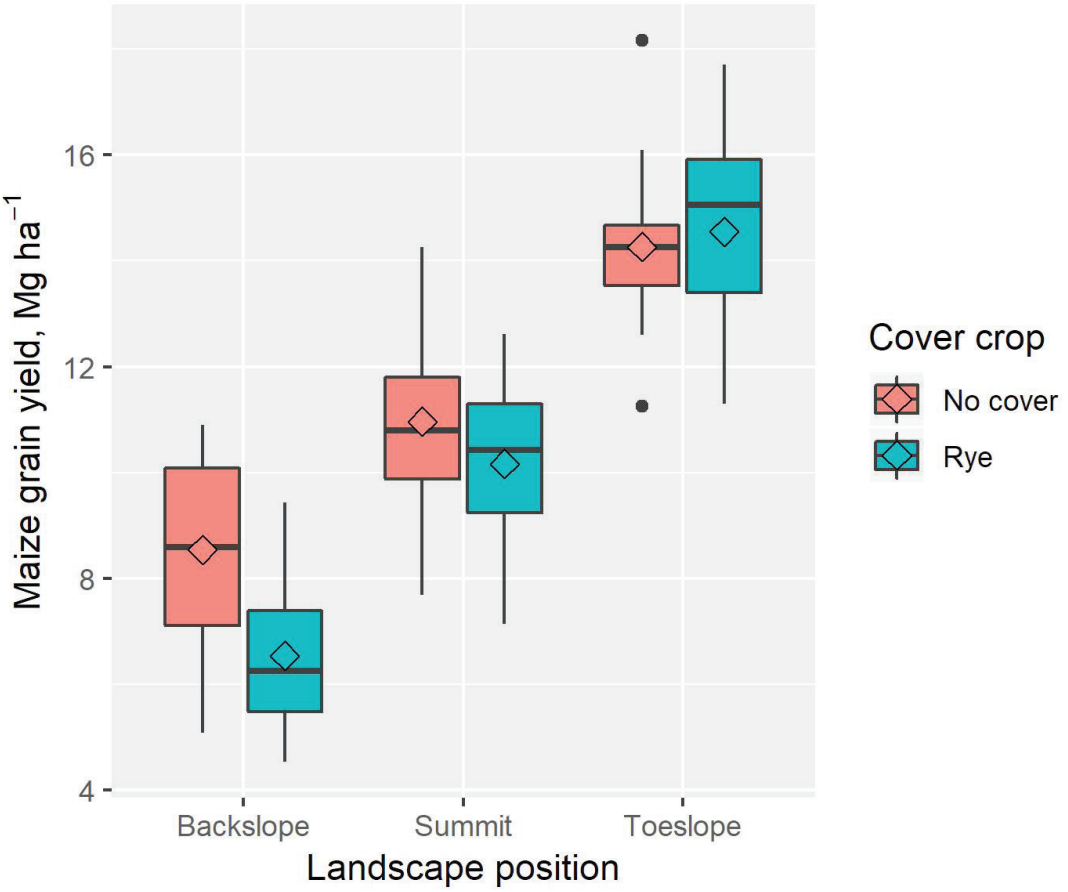

Figure 1. Boxplot showing the effect of landscape position on 2019 maize grain yield as influenced by a preceding cereal rye cover crop in Lexington, Kentucky, USA. Results are from plots with sufficient N fertilization for optimum yield. Maize grain yield is expressed at 15.5% moisture. Diamonds represent arithmetic means.

Keywords: Topography, cereal rye, DSSAT, nitrogen fertilizer.

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S2-P.09

Evaluating short-season soybean management adaptations for cover crop rotations

Salmeron Montse[1] (msalmeron@uky.edu), Sciarresi Cintia[1], Proctor Chris[2], Haramoto Erin[1], Lindsey Laura[3], Inveninato Carmona Gabriela[2], Elmore Roger[2], Everhart Sydney[2], Marroquin-Guzman Margarita[4], McMechan Justin[2], Wehrbein Joshua[2], Werle Rodrigo[5]

[1] *University of Kentucky, Lexington, KY, USA*; [2] *University of Nebraska, Lincoln, NE, USA*; [3] *Ohio State University, Columbus, OH, USA*; [4] *University of Kentucky, Lincoln, NE, USA*; [5] *Univeristy of Wisconsin-Madison, Madison, WI, USA*

Introduction

One limitation for the introduction of cover crops in grain crop rotations is a timely seeding after harvest of the main grain crop in the fall. Crop models could be used to identify short-season soybean maturity groups (MG) that advance cover crop seeding date while minimizing the risk of soybean yield losses. However, the need to obtain crop growth coefficients for new cultivars limits crop model application. The use of MG-based cultivar coefficients previously calibrated for a region could provide similar accuracy in the prediction of phenology and yield compared to cultivar-specific coefficients for this agronomic application (Salmeron and Purcell, 2016; Salmeron *et al.*, 2017). The aims of this study were: (i) to calibrate and evaluate a soybean model to predict harvest date and yield for a wide range of MG cultivars in our U.S. study region; and ii) to utilize the calibrated model to quantify the potential of early soybean MGs to advance cover crop seeding date without a yield penalty across different scenarios.

Materials and Methods

Experimental data was obtained from 13 site-years across Nebraska, Ohio and Kentucky, U.S. (2017-2018, latitudes 39.9 to 42.4°N) with 16 commercial soybean cultivars from MG 0 to 4. Five common cultivars across sites (one within each MG) were used to calibrate and obtain MG-based crop growth coefficients for the DSSAT – CROPGRO model (v.4.6.1.0) (Hoogenboom et al., 2015) with minimum observed data (phenology, harvest yield, and yield components). Thereafter, the model was evaluated to predict yield for the remaining 11 cultivars. After calibration, a sensitivity analysis was conducted using MG 0 to 4 cultivars, 30-yr of weather data, different soils, planting dates, and for irrigated and rainfed conditions.

Results and Discussion

The Root Mean Square Error (RMSE) in the prediction of yield when using MG-based cultivar coefficients (0.391 Mg ha-1) was similar to the RMSE obtained with the five cultivars used for calibration (0.396 Mg ha-1). Similarly, the RMSE in the prediction of harvest maturity (R8) only increased from 6.6 to 7.4 days when using MG-based cultivar coefficients. Thereafter, the analysis of variance from the simulated scenarios revealed that yield was most sensitive to planting date under irrigated conditions, and to soil type and year under rainfed conditions. Cultivar MG was responsible for a relatively low percentage of yield variability. Adapting to short-season MGs would advance harvest date by 6.6 to 11 days per unit decrease in cultivar maturity when planted on May 15, allowing to increase the cover crop growing window before the first freeze (Figure 1, left). The earliest MG cultivars that would advance harvest without a yield penalty were MG 0 to 3 cultivars, depending on the location, planting date, and irrigation system (Figure 1, right). Adapting to even earlier MG cultivars outside from the optimal range would have a yield penalty that ranged from0.20 – 0.60 Mg ha-1 per unit decrease in cultivar maturity in our study region.

Conclusions

Model simulations with MG-based coefficients were efficient for the prediction of harvest maturity and yield of MG 0 to 4 in our study region. Our analysis provides a useful framework to apply crop simulation models to identify management adaptations that can facilitate rotations with cover crops.

Acknowledgements

This work was supported by the USDA-NIFA project no.93910, 2016-2019 and the University of Kentucky.

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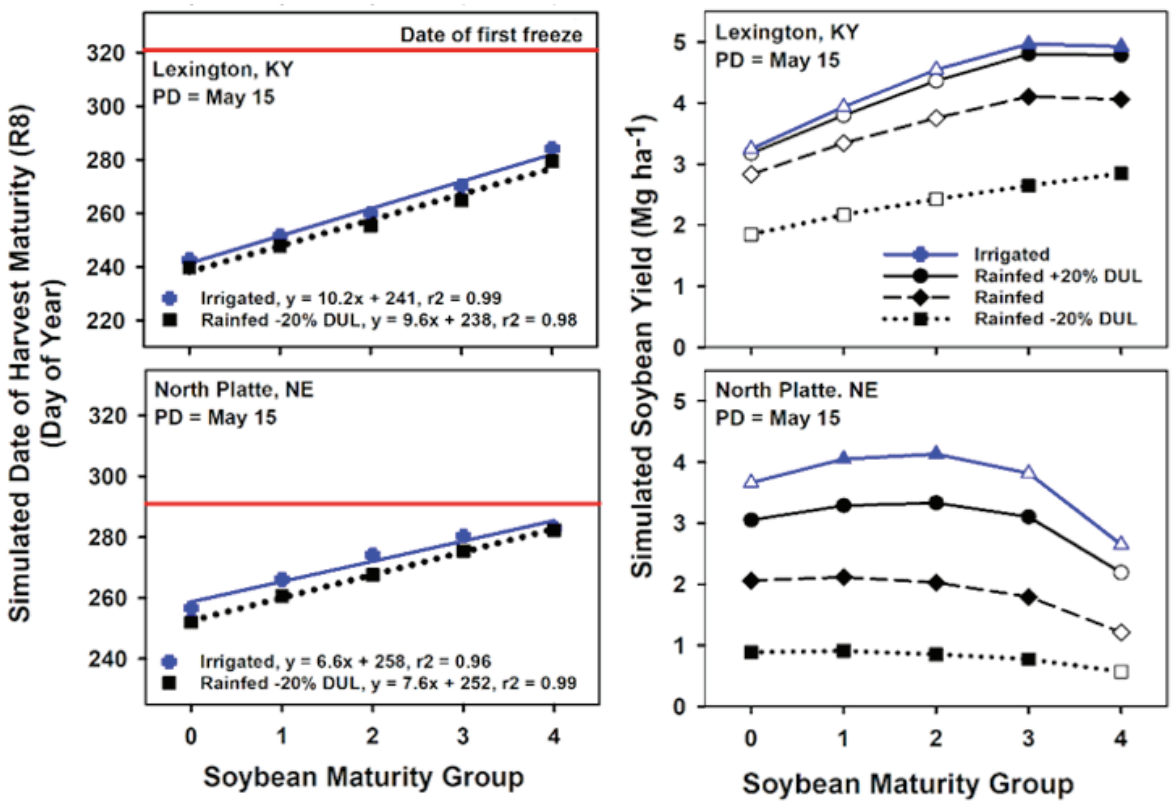

Figure 1. (Left) Simulated day of soybean harvest maturity (R8) by cultivar maturity group at two select sites in our study. Red lines indicate the average date of first freeze. (Right). Simulated soybean yield by maturity group under irrigation (blue), and under rainfed conditions (black lines) with changes in the soil drained upper limit (DUL). Simulations are averaged across 30-yr of weather data. Solid symbols indicate cultivar MG with the highest yield or not significantly different than the highest yielding, within a location, irrigation management, and soil type.

Keywords: cover crop, management adaptation, cultivar calibration, soybean.

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S2-P.10

The relative impact of soil variability on the value of variable rate irrigation strategies

Sharp Joanna[1] (joanna.sharp@plantandfood.co.nz), Hedley Carolyn[2]

[1] *Plant and Food Research, Christchurch, Canterbury, New Zealand*; [2] *Manaaki Whenua - Landcare Research, Palmerston North, New Zealand*

Introduction

Although New Zealand (NZ) could be considered water-rich, many of the intensively farmed lowland areas frequently suffer summer droughts. New irrigation schemes move water from rivers and aquifers to support agricultural production, which has seen 100% increase, to 750,000 ha, in irrigated land since 2002 (Statistics NZ 2017). The production and economic benefits are substantial, with estimates that irrigation contributes $NZ2.17 billion to GDP each year (NZIER 2014). However agricultural intensification has increased nutrients lost to ground water (Parfitt et al. 2008), and with large areas of highly variable alluvial soils, there is concern that this variability may be contributing to the decline in freshwater quality. NZ irrigation systems are now predominantly sprinkler which can be adapted for variable rate irrigation (VRI), offering the potential to control water application based on soil variability. We endeavoured to test this in real irrigated cropping systems using a modelling approach.

Materials and Methods

Five irrigated cropping sites across NZ were selected to cover a range of soil variability. Electromagnetic and gamma soil surveys were conducted at each site. Data were used to guide detailed soil survey and to delineate sites into distinct soil zones with known characteristics such as permeability and water storage. The impact of this variability and the potential for its management was then explored using a spatial framework developed for the systems model APSIM (Holzworth et al. 2014) that could take in to account variability in soil properties observed under a single irrigator with constrained water and infrastructure availability (Sharp & Brown 2016). Simulations of potato and maize at each of the sites were created with industry informed management. A factorial of 35 seasons of meteorological data, from 1980 to 2015, was then applied to explore inter-annual variability in weather. Irrigation scenarios considered used a deficit approach and irrigation was either managed uniformly, using a proportional mean across the site, or VRI. Outputs from the simulations were irrigation application, yield, drainage and WUE, and were transformed to give the percentage difference between VRI and uniform irrigation within a given growing season.

Results and Discussion

Managing deficit irrigation using VRI, compared with uniform irrigation, resulted in little difference in yield across sites (not shown), however less irrigation was applied, up to 37% in maize and 31% in potatoes. There was an associated decrease in drainage, up to 44% in maize and 43% in potatoes, and an increase in WUE, up to 16% in maize and 10% in potatoes. Analysis of site characteristics indicated that across the study sites the magnitude of the effect was largely driven by characteristics associated with site variability in PAW storage in the surface soil layers.

Conclusions

VRI may be a useful tool in adapting irrigation management to soil variability, reducing irrigation water use, increasing WUE and reducing drainage in systems with large variability in soil water properties, without sacrificing yield. However, where variability is low, these benefits are marginal.

Acknowledgements

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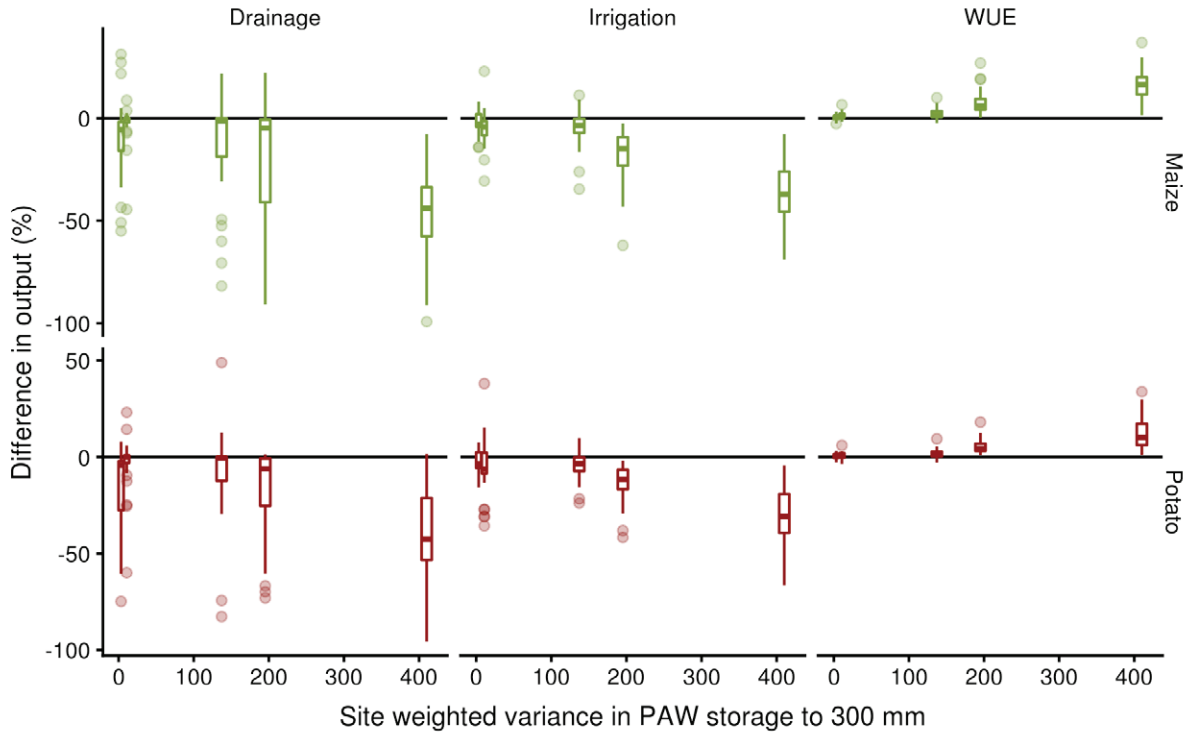

Percentage difference in outcomes under VRI compared with uniform irrigation within a given season over 35 growing seasons across all sites for both maize (green) and potato (red). Data are shown relative to the site-weighted variance in PAW to 300 mm.

Keywords: APSIM, VRI, WUE.

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S2-P.11

Developing and exploiting a crop model to simulate novel semi-dwarf rye genotypes

Shawon Ashifur Rahman[1] (til.feike@julius-kuehn.de), Bergjord Olsen Anne-Kari[2], Waalen Wendy[2], Harvie Jordan[3], Haikka Hanna[4], Tupits Ilme[5], Tamm Ilmar[5], Kottmann Lorenz[6], Schittenhelm Siegfried[6], Tenhola-Roininen Teija[7], Zechner Elisabeth[8], Wiesner Franz[8], Hanek Monica[9], Niewinska Malgorzata[9], Siekmann Dörthe[10], Fromme Franz Joachim[10], Baga Monica[11], Chibbar Ravindra N.[11], Grausgruber Heinrich[12], Hackauf Bernd[13], Feike Til[1]

[1] *Strategies and Technology Assessment, Julius Kühn-Institut, Kleinmachnow, Germany*; [2] *Norwegian Institute Bioeconomy Research, Steinkjer, Norway*; [3] *Agriculture and Agri-Food Canada, Lethbridge, Canada*; [4] *Boreal Plant Breeding Ltd., Jokioinen, Finland*; [5] *Estonian Crop Research Institute, Jõgeva, Estonia*; [6] *Crop and Soil Science, Julius Kühn-Institut, Braunschweig, Germany*; [7] *Natural Resource Institute Finland, Jokioinen, Finland*; [8] *Saatzucht Edelhof, Zwettl, Austria*; [9] *Danko Hodowla Roślin Sp. z o.o., Kościan, Poland*; [10] *HYBRO Saatzucht GmbH & Co. KG, Schenkenberg, Germany*; [11] *University of saskatchewan, Saskatoon, Canada*; [12] *BOKU, Vienna, Tulln, Austria*; [13] *Breeding Research on Agricultural Crops, Julius Kühn-Institut, Sanitz OT Groß Lüsewitz, Germany*

Background

Global production of rye (*Secale cereale* L.) has substantially decreased over the last decades on the expense of intensive wheat and barley production. This continuous concentration on few intensive crops results in a marginalization of traditional land management systems and loss in agricultural biodiversity. Rye is a traditional temperate climate cereal cultivated on marginal sites throughout Northern Europe, Russia and Northern America.

To strengthen and promote rye as a sustainable and healthy minor cereal eleven partners from six European countries and Canada joined in the SusCrop ERA-Net Cofunded Project "RYE-SUS". In the frame of the project the dwarfing gene Ddw1 will be introgressed into rye aiming to increase rye's harvest-index, resource use efficiency and winter-hardiness, and to reduce its lodging susceptibility as well as ergot problems.

Marker assisted selection allows the exact introgression of Ddw1 in rye breeding lines to generate near-isogenic tall and semi-dwarf hybrids, which are genetically identical but differ solely in the dwarfing gene. A large number of such near-isogenic tall and semi-dwarf genotypes are produced and tested at various RYE-SUS environments. This allows the robust assessment of the morphological, physiological and phenological effects of introgressing the dwarfing gene on a large set of diverse genotypes.

Despite the availability of numerous crop models for wheat, to the best of our knowledge no crop model for simulating rye exists. Hence, we develop a rye crop model building on the existing N-Wheat model. This will allow us to simulate growth, phenology and yield of tall and novel semi-dwarf rye genotypes under diverse environments to support the development and optimization of climate smart rye cropping systems.

Model development and Application

A vast long-term multi-site experimental data set of state variety trials of released tall rye varieties from Germany is available to calibrate for rye phenology. Additionally, experimental data sets are available featuring rye and wheat within one experimental set-up providing detailed in-season data on crop growth, development and yield formation under varying water and nitrogen availability (cf. Table 1.). Furthermore, an experiment with different sowing densities and genotypes will be conducted in 2020 at three German sites to complement the data for model development. Finally, precision root phenotyping of selected genotypes will be conducted at three RYE-SUS sites in 2021.

Major model adjustments for rye will consider among others for an accelerated growth in spring, a high-performance root system, stronger winter hardiness and extended "stay green" of rye as compared to wheat.

To improve the simulation of winter survival, the rye model will be linked to the FROSTOL model (Bergjord et al., 2008). This will be realized by including a spring field plant coverage factor derived from FROSTOL, to better account for possible winter damages, and improve growth and yield predictions.

Furthermore, dynamic QTL-effect modules will be developed to simulate specific crop characteristics as a function of QTL, E, and QTL x E, utilizing the recently described geno- and phenotypic data for a bi-parental mapping population (Hackauf et al., 2017). Finally, the validated model will be used to assess the performance and sustainability (e.g., N-leaching, N use efficiency) of semi-dwarf vs. tall genotypes at several sites under current and future climatic conditions.

.../...

2009-2011	Braunschweig	Stored soil moisture	Schittenhelm et al. (2014) Eur J Agron
2007-2009	Kiel	Nitrogen supply	Sieling et al. (2016) Agr Res

Tab. 1. Available experimental data of rye (+ wheat) experiments for model calibration.

Keywords: crop model, rye, genotypes, breeding, frost tolerance.

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S2-P.12

Seasonal Analysis of Maize yield and yield component using DSSAT – CERSES Model in central rift valley of Ethiopia

Tekle Addis Tadesse (addytad@gmail.com)

Ethiopian Biodiversity Institute, Addis Ababa, Ethiopia

Abstract

The objective of the study is to develop agronomic recommendation for maize production based on DSSAT tool seasonal analysis at Melkassa, Ethiopia. All measured data on phenology, grain yield and biomass from the field experiment were used for model simulations. These weather scenarios were used in the seasonal analysis program to run each treatment combination with 30 year data. The results of both biophysical and economic analyses of the Seasonal Analysis program predicted an application of medium season cultivar with irrigation water as moisture source and 400 kg/ha urea with 200kg/ha crop residues as the most dominant management option for maize production at Melkassa Ethiopia.

Introduction

Maize (*Zea mays* L.) is the second most widely cultivated crop and is first in production with smallholder farmers accounting for 94% its production in Ethiopia (Shiferaw *et al*., 2011; Tesfaye *et al*., 2015b. Identifying the optimum level of management for attaining economically efficient yields remains problematic in agricultural production, and crop simulation models are often found to be useful in this context (Ray & Kar, 2006; Yadav *et al*., 2012).

Material and Method

1.Description of study site

The field experiment was conducted at Melkassa, which is situated at about 107 km from Addis Ababa and 17 km from Adama on the way to Asella, Ethiopia. Geographically located at latitude of 8° 4'North and longitude 39° 33'east on altitude of 1750 m.a.s.l. Soil parent classified under Andosol and surface texture is Sand loam, drainage type is surface furrows.

2. Planting and treatment arrangement

The treatment has 3 factors among which three maize cultivars from short season; medium Season and long Season, used as a planting material; 2 level of moisture source and eight rates of urea fertilizer as a source of N fertilizer; were combined and laid out in factorial arrangement. 1000kg/ha straw residues; 200k/ha and 0.1% nitrogen were existed before; 100% incorporated in to the field. Planting were undertaken in dry seed method in row arrangement with population density of 5.3 plants per square meter, having inter-row spacing of 75cm and sowing depth of 5cm.

Result and Discussion

1.Biophysical Analysis

The summary data indicate minimum and maximum harvested yield within the 30 year period of simulation with their mean yields and standard deviations. Treatment 16 recorded the highest yield of 12,364kg/ha; minimum yield of 7236 kg/ha with a mean yield and standard deviation of 9744kg/ha and 1440, respectively.

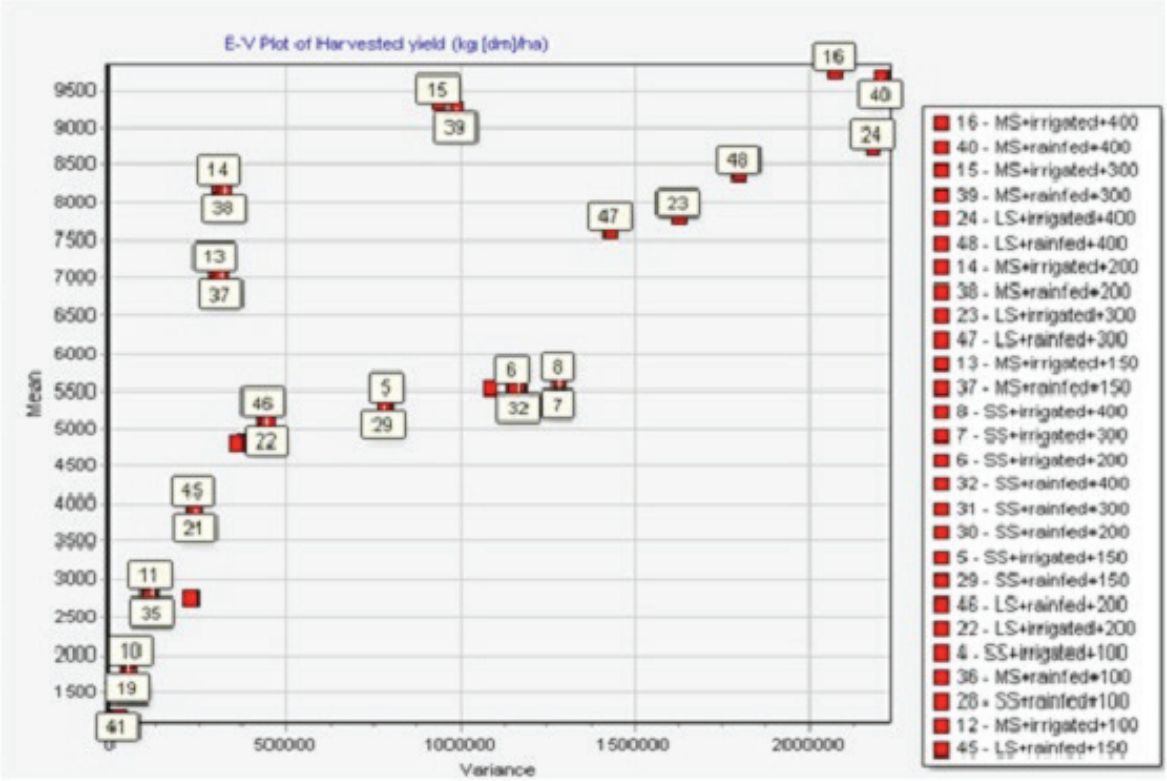
2.Strategic analysis

The strategic analysis from Mean-Gini dominance values showed that from 48 treatment combinations, the economic strategic analysis for the 30 years showed that treatment 16 is efficient treatment among the rest of treatment. The mean return and Gini dominance (mean return - Gini coefficient) value of treatment 16 is higher among treatments, **2564.9$/ha and 2289.3**$/ha respectively.

.../...

Conclusion

The biophysical; economic and strategic analysis treatment 16 become the better performer over the other factors. The economic analysis insures that one can get 2564.91 $/ha return as compared a -192.91$/ha of treatment one (SS + Irrigated + unfertilized) with net benefit of 2757.82$/ha where as a 2750.8 $/ha net benefit over treatment (SS + rain-fed + unfertilized).



Keywords: CERES crop mode, Fertilizer recommendation, Seasonal analysis, Yield variability.

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S2-P.13

Modelling crop-weed canopies as a tool to optimise crop diversification in agroecological cropping systems

Colbach Nathalie[1] (Nathalie.Colbach@inra.fr), Colas Floriane[1], Cordeau Stéphane[1], Maillot Thibault[2], Queyrel Wilfried[2], Villerd Jean[1], Moreau Delphine[1]

[1] *Agroécologie, INRA, Dijon, France*; [2] *Agroécologie, AgroSup Dijon, Dijon, France*

Introduction

Crop diversification is vital for agroecological pest management. Process-based weed dynamics models are crucial to synthesize knowledge on crop diversification, apply this knowledge to cropping-system design and transfer it to stakeholders. Indeed, weeds which are very harmful for arable crops must be managed at the rotation scale, and crop-weed interactions are similar to crop-crop interactions in crop mixtures and crop rotations. This paper illustrates these items with the FLORSYS model.

Material and Methods

FLORSYS is a virtual field for which the user enters a list of cultural operations lasting for several years (crop succession including cover crops and crop mixtures, all management techniques), together with daily weather, soil properties and a regional weed species pool. These inputs drive the biophysical processes in the field at a daily time step. FLORSYS focuses on processes leading to:

- plant emergence and establishment of crop and weed species with diverse ecological requirements (which allows for crops sown in different seasons and in mixtures where timing determines the fate of a species)
- the functioning of heterogeneous crop-weed canopies including diverse plant ages, morphologies and shade responses (as in crop mixtures)
- carryover effects on future cropping seasons (which is crucial for crop rotations).

The detailed biophysical model outputs are aggregated into indicators of crop production and weed (dis)services to easily compare cropping systems. Case studies with different regions, cropping systems and stakeholders illustrate how FLORSYS evaluates and promotes the benefits of crop diversification, by:

- identifying competitive crop ideotypes for agroecological weed management
- tracking crop-diverse solutions in virtual farm-field networks
- *ex ante* evaluation of crop-diverse solutions proposed by experts and stakeholders
- participatory workshops with farmers.

Results

The simulations show that, compared to high-loss crops, those with a low yield loss due to weeds present a larger plant width per unit biomass in unshaded conditions, thinner leaves to increase leaf area, chiefly from flowering onwards, and etiolate when shaded by neighbor plants, with taller plants per unit plant biomass and even thinner larger leaves.

The simulations identified 3 cropping-system types that reconcile low yield loss with low herbicide use: maize monocultures and 2 systems with diverse rotations (different species, both winter and summer crops, intercropping, temporary grassland) and/or crop mixtures, combined with well-reasoned tillage (stale seed bed, occasional ploughing).

FLORSYS was also used to assess cropping systems designed by scientists or farmers in workshops (Table). These led to major take-home messages on crop diversification for farmers (e.g., assess crops at the rotation scale, weather and inadequate crop management can cancel out diversification benefits, weed floras do not disappear but change) and scientists (e.g., farmers need biophysical explanations of cropping system performance).

Conclusion

The studies demonstrate that the benefits of crop diversification for weed management depend on the production situation and cropping system. We thus need flexible rules on crop diversification, and models such as FLORSYS are essential to establish these rules.

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Cropping system[§]	Crop diversity over 12 years			Herbi-cide use (TFI[$])	Yield (MJ/ha)		Weed impact			
	Number of species and cultivars	% winter crops	% years with cover crops				Yield loss		Bee food	
Reference	4	100%	8%	1.6	63563	C	50.9	D	2.30	B
IWM-simplified	18	77%	39%	1.7	51067	ED	58.4	C	2.42	B
IWM-intermediate	10	63%	8%	0.8	54443	D	55.3	DC	2.74	A
IWM-complete	8	55%	0%	0.7	67402	BC	40.9	FE	2.05	DC
IWM-no herbicides	12	63%	16%	0	69077	BC	50.5	D	2.10	C

[§] Scenarios were simplified (no plough, little tillage, no mechanical weeding, herbicides), intermediate (plough, tillage, no mechanical weeding, herbicides), all (plough, tillage, mechanical weeding, herbicides), no herbicides (plough, tillage, mechanical weeding, no herbicides). [$] Treatment frequency index, 1 means one product per year at full dosage over whole field area

Table. Weed impact on biodiversity and crop production in Integrated Weed Management (IWM) strategies simulated with FLORSYS and averaged over 30 years and 10 weather repetitions. In each column, cells were coloured from green (the best performance) to red (the worst performance) for crop diversity, weed services and crop production, and vice-versa for weed disservices. Numbers of a given column followed by the same letter were not significantly different at p=0.05.

Keywords: Mechanistic model, biological interaction, cropping-system design, intercropping, ideotype.

S2-P.14

A generic pest submodel for use in integrated assessment models

Rasche Livia[1] (livia.rasche@uni-hamburg.de), Taylor Robin[2]

[1] *Universität Hamburg, Hamburg, Germany*; [2] *Ohio State University, Wooster, United States*

The sustainability of agricultural land use has been the subject of integrated assessments for some time. Crop models are often used in these assessments. The more details the models can provide, the more factors can be considered. The crop model EPIC for example can determine fertilizer and irrigation water use based on crop demand. Pesticides, however, can only be applied manually and have no impact on the crop. We therefore developed a pest submodel providing estimates of pesticide consumption based on pest pressure, and the corresponding reactions of crops, thus completing a process loop analogous to the application of fertilizers.
We distinguish three pest categories, insects, fungi and weeds. For insects, a biological temperature response function is used to model the daily feeding rate, from which population growth is derived. Insect mortality is dependent on temperature and on nutrient availability. Fungal disease spread depends on coefficients of primary and secondary infection, abundance of spores and host density. The number of spores increases depending on a humidity and temperature function, and decreases according to a decay rate. Crop stress is dependent on the ratio of healthy to infected plant tissue. Weeds are grown in EPIC the same way as crops and compete for the same resources. Herbicide applications are triggered when a specified ratio of weed/crop LAI is reached. Pesticide-induced mortality is modelled as a chemistry-specific dose-response curve.
We tested the model by simulating five crops with the highest use of pesticides in the US (corn, cotton, potatoes, soybeans, wheat). We show, among others, that mean simulated application rates approach reported mean application rates and that the spatial distributions of simulated and reported application rates match well. We conclude that the new pest submodel is appropriate to estimate pesticide use on larger scales and can be employed to enhance integrated assessments.

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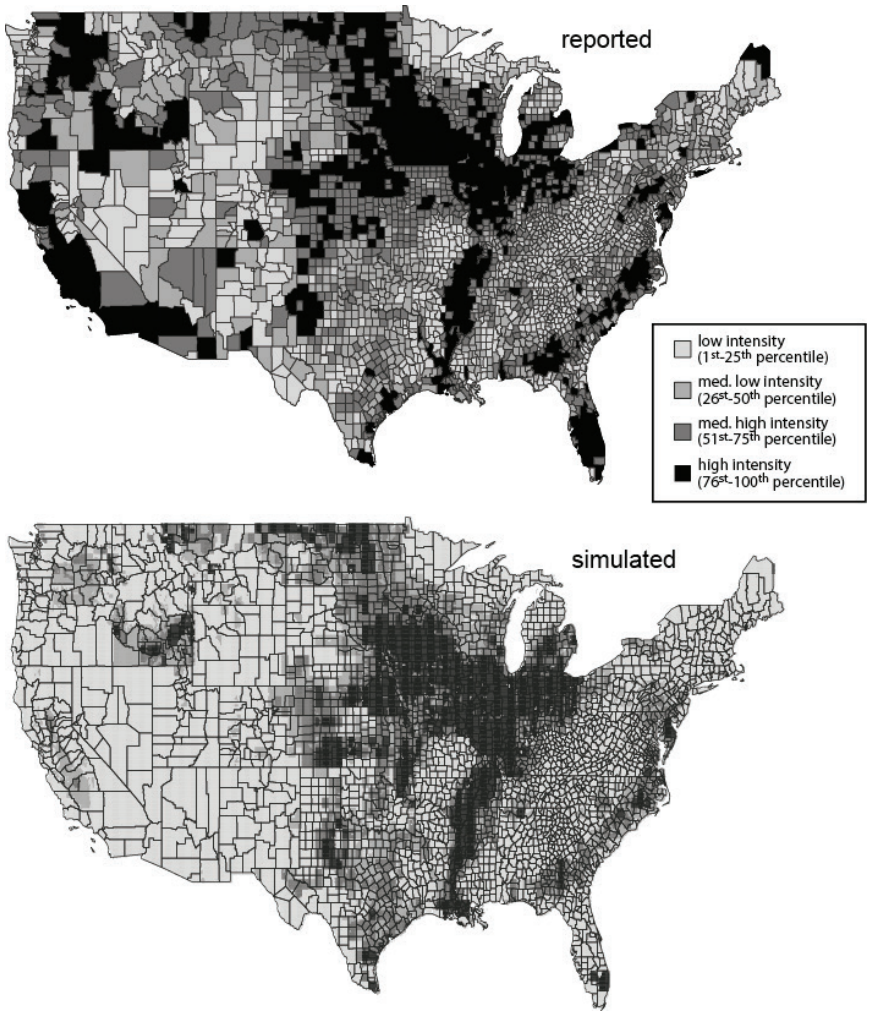

Simulated and reported spatial distribution of mean pesticide application intensities. Reported values (total annual amount per county, averaged over 1992-2009) were taken from Thelin and Stone (2013); simulation results (total annual amount per simulation unit) were averaged over all simulation years. To emphasize spatial patterns of pesticide application intensities and facilitate a comparison, we classified both data sets into four classes, using the first, second and third quartile of the distributions as break points.

Keywords: fungal diseases, insect pests, pesticides, yield loss, weeds.

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S2-P.15

Water and nitrogen sharing in annual pepper crop intercropped with olive tree: conceptualization and modeling

Akakpo Koladé[1] (kolade.akakpo@supagro.fr), Leathaud Crystèle[2], Cheviron Bruno[3], Lopez Jean-Marie[2], Dejean Cyril[3], Elamri Yassin[3], Bouarfa Sami[3]

[1] *UMR G-eau, Montpellier SupAgro, Montpellier, France*; [2] *UMR G-eau, CIRAD, Montpellier, France*; [3] *UMR G-eau, Irstea, Montpellier, France*

Intercropping systems are considered to have agroecological virtues by offering a better use of resources. Resource sharing in these systems are complex and partly linked with farmers practices. This study aimed to explain the impact of the presence of olive trees (*Olea europaea*) on pepper crop (*Capsicum annuum*) cultivation by understanding water and nitrogen dynamics in this system, in the irrigated plain of the Merguellil river, in Central Tunisia. In this region, the olive trees' inter-rows are usually ploughed three to four times a year, in order to control weeds, and are commonly intercropped with high-value market gardening crops. In 2019, a field experimentation was carried out on an olive tree – pepper crop system plot. Hypothesis of a gradient of impact as a function of distance of the annual crop to the tree was tested, and the pepper water and nitrogen balance was simulated using the Optirrig model. Nitrogen dynamics were assumed to be driven by water fluxes. Soil moisture and residual N, meteorological data and yield were monitored. The results showed that the tillage creates a "no olive tree roots zone" where there are no interactions between pepper and olive tree roots. Pepper crop primarily uptake water and nutrients from this 0 – 40 cm soil layer, corresponding to ploughing depth, and the olive tree uptakes water in the lower layer. The olive tree water uptake declines with the distance between crop and tree. There are almost no lateral flows, as far as the closest pepper row to the tree is far from ploughing limits. The model outputs match fairly well with field data. These results suggest a complementarity between olive tree and pepper crop in sharing water and nitrogen.

Keywords: modeling, nitrogen balance, pepper, olive tree, water balance.

S2-P.16

Modelling light absorption of grapevine in agroforestry and monocropped vineyards using DART

Grimaldi Juliette[1] (juliette.grimaldi@inra.fr), Wang Yingjie[2], Chavanon Eric[2], Lauret Nicolas[2], Guilleux Jordan[2], Bustillo Vincent[3], Houet Thomas[4], Gastellu-Etchegorry Jean-Philippe[2]

[1] *UMR System, INRA, Montpellier, France*; [2] *UMR CESBIO, Université Toulouse III, Toulouse, France*; [3] *UMR CESBIO, Université Toulouse III, Auch, France*; [4] *LETG-Rennes, CNRS, Rennes, France*

Introduction

Intercropping trees with grapevines may be a sound strategy towards more sustainable grape and wine production. Nonetheless shading may impact grapevine yield and berry quality through modulating photosynthesis, temperature and the evaporation demand. Quantifying the amount of light available for grapevine considering various vegetation arrangement was the main scientific objective of this work.

Former modelling of light patterns in agroforestry systems / vineyards showed that both 3D vegetation structure and the state of the atmosphere stand as key but challenging parameters (Grimaldi 2018). The 3D radiative budget model DART (Discrete Anisotropic Radiative Transfer) was chosen (Gastellu-Etchegorry et al. 2012, 2017). Comparing complex to simplified approaches for modelling vegetation and light was the main methodologial obective of this work.

Material and Methods

A vineyard where alleys of timber trees are intercropped between vinerows was selected in Lagardere, South-Western France (humid-continental climate). Based on drone-borne RGB and DSM images of this vineyard, several 3D numeric mock-ups of agroforestry vinerows and their corresponding monocropped reference were built. Their radiative budgets were simulated with DART in the photosynthetically active radiations (PAR) every hour of every 5 days from April-15th (budburst) to September-12th (harvest). Cloudiness was modelled by adjusting aerosol content according to the global solar irradiance measured on site.

Accurate 3D representation of canopies and light (*a*) was compared to simpler modelling strategies: foliage of grapevine and trees represented as turbid voxels (*b*), same as b + direct light only (*c*) and 2D horizontal representation of grapevine (*d*).

Results and Discussion

Under clear sky conditions, grapevines falling inside the shade of trees absorbed 20% to 40% of the PAR that is absorbed in full sun, depending on the tree leaf density, while under overcast conditions, no shade pattern appeared as most of the light irradiance is diffuse. Over the whole simulated time period, alley-cropped grapevines absorbed 90% to 85% of the cumulated PAR that is absorbed under monocropped arrangements, depending on tree heights.

Vegetation canopies can be modelled as turbid media as soon as canopy gaps are included while 2D representation of grapevine foliage led to a completely different order of magnitude of absorbed energy.

Our work also strongly encourages modelling multiple scattering of light from diffuse sources, notably clouds. The meteorological conditions that were simulated are plausible in terms of total cumulated solar irradiance but may have led underestimating shade as the phase function of aerosols in the PAR is not as steady as that of clouds. In order to improve our estimations, new simulations are being processed considering both clouds and aersols and will be presented at the conference.

Conclusions

Our work brings first order of magnitudes: the potential impact from tree shade seems negligible for all the tested arrangements, while the architecture of grapevine itself greatly contributes to its light absorption regime. The methodological approach shall in the future be widened to other climatic contexts and vegetation arrangements.

Acknowledgements

We thank P. and C. Dubos for welcoming us in their vineyard as well as the Fondation de France and the French Ministry of Agriculture, Food and Forestry (CASDAR Vitiforest) for their financial support.

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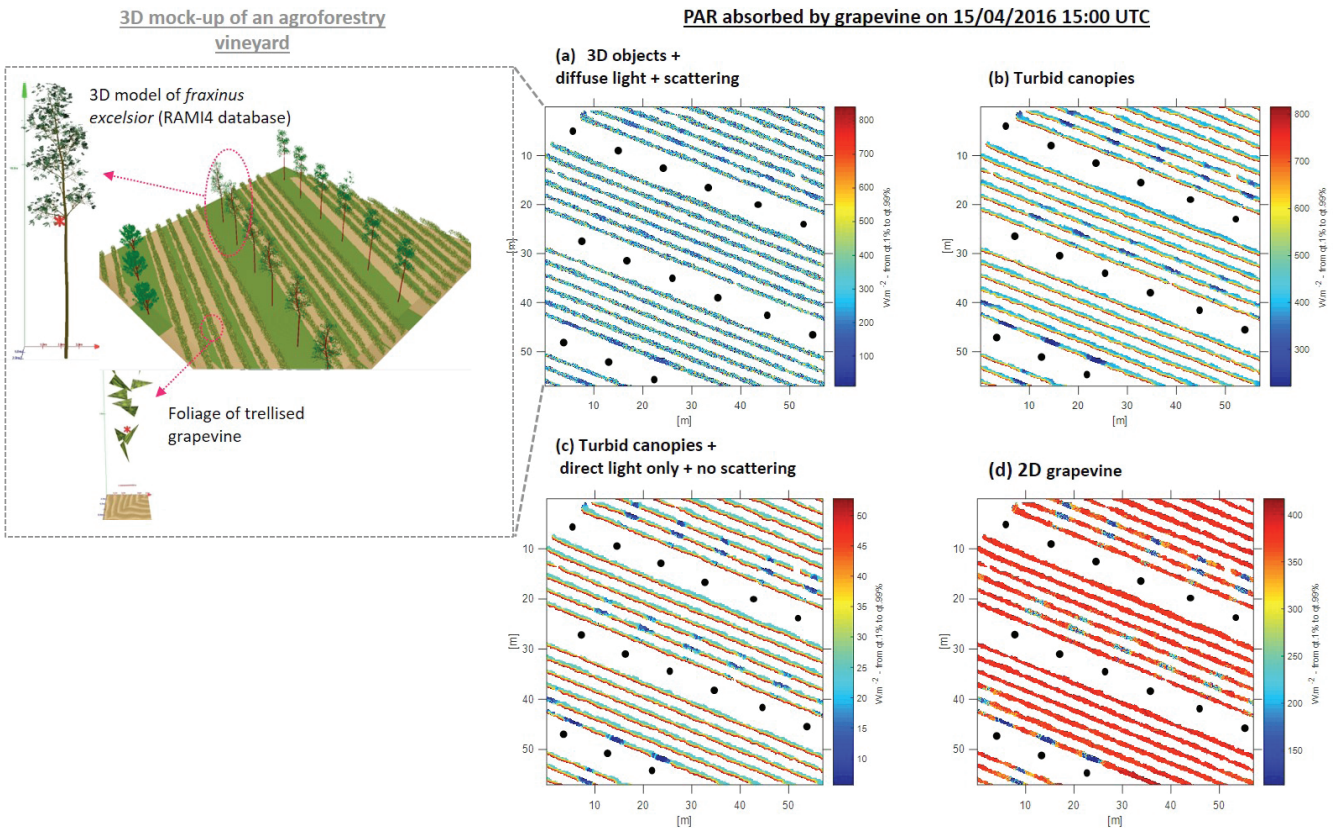

3D mock-up of agroforestry vineyard and the corresponding instantaneous PAR absorbed by grapevine simulated with DART model (a). Complex to simple representations of vegetation canopies and/or light are compared (b,c,d). Simulations were performed on the 15/04/2016 15:00 UTC. Total solar irradiance is 370 W/m2 and diffuse to total irradiance ratio was 33% and 0% in cases (a,b,d) and (c) respectively.

Keywords: agroforestry, vitis vinifera, tree shade, radiative budget modelling, DART.

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S2-P.17

Sensitivity analysis of the water balance in the WaNuLCAS crop-tree model: a case study using cocoa-based agroforest.

Fayolle Stolïan[1] (stolian.fayolle@cirad.fr), Metay Aurélie[2], Saj Stéphane[3], Khasanah Ni'matul[4], Lusiana Betha[4], van Noordwijk Meine[4], Justes Eric[5]

[1] *CIRAD, Montpellier, France*; [2] *Montpellier SupAgro, Montpellier, France*; [3] *CIRAD, Kourou, Guyane, France*; [4] *ICRAF, Bogor, Indonesia*; [5] *PERSYST Department, CIRAD, Montpellier, France*

Introduction

In Central Cameroon where cocoa production is already carried out in areas where rainfall is not always optimal, forecasted trends of climatic change could threaten cocoa yield which is a crucial source of revenue for farmers. Yet, local cocoa systems include complex agroforestry systems (AFS) that may not respond similarly to rainfall variability and drought as simplest AFS and monospecific cocoa plantations (Jagoret et al., 2017). The impact of climate change on AFS and their resilience has been discussed in recent literature and needs to be deeply studied. Modelling could contribute significantly to the understanding of the main processes governing AFS production and is useful to predict the effects of climate change on the soil-trees system functioning. AFS modelling remains a scientific challenge and, in fact, few models are currently available. Yet, WaNuLCAS model has been shown to efficiently simulate agroforestry crop-tree systems although it has not been used for tree-tree or complex AFS systems (VanNoordwijk and Lusiana, 1999). Furthermore, cocoa AFS often exhibit diverse structural parameters of functional motifs representing AFS (functional type, height and age of cocoa or associated trees) which questions the ability of WaNuLCAS to simulate realistic outputs (Coulibaly et al., 2014. We thus carried out a sensitivity analysis to understand and evaluate the functioning of WaNuLCAS and its relevance to represent the changes in water fluxes in cocoa AFS.

Materials and Methods

WaNuLCAS was parameterized with soil and plant data collected in a previous study in Cameroon from 144 farmer' fields of AFS distributed over three pedoclimatic sites (Saj *et al*., 2017). The dataset contained information on: i) cocoa and associated trees densities, ii) DBH and basal area, iii) year of establishment, and iv) soil characteristics. Weather data were extracted from AgMIP forcing dataset (Ruane et al., 2015). We performed a sensitivity analysis of WaNuLCAS v4.3 in order to analyze the effects of input parameters on the water balance. The parameters tested were: i) tree density, ii) soil characteristics such as depth and composition, iii) rainfall amount and seasonal pattern, and iv) species association. We simulated 30 years of functioning in a row. At the end of each 30-yr run, we analyzed the simulated outputs of cocoa and associated tree transpiration, soil evaporation, drainage, and run-off, as well as cocoa tree biomass, pod production and yearly final soil water stocks.

Results and Discussion

The analysis of the results is still ongoing but will be completed for iCROPM 2020. First results show expected responses of the model and reasonable range of variation according to expert knowledge. WaNuLCAS shows a coherent sensitivity to rainfall variability and actual tree transpiration seems consistent with the tree aboveground biomass (10-200 t/ha) (fig 1). However, the model shows a high sensitivity to the species allometric equation parameters, which therefore need to be assessed carefully to avoid unrealistic results. A next validation step will consist in comparing these simulated results to data taken from literature.

Conclusion

WaNuLCAS model seems relevant to simulate the impact of climatic variability on cocoa-based AFS functioning. Then, these results will help to determine the parameters and variables that must be measured promptly in a farmer's fields in Cameroun for a final calibration and validation step of cocoa-based AFS..

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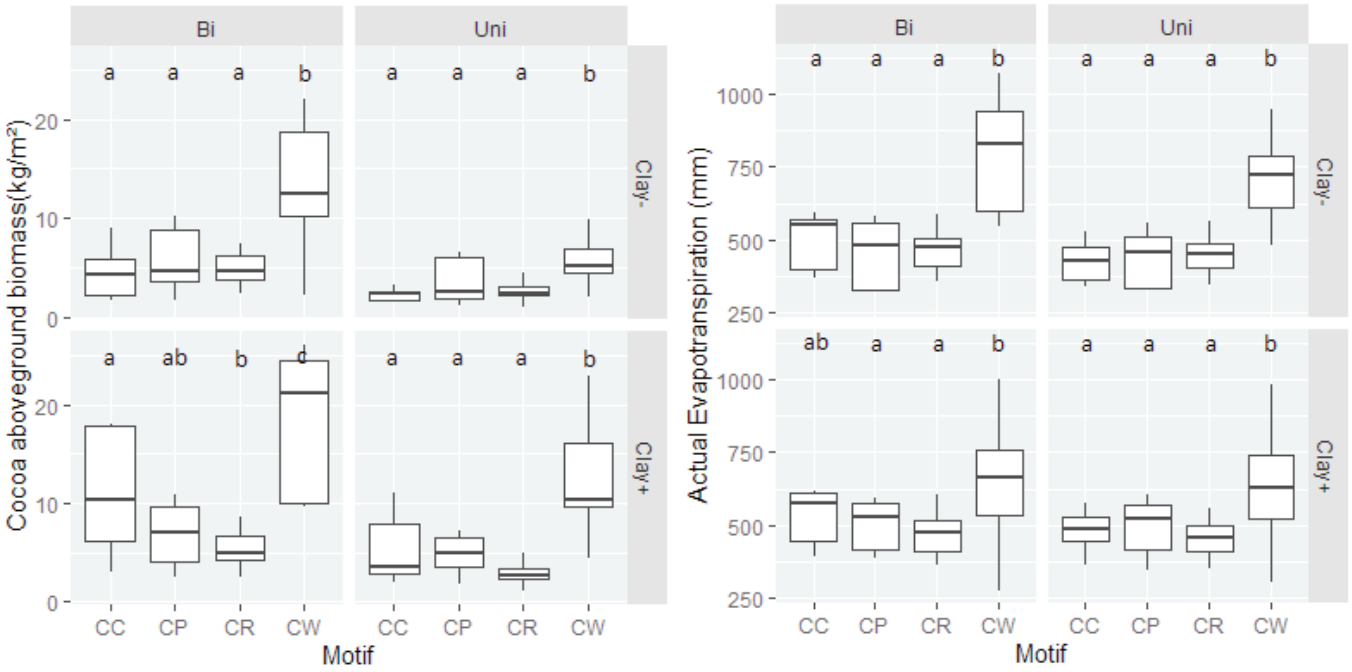

Figure 1: Cocoa aboveground biomass (kg/m2) (left) and annual actual evapotranspiration (mm) (right) during the 30th year of simulation according to i) Functional motif: CC Cocoa-Cocoa; CP Cocoa-Palm tree; CR Cocoa-Rubber and CW Cocoa-Wood shade tree, ii) Rainfall regime (top) with bimodal and unimodal distribution (Bi and Uni), iii) Soil composition (right) with high and low clay content ("Clay+" and "Clay-"). Different letters above boxplots indicate significant differences (p<0,05) between trees combinations.

Keywords: WaNuLCAS, Water budget, Cocoa, Complex systems, Sensitivity analysis.

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S2-P.18

Calibration and Evaluation of the STICS Intercrop Model for Two Cereal-Legume Mixtures

Paff Kirsten[1] (kirsten.paff@inra.fr), Munz Sebastian[2], Vezy Rémi[3], Gaudio Noémie[4], Bedoussac Laurent[4], Justes Éric[5]

[1] *UMR SYSTEM, INRA, Montpellier, France*; [2] *Institute of Crop Science, University of Hohenheim, Stuttgart, Germany*; [3] *UMR AMAP, CIRAD, Montpellier, France*; [4] *UMR AGIR, INRA, Castanet-Tolosan, France*; [5] *PERSYST Department, CIRAD, Montpellier, France*

Introduction

STICS is a soil-crop model capable of simulating crops in succession (Brisson et al., 2003). Intercropping occurs when multiple species are grown simultaneously on the same field. There has been a growing interest in adapting this traditional technique for modern agriculture as a way of ecological intensification, especially for combining leguminous and cereal crops in order to reduce N inputs and potential environmental damage through N losses. Intercropping adds complexity to the system by adding inter-species competition. Crop models are useful tools for analyzing complex systems, as they allow the user far more control over individual variables than is possible in field experiments. A first version of the STICS intercrop model was created by Brisson et al. (2004) and was recently improved by Vezy et al. (2020). The aim of this study was to calibrate and evaluate this improved STICS-Intercrop model by simulating a winter and a spring intercrop mixture: durum wheat-winter pea and barley-spring pea.

Materials and Methods

The data set used for modelling comprised of four years of wheat (*Triticum turgidum* L.) and pea (*Pisum sativum* L.) field data from Auzeville, France with multiple levels of nitrogen fertilizer, and four years of barley (*Hordeum vulgare* L.) and pea field data from Angers, France (Corre-Hellou, 2005), which in some years included two levels of nitrogen fertilizer and two different plant densities of the intercrops. The sole crop trials were used for calibration and the intercrop trials for evaluation, except for a subset of intercrop data that was used to calibrate the parameters unique to the intercrop model. The assumption was that parameters common to both sole and intercropping, such as plant-soil interactions and phenology, would be the same for both. The optimization method used for calibration was based on Wallach et al. (2011). The parameters were broken down into 15 groups (16 for pea including nitrogen fixation) for calibration, each corresponding to a different process.

Results and Discussion

The model calibration process is still ongoing. The root mean square error (RMSE) for shoot biomass was 1.92 t/ha for winter pea and 1.37 t/ha for durum wheat. The RMSE for grain yield was 1.84 t/ha for spring pea and 1.15 t/ha for barley. Overall the model captured the dominancy of one species quite well, however the accuracy has to be increased. The phenology and height were correctly simulated. Some of the discrepancies could be due to biological stresses that STICS does not capture. Some parameters for the pea-wheat model have not been calibrated yet, so the RMSE is likely to improve.

Conclusions

Intercrop systems are difficult to model in comparison to sole crops due to their complex interactions, but the STICS model, after having completed the calibration, could be a useful tool for better understanding the biological functions of this management practice.

Acknowledgements

This work was funded by the ReMIX project, a Research and Innovation project from the EU's Horizon 2020 Program. Special thanks to Nadine Brisson for beginning the work on the STICS intercrop model. We also thank Marie Launay, Dominique Ripoche, and Patrice Lecharpentier for their work on the model.

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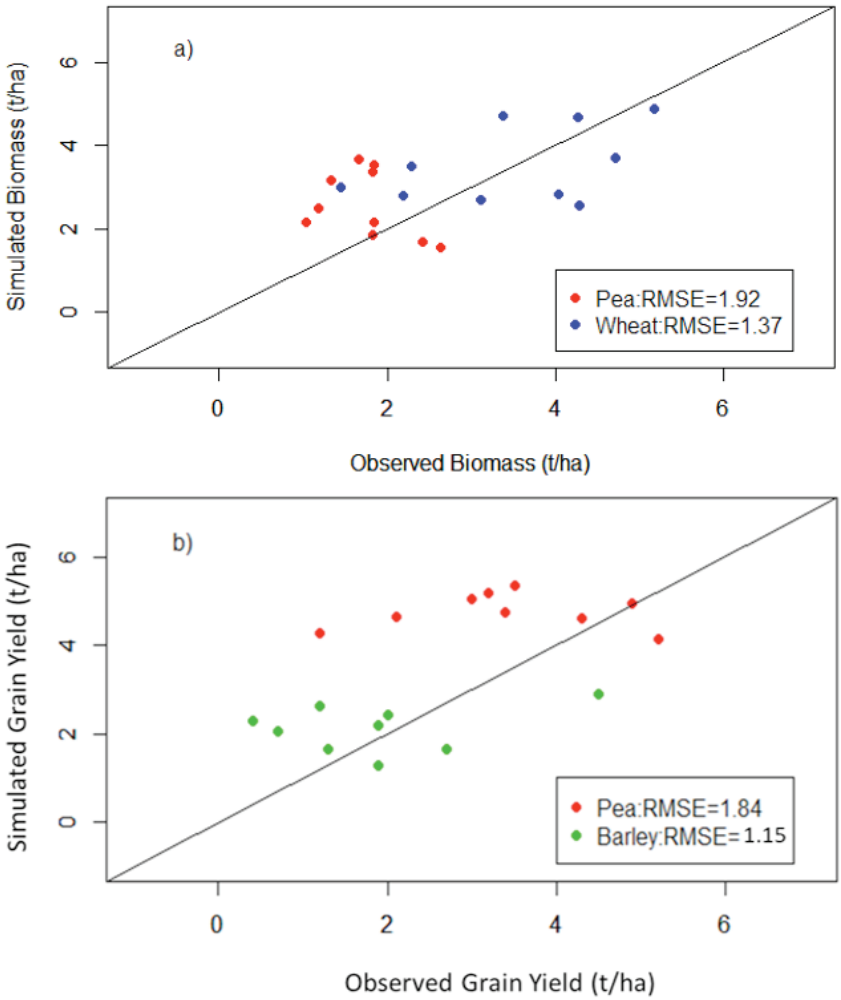

Figure 1. a) Simulated versus observed above-ground biomass for intercropped winter pea (red) and winter wheat (blue) grown under varying N levels across 4 years. b) Simulated versus observed grain yield for intercropped spring pea (red) and spring barley (green) grown under varying N levels and plant densities across 4 years.

Keywords: Ecological Intensification, Crop Modeling, Pea, Barley, Durum Wheat.

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S2-P.19

Analysis resource use efficiency in sugarcane-legume intercropping system using STICS model

Viaud Pauline[1] (paulineviaud@yahoo.fr), Christina Mathias[2], Versini Antoine[3], Ripoche Aude[4], Naudin Krishna[4]

[1] *UPR 115 AIDA, CIRAD, Sainte-Clotilde, Réunion*; [2] *UPR 115 AIDA, CIRAD, Sainte-Clotilde, Reunion*; [3] *UPR 78 Recyclage & Risques, CIRAD, Sainte-Clotilde, Reunion*; [4] *UPR 115 AIDA, CIRAD, Montpellier, France*

Backgrounds

In response to the current issues of reducing inputs, crop associations are presented as efficient and sustainable agrosystems. In cane crops, wide row spacing and slow growth rate in the initial stage of sugarcane are suitable for intercrops. Weed control is a major problem in cane plantations, the introduction of cover crops is an interesting alternative to reduce the use of herbicides. Moreover, service plants produce a large variety of ecosystem services such as maintaining soil biodiversity, water supply and increasing soil fertility. However, introducing a new crop makes the system more complex and could result to a problem of trade-off between agronomic (risk of excessive inter-specific competition) and environmental performances.

Many studies have considered the positive effect of legumes as a rotation break crop in sugarcane systems in terms of reducing mineral inputs. On the contrary, the interest of legumes in the inter-rows of cane plantations is much more recent. There is little known about competitive processes for resources (water, nitrogen, light) or facilitation (symbiotic fixation and nitrogen restitution) in these alternative agrosystems.

Aims

The objective of this thesis is to assess the capacity of multi-species sugarcane / legume systems to improve resource use efficiency while optimizing some selected services (production, soil fertility, reduction of chemical inputs), as compared to conventional crop systems.

Methods

This work is based on the follow-up of a three-year (2019-2022) field experiment using a randomized block design with two crop arrangement patterns (sugarcane monoculture and sugarcane-legume (*Canavalia ensiformis*) intercropping) and two levels of nitrogen fertilization and irrigation. The aim will be to evaluate and model, with the STICS-intercrop model, the resource allocation (nitrogen, water, light) between cane and legume under contrasting nitrogen and water availability. Before undertaking this modelling analysis, the parameterization of the cane and legume species of interest will be performed in STICS with independent data. In parallel, symbiotic nitrogen fixation by legumes will be quantified by the 15N natural abundance technique and the fate of nitrogen in the system will be investigated by using 15N-labelled fertilizer and legume. After calibration, the STICS model will be applied to a network of sugarcane / legume intercropping experiments (Dephy Expé and Ecocanne projects). Through this modelling approach, the aim is to assess the efficiency of sugarcane-legume agrosystems in different soil and climate conditions in Reunion Island.

Perspectives

One expected result is to identify the territories for which legumes will contribute to the reduction of herbicide use in cane crops in order to meet the objectives of the Ecophyto plan (50% reduction in pesticides by 2025). In addition, through understanding the facilitation/competition processes for nitrogen, the potential reduction of fertilizer over time when introducing legumes will be estimated. This work will also allow progress on the STICS-intercrop model in tropical conditions.

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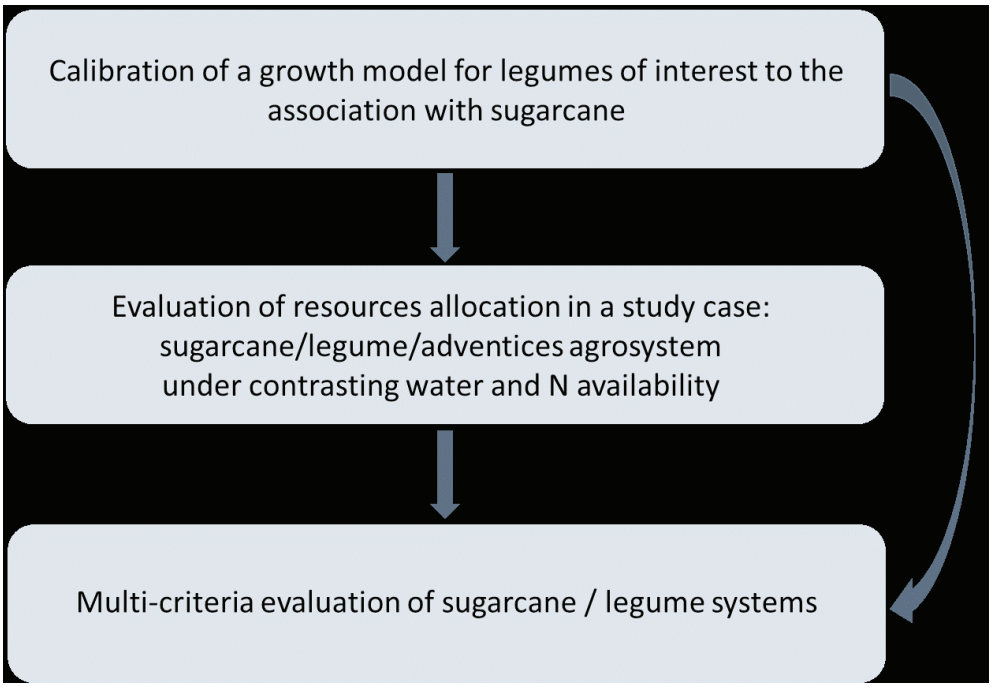

Figure 1. Conceptual scheme of the project approach.

Keywords: intercrop, companion crop, nitrogen, sugarcane, Reunion.

S2-P.20

Effects of spatial variability of soil properties on maize yield, soil water content and residual N

Chen Shichao[1] (chenshichaocsc@cau.edu.cn), Du Taisheng[2], Parsons David[3], Wang Sufen[2], Ahmed Mukhtar[4]

[1] *China Agricultural University, Beijing, Beijing, China*; [2] *China Agricultural University, Beijing, China*; [3] *Swedish University of Agricultural Scie, Umeå, Sweden*; [4] *Agricultural Research for Northern Sweden, University of Agricultural Sciences, Umeå, Sweden*

Introduction

Spatial variability of soil properties is a major reason for spatial variability of yield, soil water content and residual N within agricultural landscapes (Xu et al., 2017; Maestrini and Basso, 2018). Evaluation of residual N based on soil spatial variability is a focus of sustainable agriculture (Basso et al., 2011). Using crop models is an effective way to simulate crop growth, soil water and nitrogen. In this study, we compared the performance of WHCNS (soil Water Heat Carbon Nitrogen Simulator) and APSIM (Agricultural Production Systems sIMulator), in simulating yield, soil water content and residual N, based on the spatial variability of soil properties under uniform management within a field.

Materials and Methods

The study was conducted on a 54-ha maize field in Huangyanghe Farm, located in Wuwei City, Gansu Province, China. In 2016, the study area was 6.8 ha, which was a part of the field used in 2017 and 2018. In 2016, 91 samples were recorded across a grid with 30-m spacing. In 2017 and 2018, the study area was 54 ha, with a 70-m grid, totaling 110 sample points across the field. Soil water content (SWC), bulk density, particle-size distribution, available nitrogen, electrical conductivity, soil organic carbon, total N and total P for 0-100 cm soil depth at 20-cm intervals were measured before sowing and after harvesting over three years. SWC and available nitrogen were measured before and after irrigation during the growth period of maize. Leaf area index and crop height were measured every 10 days after emergence. Measurements in 2016 were used to calibrated WHCNS (Liang et al, 2016) and APSIM 7.10 (Keating, 2003), and 2017 and 2018 data were used to validate models.

Results and Discussion

Both APSIM and WHCNS were able to simulate maize yield, SWC and residual N with good accuracy. Measured yield ranged from 4500 to 10600 kg·ha-1, while simulated yield was 5500-8600 and 5300-8800 kg·ha-1 using APSIM and WHCNS, respectively. For areas with yield more than 7800 kg·ha-1, simulated yield was lower than the measured, while less than 6000 kg·ha-1, the model overestimated the measured yields (Figure 1). For simulated SWC, values of IA and NSE in WHCNS were higher than APSIM, which indicated that simulations in WHCNS were more accurate than APSIM. Values of IA and NSE in APSIM for simulating residual N were higher than WHCNS.
The main reason for the abundant residual N (160 - 470 kg·ha-1) is excessive nitrogen application, which is undertaken without considering the initial N content or soil texture. Residual N can be used as a source of N for the following crop, and should be considered in fertilization management.

Conclusions

Simulations of maize yield, soil water content and residual N based on spatial variability of soil properties by using calibrated APSIM and WHCNS were acceptable. Yield, SWC and residual N were spatially heterogeneous across the field, depending on the soil properties. Soil spatial heterogeneity residual N should be considered in precision agriculture applications to achieve higher economic benefits and utilization efficiency.

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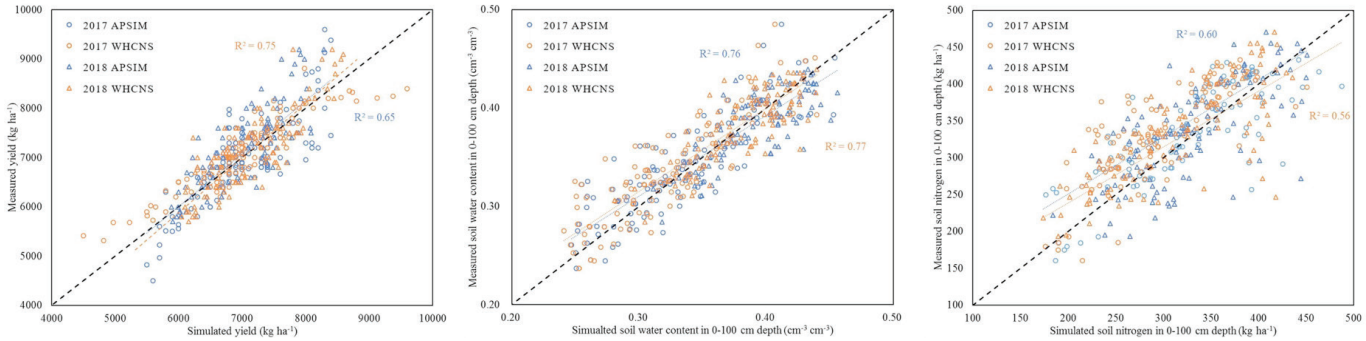

Figure 1 Measurements and simulations of yield, soil water content (0-100 cm) and residual N (0-100 cm) after harvest in 2017 and 2018.

Keywords: maize yield, residual N, APSIM, WHCNS.

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S2-P.21

Linear Programming-Based Cropland Allocation to Enhance Performance of Smallholder Production: A Pilot Study in Ethiopia

Mellaku Meselu[1] (mtmtegenie@gmail.com), W. Reynolds Travis[2], Woldeamanuel Teshale[1]

[1] *Natural Resource Economics & Policy, Hawassa University, WGCFNR, Wondo Genet, SNNPRs, Ethiopia*; [2] *Community Development and Applied Econom, University of Vermont, Burlington, Burlington, USA*

Smallholder crop production is a mainstay of the Ethiopian economy. Agricultural extension programs have been implemented since the 1950s in an effort to improve smallholder productivity. However, in many ways its performance is low, and the country remains one of the least developed economies. Ethiopia has made substantial efforts to enhance the performance of the sector through agricultural extension programs, however, the strategy focuses on enhancing productivity and farm decision making is hardly considered. In some cases, increased production may be achieved at the expense of high input costs; which may not bring the intended outcomes as Munthali and Murayama (2013). As Baden and Harvey (2011), improvements to agriculture resource use efficiency may have the potential to meet the twin objectives of poverty reduction and sustainable agricultural productivity growth. In this study, we argue that the limited attention given to cropland allocation by smallholders is one key driver of low performance of crop production as well as a key factor in environmental degradation. Drawing on data from a household survey of 75 randomly selected households in densely populated typical smallholder agricultural area, Abaro Kebele, Ethiopia, combined with focus-group discussions, key informant interviews, and secondary data collected. We use linear programming(LP) based cropland allocation as in Delgado-Matas and Pukkala (2014) and Walangitan et al. (2012), to highlight the impact of cropland allocation decisions on the performance of smallholder crop production systems. Crop production is practiced in the study area primarily to meet subsistence needs followed by profit. Based on this fact, profit maximization objective LP subject to social, financial, and ecological constraints were used. Six crops *Triticum aestivum*, *Zea mays*, *Solanum tuberosum*, *Beta vulgaris*, *Daucus carota*, and *Hordeum vulgare*, were selected based on cultivation prevalence. Profit performance was evaluated for three scenarios. A profit of ETB 591,324.6 was estimated from current practice (scenario 1) and a production shortfall of 13 metric tons was estimated to meet consumption requirement of maize. Assuming the same crop management practice as usual but using LP model, a profit of 1,347,871.22 appears to be possible in Scenario 2. Besides the inefficiency of current cropland allocation, farmers were found practicing crop management divergent from scientific recommendations. Hence, in the third scenario the LP model was solved assuming practice of scientific crop management and a profit of ETB 1,576,009.03 were estimated. We find that under current land use practices households are not able to meet their consumption needs. The average profitability of farms under the current cropland allocation is also significantly below the estimated profit that could be realized using linear programming. Additionally, survey results suggest that low crop production performance (in terms of meeting both subsistence and profit goals) is the primary reason why households do not participate in conservation efforts and sustainable resource management practices. This study suggests that linear programming-based cropland allocation modeling might be applied to enhance the profit performance of smallholder crop production, help meet household production goals, and thereby promote the sustainable utilization of environmental resources.

Acknowledgments
We acknowledge WGCF-NR, HU for financing.

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$$\left.\begin{aligned} &\text{Maximize } \Pi = \sum_{i=1}^{n} (P_i L_i q_i - c_i L_i) \\ &\text{Subject to :} \\ &\sum_{i=1}^{n} c_i L_i \le Y \text{ (Budget Constraint)} \\ &\sum_{i=1}^{n} L_i \le L \text{ (Land Constraint)} \\ &L_i \ge 0,\ i = 1,2,3,\ldots,n \end{aligned}\right\}$$

Equation 1: Linear Programming Model.

Keywords: subsistance, current practice, productivity, profit, sustainable utilization.

References:

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S2-P.22

Modeling Phenological responses of table grape cultivars in pothwar region of Pakistan

Rafique Rizwan[1] (rizwanrafiqueao@gmail.com), Ahmad Touqeer[2], Abbasi Nadeem[2], Ahmed Mukhtar[3]

[1] *Horticulture Department PMAS-AAUR, Rawalpindi, Pakistan, Pakistan*; [2] *Horticulture Department PMAS-AAUR, Rawalpindi, Pakistan*; [3] *Agronomy Department PMAS-AAUR, Rawalpindi, Pakistan*

Introduction

Grapevine phenology is really facinationg for nature lovers and it is good bioclimatic indicator of climate change. Pothwar region with humid subtropical to warm semi-arid climate has emerged as new viticulture zones in Pakistan. Commercial viticulture has transformed the traditional rain-fed agriculture, socio-economic life of farmers in Pothwar region and helped in poverty elevation. Precision viticulture and phenological assessment is necessary for overcoming the challenges faced by emerging viticulture industry due to varying environmental conditions through efficient utilization of resources and for enhancing the production of this high value crop. The key phenological stages of grapevine are; budburst, blooming, setting, verasion, grape maturity Kose, (2014). crop models are more accurate and reliable in simulating phenological behaviour, growth, development and physiological responses of the crop system (Brisson et al., 2008). Therefore, the present research study has been designed with following

Objectives

1) Assessment of phenological responses of table grape cultivars; Kings Ruby, Perlette, NARC Black and Sugra One in Pothwar region.
2) Modeling grapevine phenology using GDD and STICS models.

Materials and Methods

Phenological observations were made at two locations i.e. Islamabad (Sub-humid) and Chakwal (Semi arid) with varing pedo-climatic conditions in four table grape cultivars; Kings Ruby, Perlette, NARC Black Sugra One. Nine vines of uniform vigor trained on I Trellis system with age 4-6 years were selected for rerding observatoions

Location I: Baharakahu, Islamabad Location II: BARI, Chakwal
Latitude and Longitude 33.73°N,73.08°E Latitude and Longitude 33.76°N, 72.36°E
Altitude 1,982 feet Altitude 1,634 feet
Climate Sub-humid Climate Semi-arid

Results and Discussions

The results show that there exists wide variability in the phenological timing of table grape cultivars. All the phenological stages i.e. bud burst, 5 leaf stage, start of bloom, full bloom, verasion and harvest reached earlier in Chakwal in comparison with Islamabad. Perlette and NARC Black have more variation in their timing of verasion and maturity at both locations. Full bloom stage was attained earlier in cv. NARC Black as it took 21 and 24 days, while cv. Sugra One took 38 and 41 days to attain this stage at Chakwal and Islamabad respectively. Days to reach maturity from bud burst were more in cv. Sugra One as it took 112 and 118 days at Chakwal and Islamabad respectively.
It is obvious that phenology is driven by temperature and phenological stages reach earlier in Chakwal with 1°C -1.5°C higher temperature than islamabad where phenological stages arrive later due to less heat unit accumulation. Bud burst is 3-4 days earlier while flowering is 6-7 days earlier in semi-arid conditions of Chakwal.

Conclusion

There exist a variation of phenological responses due to tempereature fluctuations at both expermental vineyards. Varieties also have differences in phenological timings due to varaition in heat unit requiements of different cultivars. The findings of the present research are useful in developing a grapevine phenological model for eco-friendly, resilient and precision viticulture in this emerging region by predicting key phenological events.

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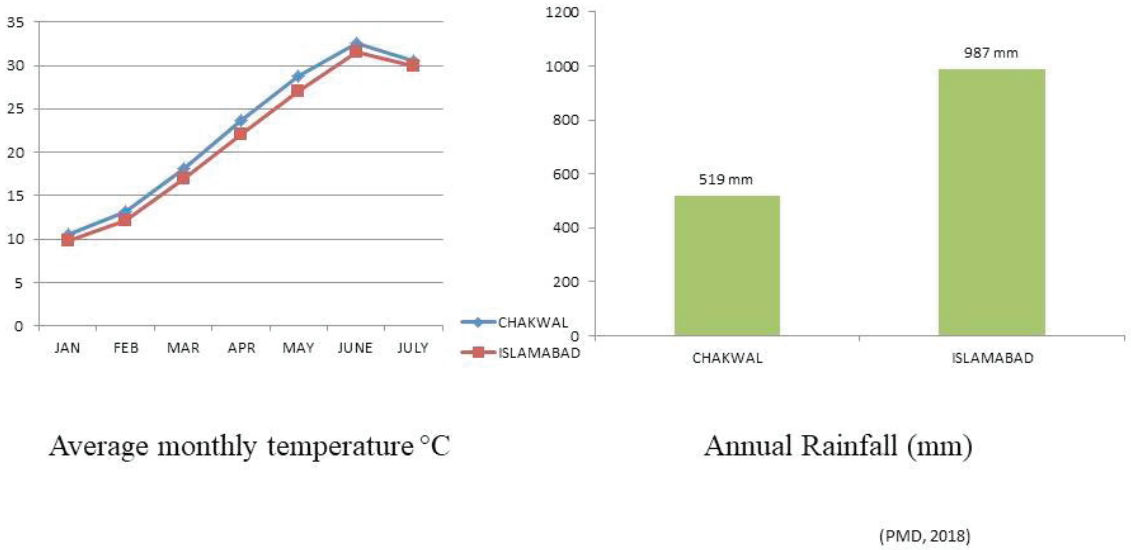

Figure: Annual rainfall and mean temperature trends during active growth season at Islamabad and Chakwal.

Keywords: Modeling, phenology, grapevine, STICS, pothwar region.

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ABSTRACTS POSTERS

SESSION III

LINKING CROP/PLANT MODELS AND GENETICS

S3-P.01

Evaluation of the potential adaptation of soybean (*Glycine max* L.) to northern France using crop modeling simulations

Boulch Guénolé (guenole.boulch@unilasalle.fr), Djemel Amina, Lange Bastien

AGHYLE, Institut Polytechnique UniLaSalle, Beauvais, Haut-de-France, France

Introduction

The study fits into a European initiative to increase the independency of Europe for leguminous protein crops. Soybean is a crop that requires few inputs compared to other legumes in our context, and appears to be a good candidate. However, its adaptation to the northern France is not yet well defined. The objectives were to (i) evaluate agronomic suitability and yield potential of soybean by crop modeling simulations on a historical weather database and (ii) validate simulations using field experimental data.

Materials and Methods

A 21-year weather database (1999-2019) including maximum, minimum daily temperatures, daily precipitation and solar radiation, has been consolidated for UniLaSalle farm (Beauvais, France, N 49.46°, E 2.07°). The CROPGRO soybean model, part of DSSAT v4.7, has been used to simulate soybean phenology and estimate yield (Boote, 1998). Simulations have been performed on generic genotypes of maturity groups (MG) 000 and 00, which are the potentially most adapted to the region. In order to validate simulations data, 6 cultivars representing the two major MG (4 MG 000 and 2 MG 00) have been planted on 4 replications and 2 planting dates (Fig. 1). Leaf area index (LAI), crop and pod biomass have been measured on 6 dates, main phenological stages (Emergence, V2, R5, R7) and yield were recorded to evaluate the predictabiblity of the model and eventually adjust genetic coefficients.

Results and Discussion

Simulations showed a median dry matter yield potential around 1.4 t ha-1 under rainfed conditions with a strong variability for each maturity group (from 0.7 to 3.1 t ha-1). Physiological maturity was estimated to occur from mid-august to august 21st (±15 days) for MG000 and MG00 respectively. Simulation results first highlight that soybean crop cycle can fit within a winter cereal crop rotation commonly practiced in the region. However, the low yield levels and the large associated variability make the economical viability questionable. A second simulation considering no water limitation suggested that water stress was a strong limiting factor impacting both the yield potential (-2.2 t ha-1) and its variability. A scenario with three 30 mm irrigation paths starting around first flower stage was tested and showed an increase of around +1 t ha-1 of the yield potential with no impact on its variability. In the latter scenario, physiological maturity was slightly delayed by three days. Irrigation application appears to be an interesting managing option to consider. Experimental data were used to confirm the simulations. It appears that the simulation done on 2019 matches reasonably well with the first field results.

Conclusions

Additional field experiments using commonly grown cultivars in the study region will be set up to add observations into the model. By adjusting genetic coefficients to match observed data with predicted data, new cultivars will be released in the model to make simulations more predictable. Then, the response of the calibrated genotypes to various agronomic practices could be evaluated on the one side. On the other side, impact of modification of growth and development parameters will bring indication to the breeders to adapt the existing genetic material to northern France.

Acknowledgements

The European Agricultural Fund for Rural Development (EAFRD) is acknowledged for financial support. The authors are grateful to EURALIS Semences, SARL Raoul ROLLY and RAGT Semences for providing trial seed.

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Experimental field for calibration of soybean genotypes in Beauvais (France).

Keywords: Calibration, CROPGRO, DSSAT, Protein crops.

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S3-P.02

Identifying improved *Eucalyptus* traits to climate change by combining modelling and global sensitivity analysis

Elli Elvis Felipe[1] (elvisfelipeelli@usp.br), Huth Neil[2], Sentelhas Paulo Cesar[1]

[1] *University of São Paulo (ESALQ/USP), Piracicaba, SP, Brazil*; [2] *CSIRO, Toowoomba, Qld, Australia*

Introduction

Eucalyptus plantations productivity is strongly affected by climate conditions. Breeding efforts have been made to identify superior clones in terms of increased productivity and resilience to climate change. Approaches using global sensitivity analisys have been combined with process-based simulation models to identify suitable traits that may provide advantages in given environments (Makowski et al., 2006). Such approaches are still scarce, especially for *Eucalyptus* plantations. For these reasons, this study combines a global sensitivity analisys with a process-based forest model to identify superior *Eucalyptus* genetic traits for climate change adaptation for various environments in Brazil.

Materials and methods

The APSIM Next Generation (Holzworth et al., 2014) *Eucalyptus* model was validated against yield data and then used to perform the simulations of basal area (m2 ha-1), total height (m) and leaf area index - LAI at seven years. The simulations were performed for 23 locations in Brazil, covering a latitudinal range of 20 degrees, using weather data from 1980 to 2009. Climate change scenarios were obtained using three Global Circulation models and two contrasting greenhouse gases emission scenarios (RCP4.5 and RCP8.5), for the period 2020 to 2049. The Morris sensitivity method (Morris, 1991) was used to perform global sensitivity analysis for 10 genetic parameters (traits) of the APSIM *Eucalyptus* model. Two sensitivity indexes were obtained for each parameter: the mean of absolute values of the elementary effects (μ*) and the standard deviation (σ) of the elementary effects.

Results and discussion

Traits related to leaf partitioning and light extinction coefficient were, on average, the most influential for the present climate for basal area, total height and LAI (Figure 1), as indicated by high values of μ*. These traits also presented the highest interaction levels with other parameters (highest σ). When future climates were assessed, traits related to temperature response increased in influence for basal area and interactions with other parameters in simulating total height and LAI. Whilst no similar approaches were found in the literature for *Eucalyptus* plantations, our results are in agreement with those obtained by Casadebaig et al. (2016) and Sexton et al. (2017), who also used APSIM and the Morris method for wheat and sugarcane in Australia under present climate.

Conclusions

Process-based modelling coupled with global sensitivity analysis is suitable for identifying improved traits of *Eucalyptus* for climate change adaptation. Traits related to temperature response are expected to be more influential under climate change. Therefore, future breeding programs and genotype × environment studies should look at these traits for increasing *Eucalyptus* resilience to climate change.

Acknowledgements

We would like to thank the São Paulo Research Foundation - FAPESP (Processes N° 2016/26014-6 and 2018/00642-6) and Brazilian Research Council – CNPq (Process N° 155784/2016-1) for the support of this study by the PhD scholarship and Exchange scholarship at CSIRO Agriculture and Food.

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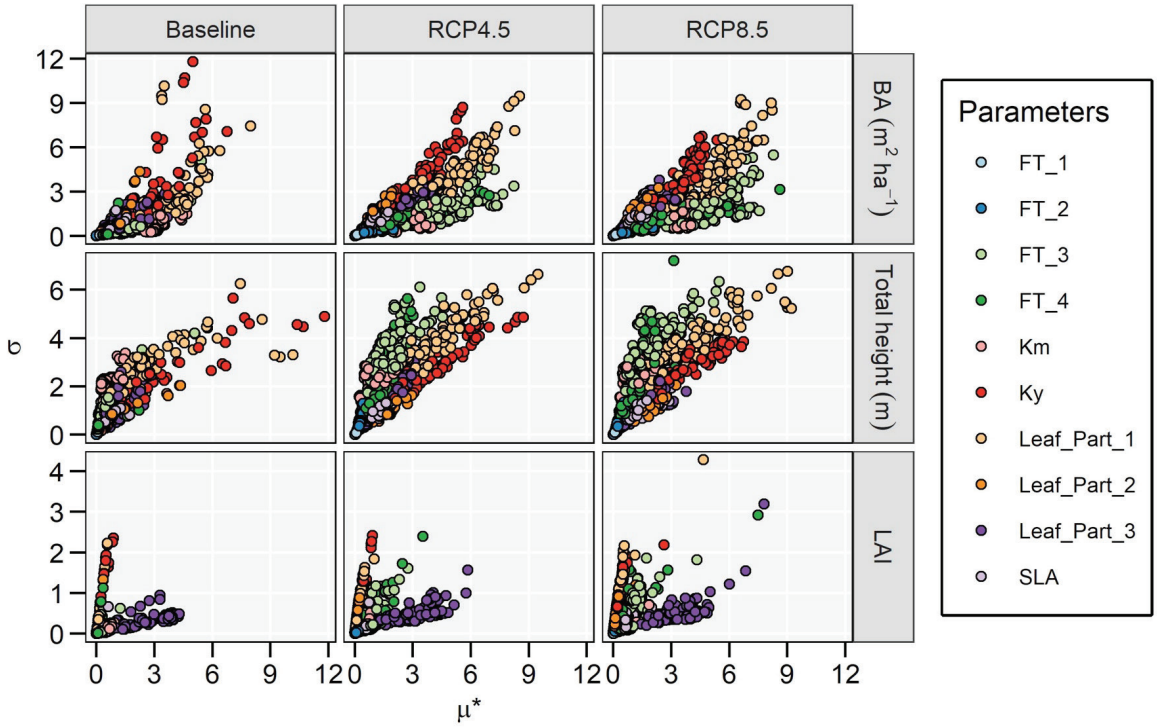

Figure 1. Levels of influence (μ*) and interaction (σ) of genetic parameters of the APSIM Next Generation Eucalyptus model to estimate basal area (BA), total height and leaf area index (LAI), considering the results from combination of five rotations of seven years (1980-2009 for baseline and 2020-2049 for RCP4.5 and RCP8.5) and 23 Brazilian locations.

Keywords: APSIM model, Morris method, Basal area, Total height, Leaf area index.

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S3-P.03

Multi-scale modeling of sunflower crop responses to genetic and environment variations.

Gosseau Florie[1] (florie.gosseau@inra.fr), Bonnafous Fanny[1], Pegot-Espagnet Prune[1], Mangin Brigitte[1], Langlade Nicolas[1], Casadebaig Pierre[2]

[1] *UMR LIPM, INRA, Castanet-Tolosan, France*; [2] *UMR AGIR, INRA, Castanet-Tolosan, France*

Current research in genomics and ecophysiology strive to improve gene-to-phenotype predictions beyond methods based solely on genetic information such as whole genome prediction (WGP). Predictive approaches coupling quantitative genetics and crop modeling are designed, either with an emphasis on ecophysiology or on statistics, according to the modeling scale of traits: from molecular to crop level (Bustos-Korts et al., 2016). Gene-to-phenotype predictions are generally carried to predict the breeding values from genome-wide information using statistical models. The difficulty with this method lies in the prediction of non-additive gene effect and gene-by-environment interactions. Crop simulation models, by representing dynamic responses of crop and soil processes to the environment, are successfully used to predict phenotypic plasticity for agronomical traits (Chenu et al., 2017). Therefore, coupling quantitative genetics and process-based modeling should improve the accuracy of breeding value prediction, with different options depending on the phenotypic distance, as illustrated by Hammer et al. (2016).

This study aims to predict the performance of a panel of sunflower hybrids in different farming environments, and therefore to identify the most promising genotypes and key physiological traits controlling yield stability and adaptation to future climatic scenarios. Our multiscale modeling strategy proceeded in two steps: (1) building whole genome prediction models to predict a set of component traits as a function of allelic combination of genotypes and (2) predicting the hybrid yield as a function of component traits, environmental variables and management practices using a crop simulation model (Casadebaig et al., 2016). We evaluated the accuracy of this multiscale model on a multi-environmental network (13 environments) where the training population was phenotyped and on independent trials with non-observed genotypes and environments (9 environments).

Over these 22 environments, we found that the overall accuracy of our multi-scale model was worse than the accuracy of a single genomic prediction model fitted for crop yield. The WGP model showed a good accuracy on the training environments and on the test environments including hybrids selected for their yield range. However, the multiscale model showed a better accuracy than the WGP model in 4 out 9 test environments, specifically when tested hybrids were not selected for their extreme yield levels.

Overall, we identified new bottlenecks related to the design of combined crop and genetic models, such as the definition of component traits articulating genomic and ecophysiological models and the environment(s) used to train the genomic models.

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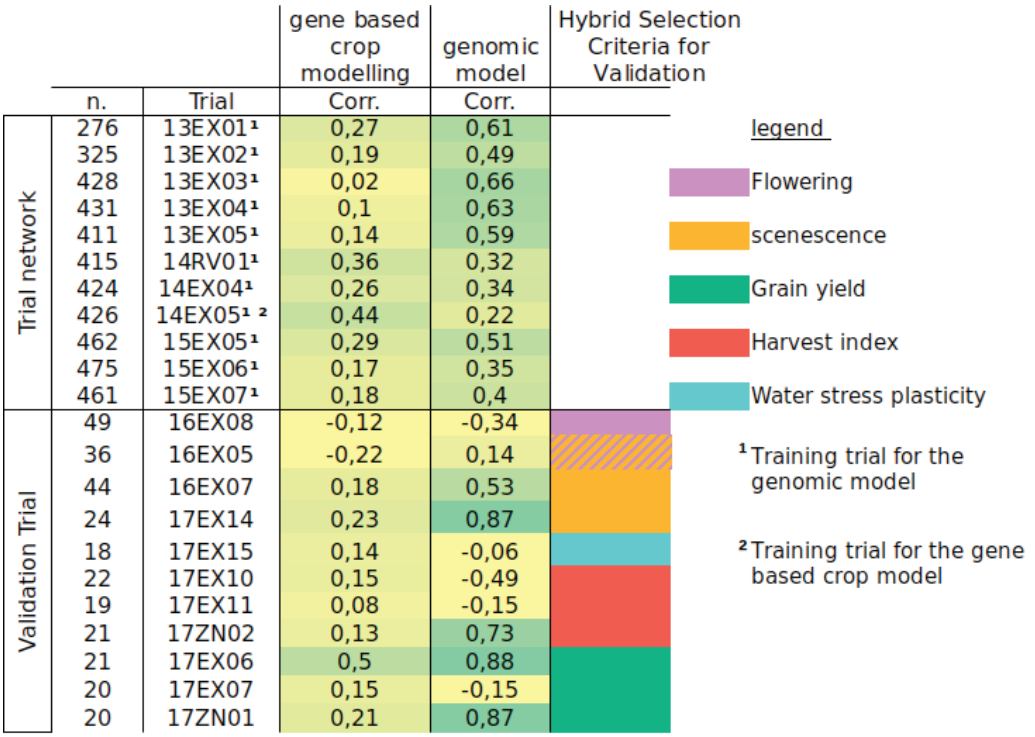

	n.	Trial	gene based crop modelling Corr.	genomic model Corr.	Hybrid Selection Criteria for Validation
Trial network	276	13EX01[1]	0,27	0,61	
	325	13EX02[1]	0,19	0,49	
	428	13EX03[1]	0,02	0,66	
	431	13EX04[1]	0,1	0,63	
	411	13EX05[1]	0,14	0,59	
	415	14RV01[1]	0,36	0,32	
	424	14EX04[1]	0,26	0,34	
	426	14EX05[1] [2]	0,44	0,22	
	462	15EX05[1]	0,29	0,51	
	475	15EX06[1]	0,17	0,35	
	461	15EX07[1]	0,18	0,4	
Validation Trial	49	16EX08	-0,12	-0,34	
	36	16EX05	-0,22	0,14	
	44	16EX07	0,18	0,53	
	24	17EX14	0,23	0,87	
	18	17EX15	0,14	-0,06	
	22	17EX10	0,15	-0,49	
	19	17EX11	0,08	-0,15	
	21	17ZN02	0,13	0,73	
	21	17EX06	0,5	0,88	
	20	17EX07	0,15	-0,15	
	20	17ZN01	0,21	0,87	

Figure 1. Summary table for the evaluation of the multiscale and whole genome prediction models Correlations between observed and predicted grain yield (q/ha) values. Values were predicted either by a gene-based crop model (multiscale model) or by a whole genome prediction model. n is the number of genotypes observed per trial.

Keywords: genomic selection, phenotypic plasticity, crop modeling, predictive biology.

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S3-P.04

Smart Reuse of High-Throughput Phenotyping Data using Scientific Workflows on the Cloud

Heidsieck Gaetan[1] (gaetan.heidsieck@inria.fr), Pacitti Esther[2], Tardieu François[3], Pradal Christophe[4]

[1] *Zenith, Inria, Montpellier, France*; [2] *LIRMM & Inria, Montpellier, France*; [3] *UMR LEPSE, INRA, Montpellier, France*; [4] *UMR AGAP & Zenith, Cirad & Inria, Montpellier, France*

Introduction

High-throughput phenotyping platforms generate terabytes of data used in plant modeling and genetic analyses. Such computational analyses require very large distributed computational infrastructure to be processed. This leads to a huge volume of data that is hard to manage. For this purpose, scientific workflows (Swf) provide a convenient solution to execute, share, reproduce and keep provenance of such analyses and simulations. We present a method that extend Swf to automatically share intermediate computational results between executions and between users. It helps saving time and money and enhance reproducibility.

Materials and Methods

The Phenomenal workflow [1], implemented in the OpenAlea platform, has been used to illustrate the speedup of our cache algorithm in the context of high-throughput analysis. This Swf is composed of nine steps including 3D reconstruction, skeletonization, and organ segmentation. Raw input images have been acquired in the PhenoArch High-throughput phenotyping platform [3]. The raw input dataset is 440 Gigabyte of images and the Swf is executed on the IFB cloud, on 80 vCPUs. We propose an adaptive caching method based on the provenance that is compared to a “no cache” method and a “greedy” where none or all the intermediate data is saved and reused respectively.

Results and Discussion

The Swf (fig.1) successfully execute on the distributed cloud environment, the overall execution time is scaling down with the increase of computation power. Our reuse data management approach is adding a small overhead to the first execution (5%).

Our solution automatically manages the reusing, storing, and sharing the data between users in a distributed environment. It both speed up the overall execution time and reduce the total amount of data to be stored compared to the “greedy” method. In our phenotyping experiments, the gain for the second execution is greater than a factor 30: it takes 40 minutes to re-execute a Swf that required 21 hours for the first execution. It is easy to see that storing and reusing intermediate results fasten future executions. However, as the data managed becomes huge, storing everything is very costly and not always feasible. Moreover, it is often challenging to decide what data is best to be stored. Our approach automatically deals with the trade-off between the storage cost and the re-execution cost by selecting the most cost-efficient result data to store and reuse.

Storing intermediate results also strengthens provenance information on the Swf executions, because the provenance metadata is linked to intermediate results.

Conclusions

The data storing method presented in this work ease the reuse and sharing of data-intensive scientific workflows. It speeds up new executions and strengthens provenance information.

Acknowledgements

This work was supported by the #DigitAg French Convergence Lab. on Digital Agriculture (http://www.hdigitag.fr/com), the SciDISC Inria associated team with Brazil, the Phenome-Emphasis project (ANR-11-INBS-0012) and IFB (ANR-11-INBS-0013), the France Grille Scientific Interest Group and the Thomas Jefferson Fund of the Embassy of France in the United States and the FACE Foundation.

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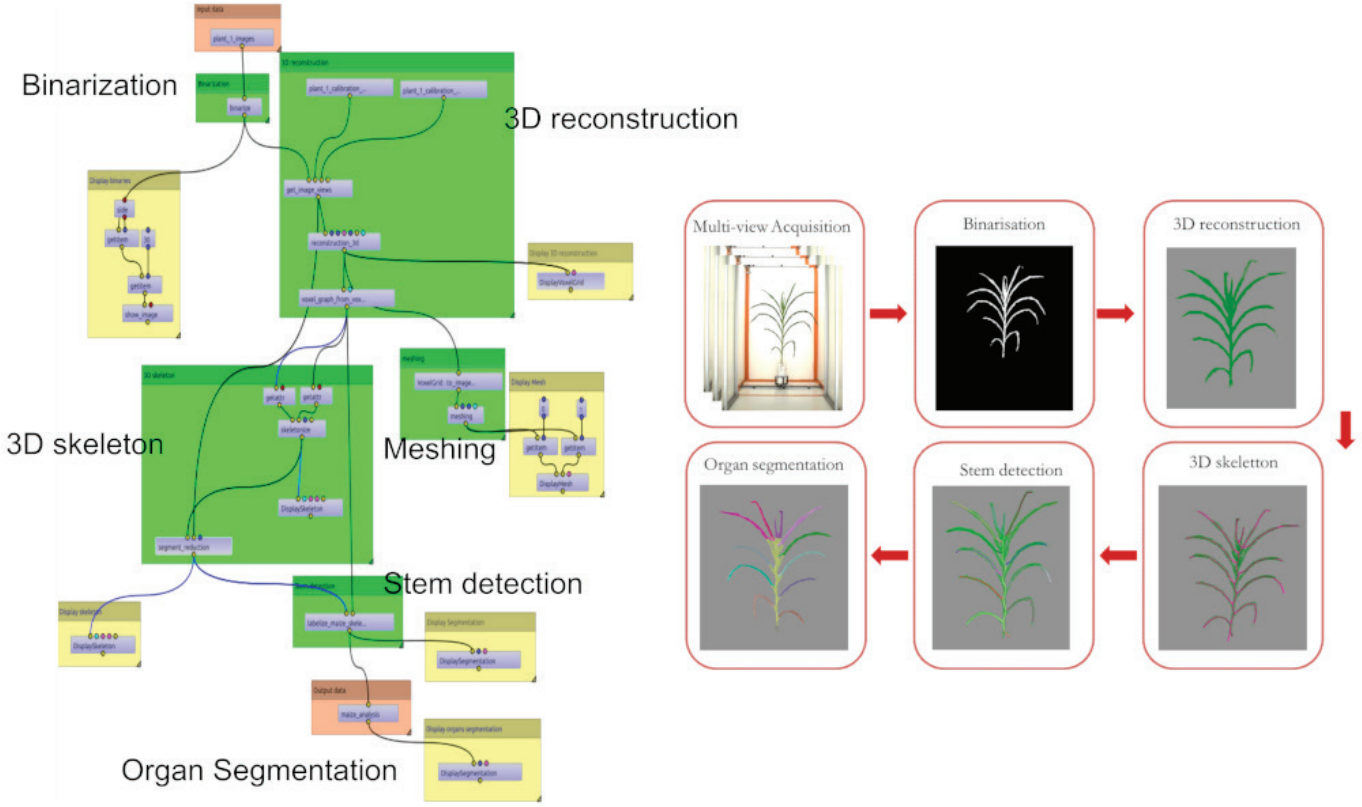

Figure 1. Phenomenal workflow in OpenAlea and its generated intermediate results.

Keywords: High Throughput Plant Phenotyping, Cloud computing, Data Sharing, Scientific Workflows, OpenAlea.

References:

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S3-P.05

Assessment of two sugarcane models for predicting genotype by environment interactions, using an international dataset

Jones Matthew[1] (matthew.jones@sugar.org.za), Singels Abraham[1], Chinorumba Simbarashe[2], Patton Alana[1], Poser Christophe[3], Singh Maninder[4], Martine Jean-Francois[3], Christina Mathias[3], Annandale John[5], Hammer Graeme[6]

[1] *SA Sugarcane Research Institute, Mt Edgecombe, KZN, South Africa*; [2] *Zimbabwe Sugar Association, Chiredzi, Zimbabwe*; [3] *CIRAD, Montpellier, France*; [4] *SIRC, Belle Glade, Florida, United States*; [5] *Department of Plant and Soil Sciences, University of Pretoria, Pretoria, Gauteng, South Africa*; [6] *ARC Centre of Excellence, University of Queensland, Brisbane, Queensland, Australia*

Introduction

Traditional sugarcane breeding is costly, and challenged by the presence of genotype (G) by environment (E) interactions. An integrated approach to crop improvement, using realistic process-based crop models, can be useful for breeding (Hammer and Jordan, 2007). Jones et al. (2019) assessed concepts of G and E control used in sugarcane models using an international multi-E, multi-G dataset. These models have not however been systematically evaluated for their abilities to predict GxE interaction effects on yield.

Our goal was to evaluate DSSAT-Canegro («DC», Jones and Singels, 2018) and Mosicas («MS», Martiné and Todoroff, 2004) for simulating G and E effects on crop development and growth using an international growth analysis data set.

Materials and Methods

The dataset (described by Jones et al., 2019) consisted of crop development and growth observations from irrigated trials using cultivars N41, R570 and CP88-1762, conducted at Pongola (South Africa), La Mare (Reunion Island, France), Belle Glade (Florida, USA) and Chiredzi (Zimbabwe). G-specific trait parameter values for DC and MS were determined by (1) deriving values directly from observations; or (2) using trial-and-error to minimise simulation prediction error of process-output variables; or (3) using default model values.

Model performance was quantified by comparing simulated and observed values of canopy development (fractional interception of photosynthetically-active radiation, FiPAR, %) and above-ground biomass accumulation (ADM, t ha^{1}). Prediction of GxE interaction was assessed by analyzing variance across Es and Gs.

Results and Discussion

DC predicted FiPAR most accurately (RMSE = 12.8%, R^2 = 0.84). MS overestimated FiPAR during warm periods and underestimated it during cool periods, suggesting a too-high default base temperature.

Simulated and observed ADM yields are shown in Figure 1. The La Mare first ratoon ("R1") crop produced highest yields, followed by the Belle Glade plant ("P") crop. Lowest yields were recorded for the Pongola P crop. Highest-yielding Gs were: CP88-1762 at Belle Glade (P and R1) and Chiredzi R1; R570 for La Mare R1; and N41 for Pongola P.

DC and MS had similar ADM simulation accuracy (RMSE ~ 6.5 t ha^{-1}, R^2 ~ 0.90). DC could not predict the low ADM yields observed for Pongola P, while MS underestimated yields for La Mare R1. All models underestimated variation between Es, suggesting inadequate process-level responses to E drivers.

G variation in ADM yields was underestimated by both models. Neither model could predict the high ADM values for R570 at La Mare R1, and N41 at Pongola P (Figure 1); this is not yet fully understood. G rankings per E were correctly predicted in three of five Es by DC, and only one of five by MS.

Further analysis is required to understand the reasons for the poor model performance; this may lead to recommendations for model improvements.

Conclusions

DSSAT-Canegro and Mosicas underestimated both E and G variation in ADM yields, and were unable reliably to predict observed G rankings, for these irrigated Es. Further analysis is required to understand why the models failed in these ways. We intend to use these findings to improve algorithms and calibration protocols to strengthen model-assisted sugarcane breeding.

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Acknowledgements
The authors gratefully acknowledge funding from the International Consortium for Sugarcane Modelling and technical and infrastructure support from participating research organizations.

Site, crop	Observed ADM (t ha^{-1})				DSSAT-Canegro sim. ADM (t ha^{-1})				Mosicas sim. ADM (t ha^{-1})			
	N41	R570	CP88-1762	Avg.	N41	R570	CP88-1762	Avg.	N41	R570	CP88-1762	Avg.
Belle Glade, P	41.9	52.3	62.4	52.2	43.7	44.9	47.0	45.2	46.7	46.7	49.7	47.7
Belle Glade, R1	34.7	46.6	48.1	43.1	44.0	45.4	48.7	46.0	49.0	47.9	51.5	49.5
Chiredzi, R1	45.8	45.7	50.0	47.2	55.5	55.1	57.5	56.0	52.2	51.5	54.1	52.6
La Mare, R1	68.3	71.2	56.4	65.3	59.7	61.4	62.9	61.3	53.2	52.9	54.9	53.7
Pongola, P	43.4	35.9	38.4	39.2	45.4	45.7	49.1	46.7	34.2	34.7	37.0	35.3
All experiments	46.8	50.3	51.1	49.4	45.4	45.7	49.1	51.1	34.2	34.7	37.0	47.7

P = Plant crop, R1 = ratoon crop

Figure 1. Heatmap of above-ground dry biomass (ADM) yields, observed and simulated by DSSAT-Canegro and Mosicas. The colour scale indicates ADM yield rank for each experiment, with green the highest and red the lowest.

Keywords: crop model, genetic trait, GxE, breeding, biomass.

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S3-P.06

Modeling of hybrid performance and yield gain in oilseed rape by systems biology

Kupisch Moritz[1] (mkupisch@uni-bonn.de), Langensiepen Matthias[1], Scholten Stefan[2], Snowden Rod[3], Usadel Björn[4], Abbadi Amine[5], Leckband Gunhild[5]

[1] *University of Bonn, Bonn, Germany*; [2] *University of Göttingen, Göttingen, Germany*; [3] *University of Gießen, Gießen, Germany*; [4] *RWTH Aachen University, Aachen, Germany*; [5] *NPZ Innovation GmbH, Holtsee, Germany*

Introduction

Rapeseed hybrid breeding has significantly increased yields and physiological resilience to climate-change related fluctuations of the physical environment. Generating and testing extensive sets of hybrids resulting from pairwise combinations of potential parents in different environments is practically impossible. To provide a solution to this problem, we developed a systems-biological approach to predict hybrid yield performance based on information about genomic and epigenetic profiles of parental genotypes and their responses to environmental stimuli. Specifically, we addressed following questions: (1) How accurate can yields be simulated across locations and seasons? (2) Can patterns of gene expression be linked to patterns of crop model parameters? (3) Can crop model parameters of hybrids be derived from information of parental gene expression?

Materials and Methods

The dataset comprised samples of mRNA and small RNA patterns taken at seedling stages. Phenology, biomass, Leaf Area Indices (LAI) and yield components were determined at different development stages and five geographical locations in Germany between 2013 and 2016. A photosynthesis-driven growth model with leaf and pod specific assimilation and rapeseed specific development was assembled, calibrated and tested to explain environmental effects on hybrid yields. The phenotypic dataset contained 427 parental lines and 725 different hybrids, whereas the gene expression data was available for the parental lines only. The dimensionality of the RNA datasets with expression levels of more than 100k genes was reduced using the LASSO regularization method and principal component analysis. Various levels of clustering within this reduced gene expression space were linked with patterns of calibrated crop model parameters using multivariate statistics. The crop growth model was also run for genotype-specific, genotype/location-specific and genotype/location/season-specific parameter configurations.

Results and Discussion

The crop growth model was calibrated using different parameterization scenarios by adjusting maximum photosynthesis (AMX), specific leaf area (SLA) and the light extinction coefficient (K). The overall model efficiencies for all simulated yields (parents and hybrids) ranged from 0.78 in the genotype-specific scenario to 0.89 when additional location-specific calibration was allowed. The physiological difference between the two scenarios was higher for AMX and SLA (0-46% and 0-48%) than for K (0 – 20%). Replacing genotype-specific parameters with genotype-cluster-specific parameters based on similarity of gene expression revealed an immediate decline of model efficiency when clustering more than 5% of the 427 parental genotypes. The patterns of the parental gene expression were linked with the calibrated crop model parameters using a GLM model. This led to model efficiencies around 0.8 whereas the parameters of hybrids as functions of parental RNA had values of 0.5.

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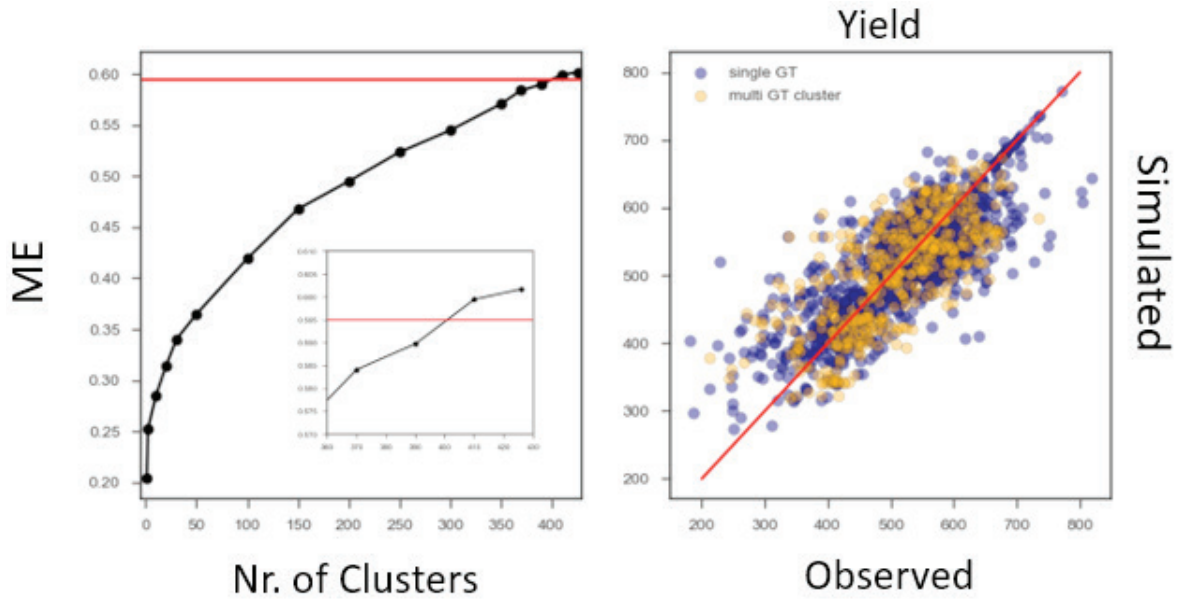

Model efficiency (ME) of different simulations runs based on the degree of clustering of parental genotypes (left). Simulated vs. Observed plot of grain yield (g/m2) of 427 parental genotypes grown at five locations in four different seasons of a simulation run with a clustering degree of 5% (right). Blue dots indicate yields of genotype-specific parameter sets, orange dots are yields of multi-genotype clusters.

S3-P.07

Autoencoding genetic markers to predict the value of ecophysiological model parameters - proof of concept

Larue Florian (florian.larue@cirad.fr), Luquet Delphine, Rouan Lauriane, Pot David, Rami Jean-François, Beurier Grégory

AGAP, CIRAD, Montpellier, France

Introduction

Crop growth modelling formalizes the biological processes at which genotype X environment interactions (GxE) are expressed. It has the potential to evaluate, in silico, the effect of elementary traits and related genetic factors on phenotype and yield elaborations. Recent studies (Technow et al., 2015, Cooper et al., 2016) showed that, by driving the value of crop model parameters using a genomic selection model, yield was predicted more accurately than by a classical genetic model. However these studies dealt with few, integrative parameters and a narrow genetic diversity, i.e. a reduced number of molecular markers. This contrasts with the necessity to make crop models more responsive to climate change variables and thus increase the number of physiological parameters, while studying wider genetic diversity to seek for adaptive markers.

With this respect, methods that reduce the dimensionality of the problem are needed. The autoencoder, a semi-supervised machine learning method, can reduce the number of predictors (markers) without prior information, by compressing input data into an encoded neural network layer. Applied to genetic diversity, it should ease modelling and predicting the genetic value of crop model parameters underlying GxE and yield variability, compared to classical regression methods.

Materials and Methods

This study aimed at testing the autoencoding of the genetic data (ca. 150000 markers) within a West-African sorghum diversity panel of 200 individuals. It evaluated then the relevance of autoencoded data to predict the genetic value of the dozen of crop/plant parameters controlling growth and plasticity in Ecomeristem model, estimated using data from an experiment in the Phenoarch platform.

Results and Discussion

Depending on the representation of the markers as input of the neural network, and the amount of markers considered, autoencoding was able to reduce the dimension of the markers to a 512 or 1024 size vector with less than 10% error. That is, about 90% of the markers where correctly reconstructed from their latent representation (i.e. the code). Several other neural networks architectures where also tested yielding different results.

Conclusions

By reducing the dimension of genetic markers in an unsupervised, non-linear way, autoencoders could be used to extract meaningful features and account for complex genetic architecture. Ultimately, the latent encoded representation of the genetic markers should ease regression on the phenotype.

Acknowledgements

This work was supported by the projects Sorghum Genomics Toolbox (funded by Bill & Melinda Gates Foundation) and Biomass for the Future (ANR-11-BTBR-0006-BFF, funded by the French National Research Agency (ANR).

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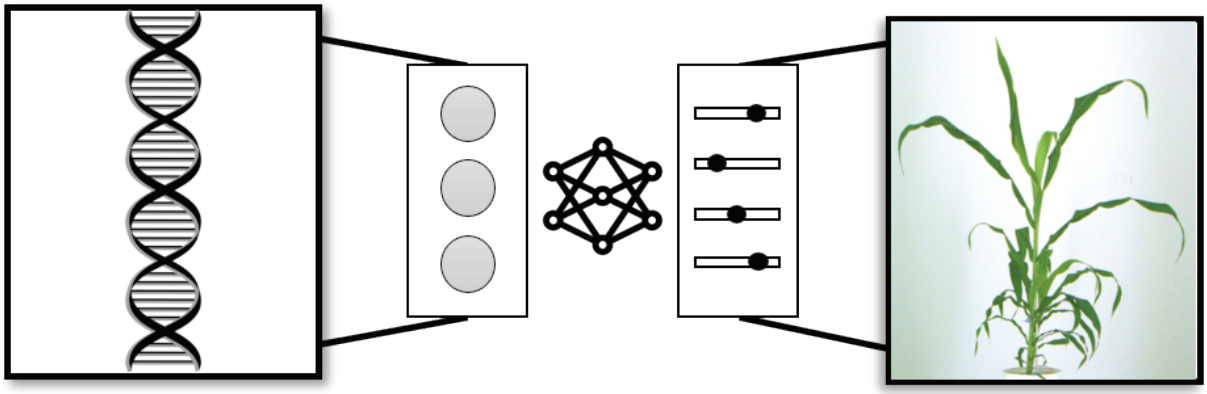

Linking the genotype to the phenotype using neural networks through the dimensionality reduction of the genotype into encoded genetic markers and of the phenotype into model parameters

Keywords: Neural networks, Autoencoder, Ecophysiological model, Parameters, Genetic markers.

References:

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S3-P.08

Application of a functional-structural plant model on two wheat varieties to enhance physiological interpretation

Lauwers Simon[1] (Simon.Lauwers@UGent.be), Coussement Jonas[1], Verbeke Sarah[1], De Schepper Veerle[2], Steppe Kathy[1]

[1] *Laboratory of Plant Ecology, Ghent University, Ghent, Belgium*; [2] *BBCC – Innovation Center Ghent, BASF, Ghent, Belgium*

Introduction

Functional-structural plant models combine process-based submodels with a detailed 3-dimensional plant structure. In this work, a static FSPM for wheat was designed and applied on two different wheat varieties to enhance physiological interpretation. Parametrization, calibration and validation of the model was performed using data from wheat plants grown inside a greenhouse. Model application was examined by comparing the two wheat varieties on different levels.

Material and Methods

For both varieties, structural data of eight plants was implemented in the model using the XL-language, as available in GroIMP. All morphological parameters were manually measured, avoiding 3-dimensional or image visualisation. Leaf curvature was approached by a circular arc and leaf shape was approached by using the lamina2Shape model introduced by Dornbusch et al. (2007). The functional counterpart of the model was divided in two submodels. First, the PROSPECT-D model (Féret et al., 2017) was used to calculate leaf spectral characteristics based on measured SPAD-values for every leaf. Second, the coupled P-SC-T model (Kim et al., 2003) was introduced combining calculations for photosynthetic rate, stomatal conductance and transpiration. Incoming light was reproduced by combining assimilation lights with a module for diffuse sunlight. Direct sunlight and the greenhouse structure were neglected. Validation was performed by comparing the photosynthetic rate of a container filled with wheat plants to the simulated photosynthetic rate of a virtual container, consisting of numerous copies of eight selected plants, distributed at random. Canopy photosynthetic rate was measured using the canopy photosynthesis and transpiration system (Song et al., 2018).

Results and Discussion

The model resulted in a similar evolution of measured and simulated photosynthetic rate. Further refinement should be conducted towards dark respiration, as simulated dark respiration tended to be constant, while measured dark respiration was not. A first application of the FSPM was a comparison of both wheat varieties. Little significant differences were observed between measured parameters of both varieties. Using the FSPM and its submodels, differences were further investigated. By separating the structural and functional characteristics of both varieties, it was concluded that the small differences in photosynthetic rate were more driven by structural characteristics compared to their functionality. Calibration of the submodels made it possible to identify important traits affecting photosynthetic rates and stomatal conductance.

Conclusions

A good model validation was obtained, even with simple, manual measurements and direct sunlight neglected. Using both the FSPM and its submodels, insights could be gathered concerning the effect of different traits on photosynthetic rates. As both measurements and calibration were rather simple, new varieties could be introduced in the FSPM fast and easy. Local sensitivity analysis could be applied to structural, functional and even environmental parameters, to further investigate the effect of changing parameters on each variety.

Acknowledgements

We would like to thank BASF (BBCC- Innovation Center Ghent) for providing us with wheat plants and for their support during measurements. We would like to thank Selwyn Villers and Jonathan Vermeiren for their contributions to the model.

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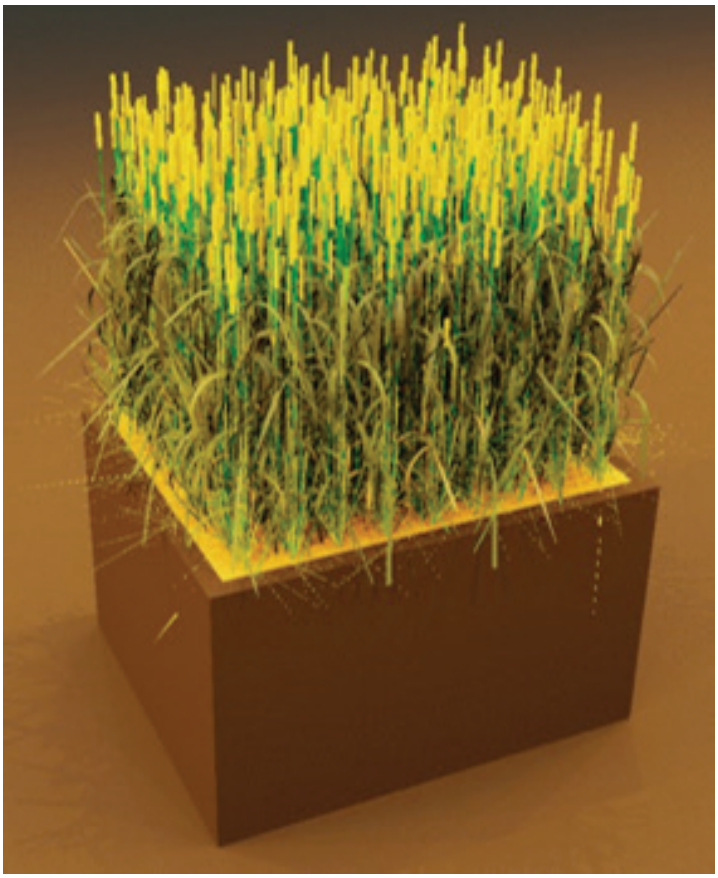

A snapshot of a virtual container containing a wheat variety.

Keywords: GroIMP, PROSPECT, Photosynthesis, Stomatal conductance, Triticum aestivum L..

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S3-P.09

A QTL-based model to quantify the yield of different spring barley genotypes under water deficit

Moualeu-Ngangue Dany (moualeu@gem.uni-hannover.de), Dolch Christoph, Stützel Hartmut

Vegetable Systems Modelling Section, Leibniz University Hannover, Hanover, Germany

Introduction

Nowadays already, water deficit is one of the most significant yield-reducing factor worldwide (Forster *et al.*, 2004) and future climate change scenarios predict the water availability to be a critical factor for agriculture (Turral *et al.*, 2011). Therefore, it is crucial to develop better tools for predicting performance of plants under water deficit and at the same time, to help breeders developing more drought tolerant varieties. Passioura (1996) defined yield or the ears dry mass (DME) as DME = WU * WUE*HI, where DM is the total plant dry mass and HI is the harvest index, defined as the ratio of grain yield to above-ground dry matter and WU is the total amount of water use by the plant. The difficulty of this model is the estimation of the total water used by the plant. The combination of an ecophysiological model and a quantitative trait loci (QTL) analysis of some plants phenes might help to predict the performance of all genotypes of a plant species under all environments and allow the genetic variability of a physiological drought response to be analyzed (Reymond *et al.*, 2003). The aim of our work was to build such a QTL-based model for spring barley under water shortage.

Materials and Methods

209 genotypes of spring barley belonging to the "barley core collection" and covering a wide range of origins, obtained from the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK, Gatersleben, Germany) were investigated in six pot experiments were conducted from 2012 to 2015 in an open-sided vegetation hall of the Institute of Horticultural Production Systems, Leibniz Universität Hannover, Germany. During the experiments, all pots were weighted three times per week to calculate transpiration and soil water content until the transpiration rate of the stressed plants decreased to 10% of the respective control plants. Different plant dynamics traits such as leaf elongation rate (LER), leaf appearance rate (LAR) and plant transpiration rate were investigated. A linear plateau model was applied to quantify the response of growth and physiological traits. An ecophysiological model for the growth of spring barley was built and calibrated for each of the 209 genotypes investigated. A simplified model description was is summarized in Figure 1.
GWAS were performed for the parameters of the linear plateau model of the investigated traits, and traits like LAR in other to identify QTLs that might explain the variability among the genotypes.

Results and Discussion

A high diversity in the response of the leaf elongation, stomatal conductance to drought stress was observed amount all the 209 genotypes and the ecophysiological model predicted successfully the yield, the leaf area, the dry weight and the water used of each individual genotype under both control and stressed condition. A total of 75 QTLs were identified for the parameters of the linear plateau model explaining the performance of the genotypes under water shortage. Significant QTLs was found as well for the LAR and the average leaf elongation rate of each genotype. Including the values of the threshold and the intensity of the reaction to soil drying, the QTL-based model predicted well the transpiration of different genotype of genotypes of barley under both control and stress conditions (Fig 1 b,c,d). In general, including the QTLs data improved the fitting of the data to the 1:1 line, although the R-square was reduced.

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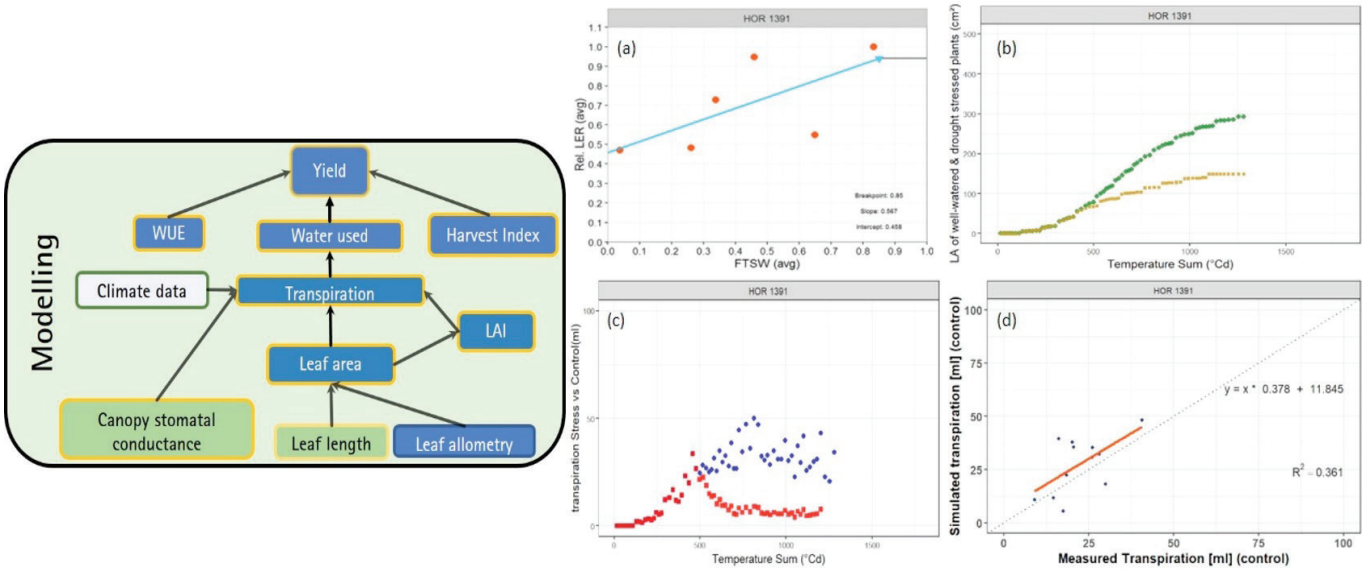

Figure 1: Global overview of the ecophysiological model for the prediction of the growth and yield of 209 Barley genotypes under soil drying and the dynamics of leaf area and transpiration for one of the investigated genotype. The yellow bordered traits are those affected by drought stress during the stress treatment.

Keywords: QTL-based model, Spring barley, Water use, Transpiration, Yield Model.

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S3-P.10

Genetic variability of the response of leaf elongation rate and transpiration to temperature and evaporative demand for wheat

Leveau Stephane (stephane.leveau@inra.fr), Parent Boris, Martre Pierre

LEPSE, INRAE, Montpellier, France

Introduction

Formalizing plant-environment responses are necessary to predict agronomic performances of plant genotypes in current and future climate scenarios. In *Arabidopsis thaliana*, rice and maize, the parameters of the response to temperature of development and shoot expansion processes are unique within a species for several processes (Parent and Tardieu, 2012). However, in rice and maize, responses to evaporative demand show high intraspecific genetic variability (Parent et al., 2010). In wheat, the few published works did not analyze the specific effects of temperature and evaporative demand (Schoppach and Sadok, 2012). Here, we analyzed the genetic variability of these responses for wild and cultivated wheat species. The associated parameters can be used to improve crop models.

Materials and Methods

We analyzed the temperature and vapor pressure deficit (VPD) response of leaf elongation rate (LER) and transpiration (TR) for five genotypes of 12 wheat species. Plants were grown in a growth chamber and transferred to the Phenodyn phenotyping platform (Sadok et la., 2007) when the fourth leaf was half its final length. A protocol was then applied to analyze the temperature and VPD responses of LER and TR during the night and diurnal periods, respectively. We modeled LER and TR responses to temperature by using a segmented linear model based with three parameters (*T*min, *T*opt, and *T*max; Fig. 1a). We used the slope of a linear model to analyze the sensitivity of LER (sLER) and TR (sTR) to VPD. Overall, we obtained five parameters for response curves, three absolute rates and nine variables related to plant structure.

Results and Discussion

We found intra- and inter-specific variability in all traits. As expected, the interspecific variability was larger than the intraspecific variability. A principal component analysis (PCA) with hierarchical classification analysis (HCA) on all traits showed a distinction between wild and domesticated species. This analysis separates species according to their ploidy level and natural hybridization events. The PCA with HCA performed only with response traits, still shows a significant distance between wild and cultivated species, with the exception of *Triticum tauschii*, which had responses close to the cultivated species and inversely for old durum wheat *cultivars (T. durum pop*).

Conclusions

Our results show that domestication and breeding of wheat species, in addition to having modified structural traits, has modified responses to temperature and VPD. Overall, our study (i) gives new insight for understanding plant adaptation to new environments and the impact of domestication and past plant breeding; (ii) it gives information on the potential genetic variability of crop model parameters for plant responses to environmental conditions; and (iii) can guide future crop breeding for adapting crops to future E x M scenarios under climate change.

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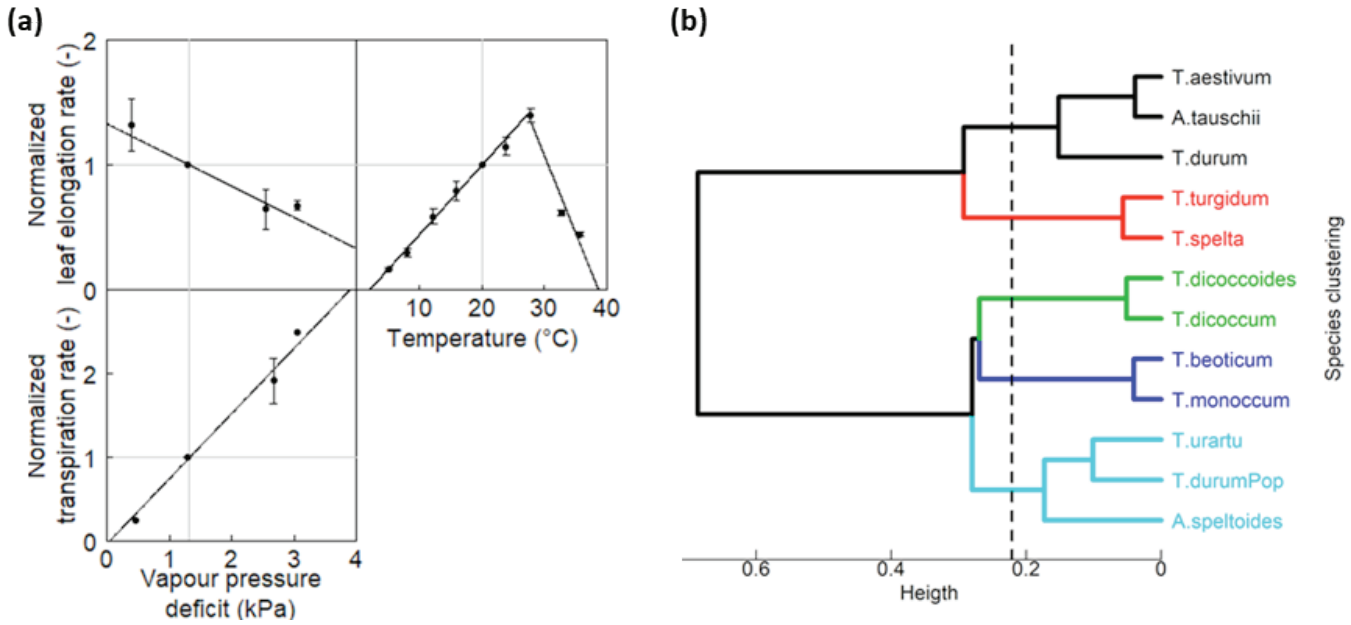

Figure 1. Response curve of LER to temperature and VPD and response curve of TR to VPD (a). Example for a genotype of T. turgidum subsp. durum. Dendrogram of hierarchical clustering analysis for the 12 studied wheat species (b) based on the five parameters of the temperature and VPD response curves.

Keywords: Leaf elongation, temperature, transpiration, vapor pressure deficit, wheat.

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S3-P.11

Durum wheat ideotypes optimized for the Mediterranean basin under future climates

Padovan Gloria[1] (gloria.padovan@unifi.it), Martre Pierre[2], Semenov Mikhail A.[3], Bindi Marco[4], Ferrise Roberto[4]

[1] *University of Florence, DAGRI, 1991, Firenze, FI, Italy*; [2] *SupAgro, INRA Montpellier, Montpellier, France*; [3] *Rothamsted Reserach, West Common, Harpenden, United Kingdom*; [4] *DAGRI, University of Florence, Firenze, Italy*

Introduction

The Mediterranean basin is one of the most productive area for wheat, producing 21 million of tonnes per year. Moreover, it is also defined as a "hot spot" (Giorgi, 2006) that is very sensitive to future climate change. Due to population growth, future climate change, the limited possibility to extend crop-growing area because of land availability and limited water resources, plant breeders are under pressure to develop cultivars that have greater yield potential and stability in our current production systems. Crop simulation models can be useful tools to help breeders to design and test *in silico* new wheat ideotypes optimized for target environments and future climate conditions. The aim of this study was to describe durum wheat ideotype characteristics able to reduce the grain yield inter annual variability and ensure high yield potential under future climatic conditions.

Materials and Methods

Four different areas are were chosen to represent different agro-climatic conditions in the Mediterranean basin: Florence in the Central of Italy; Foggia in the South of Italy; Santaella in the South of Spain; Sidi El Aydi in the North of Morocco. For the ideotype study, the crop simulation model SiriusQuality (SQ) was used. SQ was calibrated and validated using observed data from experimental field trials carried out in the four selected areas. Two general circulation models, HadGEM2-ES and GISS-E2-R-CC, were used to generate the future climate scenarios centred on 2050 according to RCP 8.5. Six varietal parameters related to phenology and biomass production, considered the most promising to improve wheat yield under future climate conditions, were used for the ideotype design. The Non Dominated Sorting Genetic Algorithms (NSGA-II) (Deb et al., 2002), was used to select the best combination of parameters for the optimization of grain yield. For each location, among the best samples, the 10 hypothetical ideotypes showing the lowest inter-annual coefficient of variation were selected. Then, they were grouped in clusters in relation with their phenotypic responses using the clustering method ward.D2 (Murtagh and Legendre, 2014).

Results and Discussion

The results suggested that under future conditions, different varietal parameter sets, which represent potential ideotypes with different phenotypic characteristics, can be identified. All of them led to yield maximization and a reduction in the inter-annual variability (Fig.1). The ideotypes were characterised by an earlier anthesis date, a longer grain filling and a greater "stay green" capacity compared to the unchanged varieties. The extension of the "stay green" of the crop during the grain filling was adopted as adaptive strategy, since a low rate of leaf senescence ensured a longer grain filling duration. The low penultimate leaf and flag leaf surface area observed especially in Foggia, in Santaella and in Sidi El Aydi might be a response to dry environments characterized by terminal drought.

Conclusions

One of the emerging message from this study was that under future climate change in the Mediterranean basin, different varietal parameters combinations led to increasing yield. But, all improved durum wheat varieties need to have an earlier anthesis date and a longer grain filling compared to the current varieties. The research in existing wheat populations of cultivars with the suggested characteristics could be effectively included in a genetic breeding program.

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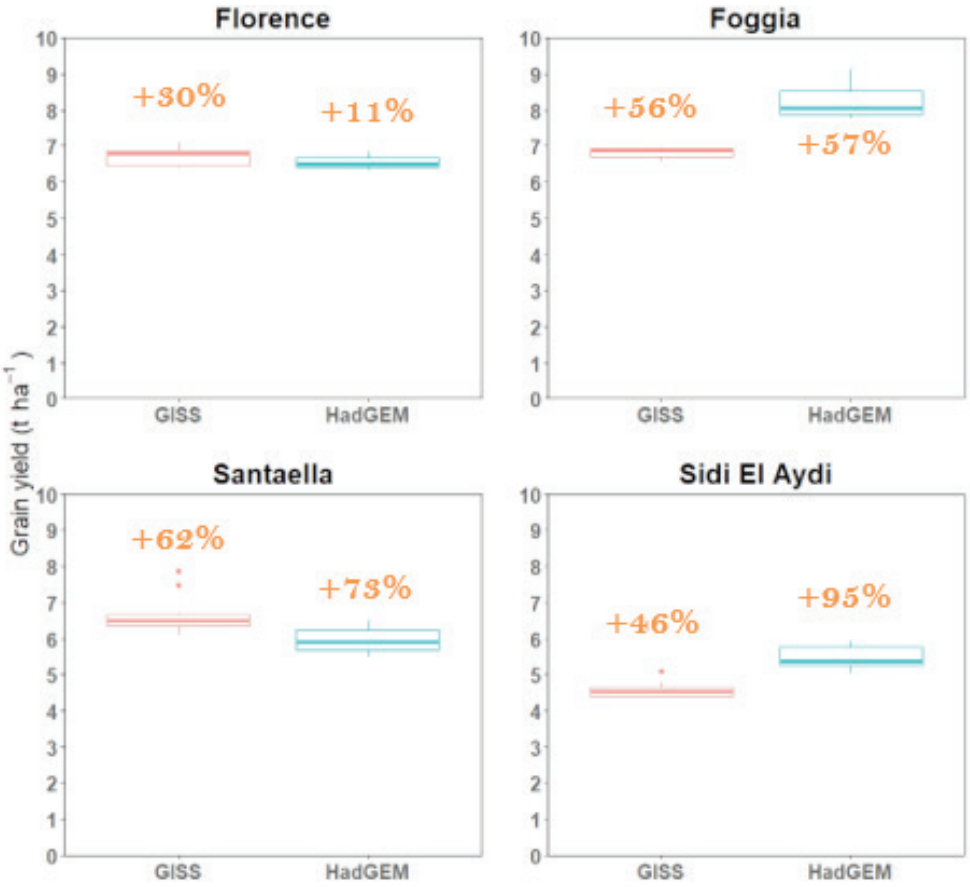

Figure 1. Box plots of simulated yield (t ha-1) using the ideotype parameters in Florence, Foggia, Santaella and Sidi El Aydi for the future climate scenarios based on GISS and HadGEM at RCP 8.5 for near future (2050s). Percentages are the yield increase of ideotypes compared to the unchanged varieties.

Keywords: Durum wheat, SiriusQuality, climate change, ideotype.

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S3-P.12

Substantial increase in yield is predicted by designing wheat ideotypes for Europe under future climate

Senapati Nimai (nimai.senapati@rothamsted.ac.uk), Semenov Mikhail A.

Rothamsted Research, Harpenden, Herts, United Kingdom

Introduction

A considerable increase in food production is needed to underpin future global food security. Raising upper limits in crop yield potential is the key for increasing food production under future climates. Europe is the largest wheat producer delivering 20% wheat globally, but its genetic yield potential under future climate is yet unknown (Semenov et al., 2014). The study objective was to design in silico future wheat ideotypes based on state-of-the-art knowledge in crop physiology and availability of genetic variation, and to assess genetic yield potential of wheat in Europe under future climate.

Materials and Methods

Representative sites across Europe were selected, covering the major wheat growing regions in Europe, from Spain in the south to Denmark in the north, and Hungary in the east to the UK in the west. To estimate variation in wheat yield due to inter-annual variation in climate and climatic extremes, a 100 years of daily weather data at each site was generated by using a stochastic weather generator (LARS-WG 6.0) for baseline and future climates. The target 2050-climate was based on projection from a global climate model HadGEM2 from the CMIP5 ensemble for the RCP8.5 The Sirius wheat model was used to design wheat ideotypes. It includes a computational framework facilitating design of crop ideotypes and optimization of cultivar traits in a target environment (Semenov et al., 2013). An ideotype was defined as a set of Sirius cultivar parameters (traits) that would deliver high yield when optimised in a target environment, representing an ideal wheat plant. A total of seven Sirius cultivar parameters representing different wheat cultivar traits, e.g. canopy architecture, growth rates, phenological development, response to abiotic stresses (Senapati et al., 2019b), were selected for optimization due to their a) importance for crop yield improvement under climate change, b) large natural variations observed in wheat germplasms, c) potential for improvement through genetic adaptation. An evolutionary search algorithm with self-adaptation (EASA) was used in Sirius to optimize cultivar parameters in a high-dimensional parameter space with a complex fitness function for the best performance of wheat ideotypes.

Results and Discussion

Genetic yield potential was assessed by optimizing wheat ideotypes to maximize grain yield under 2050-climate. Two distinct types of wheat ideotype were designed viz. heat and drought sensitive (iS) or tolerant (iT) around flowering (Senapati et al., 2019a). A wheat yield potential of 9-16 t ha^{-1} was estimated for iS under rainfed conditions for the 2050-climate in Europe, while a yield potential of 12-17 t ha^{-1} was estimated for iT. The mean yields of iS (12.8 t ha^{-1}) and iT (14.4 t ha^{-1}) ideotypes represent 66% and 89% greater yield potential compared to current local cultivars under baseline climate, and 47% and 67% greater compared to current local cultivars under the 2050-climate. Wheat ideotypes, optimised for 2050-climate in Europe, show a substantially greater yield compared to current local cultivars. An optimal crop phenology (flowering, grain filling and maturity) under future climate was the main driving force for high yield potential of wheat ideotypes. Others key traits were identified as tolerance to heat and drought stresses around flowering, optimal canopy structure (leaf area and “stay green”) and root water uptake, and tolerance to drought stress. Thus, wheat ideotypes were able of making the maximum use of local environmental conditions and represent the best possible crop adaptation for the future climate, constrained by the available wheat genetic variation. Making the best use of the local climatic conditions, exploiting genetic diversity and plant adaptation are important for increasing crop genetic yield potential.

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Conclusions

Wheat ideotypes, optimised for local environments, predicted a substantial (66-89%) increase in wheat yields compared to current local cultivars in Europe under 2050-climate. Heat and drought tolerance around flowering, optimal phenology and canopy structure were identified as key traits to achieve such high wheat yields under future climatic conditions. Designing wheat ideotype and identifying key traits has the potential to accelerate crop improvement, genetic adaptation and breeding under future climates.

Acknowledgements

Rothamsted Research receives grant-aided support from the Biotechnology and Biological Sciences Research Council (BBSRC) through Designing Future Wheat [BB/P016855/1] and Achieving Sustainable Agricultural Systems [NE/N018125/1].

Keywords: Genetic yield potential, in silico design, Sirius wheat model, LARS-WG weather generator, climate change.

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S3-P.13

Can DSSAT CSM-CROPGRO-Cotton support cotton breeding under low input rainfed conditions? A case study in Senegal

Traoré Abdou[1] (abdou.traore@cirad.fr), Loison Romain[2], Gérardeaux Edward[3], Diouf Fatimata Bintou H.[4], Ndiaye Saliou[5]

[1] *CRA-Tambacounda, Cirad / SODEFITEX / ISRA, Tambacounda, Senegal*; [2] *UPR AÏDA / CRA-Tambacounda, Cirad / ISRA, Tambacounda, Senegal*; [3] *UPR AÏDA, Cirad, Montpellier, France*; [4] *CRA-Tambacounda, ISRA, Tambacounda, Senegal*; [5] *ENSA, University of Thiès, Thiès, Senegal*

Introduction

Cotton is a major crop in the Oriental Senegal and High Casamance (SOHC). Smallholders who have limited options to adapt to climate change exclusively grow cotton under rain-fed conditions (Ndour et al., 2018). The use of resilient cultivars to the changing pattern of the rainy season should be a path to an increased stability of livelihoods for those smallholders. Crop model could assist breeders in this prospect. We evaluate the ability of DSSAT CSM-CROPGRO-Cotton to rank cotton cultivars based on their earliness and seedcotton yield in low input, rainfed conditions of Senegal.

Materials and Methods

Experiments were conducted in 2018 in three sites in SOHC (GoopleMaps locations: https://drive.google.com/open?id=1cz4Ol6wMoyrvXboABXm17pTDkIvH90ff&usp=sharing). For each site, eight cotton cultivar were compared at early and delayed planting dates in a split-plot design with 3 replications. The cultivars were chosen for their *a priori* wide range of response to drought ; Stam 129A (Togo), IRMA L484 and IRMA Q302 (Cameroon), Tamcot Camd-S-75-C (USA), CS50 and Siokra-L23 (Australia), Buja (Ivory Coast) and Allen 51-106 (Tchad).
Weather data were recorded on-site by automatic weather stations (iMETOS® IMT280 [Pessl Instruments GmbH] and ATMOS 41 [METER Group, Inc. US]) within 50 m from the plots. Initial soil conditions were estimated by soil samples.
The crop phenology, leaf area index, development and yield were measured in the field.
The model CSM-CROPGRO-Cotton from the software DSSAT version 4.7 (Hoogenboom et al., 2017) was calibrated on root mean square error (RMSE) with the genetic optimization algorithm from the R package Rgenoud (Mebane and Sekhon, 2011). Genetic algorithm explores the parameter space more fully in order to find the global optimum (Wallach et al., 2019). Koussanar and Kédougou (4 situations) were used as training data and the ranking of cultivars was evaluated in Vélingara (2 situations).

Results and Discussion

The calibration of the cotton cultivar was successful with RMSE lower than 6 days for anthesis and boll opening with bias within 1% of observed value. The leaf area was calibrated within 10% of observed mean LAIX and seedcotton yield too within 2% of observed mean HWAM.
In the evaluation process, the bias were moderate to high for the four variables. The ranking of the cultivars was not accurate for the seedcotton yield except for the worst two cultivars (Table 1). The ranking was fair for the boll opening date especially for early maturing cultivars.
Suriharn et al. (2007) found that ranking of peanuts cultivar was possible with a small number of situations. We did not find this, probably because of the high variability of observed value and the extreme conditions (yield observed ranging from 165 to 2098 kg ha^{-1}).

Conclusions

The automated calibration was unable to reproduce the existing variability and could not be used in ranking cotton cultivars in low input rainfed conditions of Senegal on a small number of situations. The impact of factors leading to high variability of yield in low input rainfed conditions such as the impact of drought spells and extreme rainfall should be modelled for better prediction. However, CSM-CROPGRO-Cotton could be used for the prediction of cultivar earliness, a trait of importance in cotton breeding in Sub-saharan Africa.

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Acknowledgements
The authors would like to thank the agreement between ISRA, SODEITEX and Cirad that supported this study and the first author PhD study.

Mean seedcotton yield [kg ha-1]		
Cultivar	Observed	Simulated
Allen 51-106	577	696
Buja	743	1127
IRMA L484	756	1210
CS50	825	1282
Tamcot Camd-S-75-C	851	1184
Siokra-L23	882	1148
IRMA Q302	902	1184
Stam 129A	1031	1133

Boll opening date [days after planting]		
Cultivar	Observed	Simulated
Tamcot Camd-S-75-C	87	106
Siokra-L23	87	106
CS50	88	106
Stam 129A	88	108
ALLEN	88	109
IRMA L484	88	108
IRMA Q302	88	108
Buja	89	107

Table 1. Ranking of cultivars based on seed cotton yield and boll opening date in observed and simulated performance.

Keywords: Cultivars ranking, in silico breeding, Sub-Saharan Africa, drought, Gossypium hirsutum L..

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S3-P.14

Combining plant sensors and high-throughput phenotyping for developing an FSPM of maize

Villers Selwyn[1] (selwyn.villers@ugent.be), R. Coussement Jonas[1], Inzé Dirk[2], Steppe Kathy[1]

[1] *Laboratory of Plant Ecology, Ghent University, Gent, Belgium*; [2] *System Biology of Yield, Flemish Institute for Biotechnology, Zwijnaarde, Belgium*

Introduction

Combining multiple technologies provides interesting opportunities for research and for the development of novel applications. Miniature plant sensors can be used to expand the dimensionality of phenotyping systems by collecting additional information on plant water relations and growth in real-time.

Materials and Methods

Small plant sensors for measuring sap flow, leaf thickness and stem diameter variation can be connected to a single data logger, which can transfer data wirelessly and is powered by a battery, forming a compact and mobile system. Such a system is compact enough to operate within many phenotyping platforms and move along with plants if necessary (see figure 1). Additional information on plant structure is recorded through the high-throughput phenotyping platform on a daily basis and supplemented with information of the climate.

Results and Discussion

This combination of technologies enables the collection of a high dimensional dataset consisting of phenotypic traits and real-time plant functioning in combination with daily acquired 3D structural information throughout plant development, resulting in a more complete picture of the plant phenotypes and their traits (Coppens et al., 2018).

In addition, it forms an ideal foundation to study mechanisms that regulate biomass accumulation across different organs, their competition for water at different developmental stages and in response to drought. The emphasis on plant-water relations and associated turgor-driven growth (Coussement et al., 2018) is crucial for simulating the impact of drought. This can be done by the development of a functional-structural plant model which describes the development over time of the 3D architecture of plants as governed by physiological processes, which in turn are driven by the environment.

Conclusions

Technological innovations have enabled us to integrate plant sensors within automated phenotyping, providing real-time information on plant physiology and growth in addition to plant structure. Gathering additional information on plant water status is necessary for modeling plant growth as driven by turgor pressure, which forms a more realistic mechanism for representing plant growth.

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Figure 1: Integrated sensor system on a high-throughput phenotyping platform.

Keywords: Phenotyping, Plant sensors, FSPM, 3D modeling.

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ABSTRACTS POSTERS

SESSION IV

LINKING CROP MODELS TO DATA STREAM SYSTEMS IN THE DIGITAL AGE

S4-P.01

A Framework for Banana plantation growth using Blockchain Technology

B. Geethanjali[1] (geethanjalibkrish@gmail.com), S Sreekanth[2]

[1] *Dept of Computer Science & Applications, Bangalore University, Bangalore, Karnataka, India*; [2] *ThinkTree Systems LLP, Bangalore, Karnataka, India*

Introduction

In the recent times, Blockchain is one of the most talked about technology. Bitcoin is purely the first mainstream reflection of its potential [1]. Looking back to the second half century of internet technologies and architectures, one might observe a trend of fluctuation between the centralization and decentralization of computing power, storage, infrastructure, protocols, and code. Currently, we are witnessing the transition from centralized computing, storage, and processing to decentralized architectures and systems. Distributed ledger technology is one of the key innovations making this shift possible. A distributed ledger is a type of data structure which resides across multiple computer devices, generally spread across locations or regions. A blockchain is a peer-to-peer distributed ledger, formed by consent, combined with a system for sensible contracts. Blockchain exists as a specific kind or set of distributed ledger technologies, that constructs a chronological chain of blocks, therefore the name 'block-chain'. A block refers to a group of transactions that are bundled along and value-added to the chain at the same time. It's primarily a public written account of who owns what and who transacts what. The transactions get secured through cryptography, and over time, that transaction history gets latched in blocks of information that are then cryptographically connected together and secured. This creates an immutable, unforgeable record of all of the transactions across this network. This record is replicated on each computer that uses the network.

Blockchain can be adopted in several logistics network chain management systems, to form a decentralised network where it will offer transparency, security, neutrality and reliableness of all the operations being done in a logistics network system chain [2] [3]. Almeida contributes the fact that 60% of the blockchain research topic addresses to the food supply chains [4]. Tian contributes to the information of the agri-food supply chain, that establishes a healthy market environment based on RFID and blockchain technology. It covers the process of gathering data of agri-food supply chain, real-time tracking of the agri-food products, and traceability management for the quality and safety of the agri-food [5].

One of the important fruits consumed worldwide is Banana, all the stages of the growth of banana that is from the planting stage till marketing stage has to be taken care, since, the quality of banana depends on how well it is supervised, during all the stages of its growth. We demonstrate an example scenario, of an overall scheme of banana growth and its supply chain system based on the blockchain technology to assure the quality of banana.

System structure

A 3-layer system is designed: Data Sensing Layer, Data Storage Layer and Application Layer. Data Sensor networks are used for real-time monitoring of banana growth through sensors. The IoT module of the data Sensing Layer primarily includes temperature sensor, humidity sensor, moisture sensor, pressure sensor, GPS module and GPRS module, that can collect temperature, humidity, moisture, pressure and location data in real time and transfer them to the server. The data obtained from sensors are effectively and securely stored on blockchain system. Other data such as, date of plantation, type of banana, irrigation details, pesticides & manures used, harvesting, and marketing details can also be stored on the blockchain. In the data Storage Layer, data storage relies on the Blockchain. Data is stored in distributed ledgers. Application Layer is expounded with applications designed for users supported data system services.

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Discussion

Blockchain system scenario can be built with the open source blockchain framework, Hyperledger fabric. There might be more than one participant in the system such as the farmer, dealers/agents, retailers and customers. Each and every details of the banana growth can be added by the farmer, starting from planting the banana till its harvesting date and storage details. The dealers/agents can obtain the data about the banana growth and add a tag to it, relating to its quality. The retailers and customers can obtain the data about the quality of banana using the chain block of the system. Data cannot be tampered, since the data is hashed blocks and decentralised. This way customers get the right quality of banana. Farmers are also benefitted, by getting paid right for the good quality banana.

Conclusions

The pursuit on agricultural products is mainly to observe the environment of the product, and to deal problems with food safety. In this paper, an example schema is shown, which demonstrates how the quality of banana is assured using the blockchain technology. The data is written into the block immutably, the safety of the data is secured, and therefore the quality of the banana is additionally secured.

Keywords: Blockchain, Sensor Network, Distributed Ledger, Banana.

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S4-P.02

Robots for data collection in biology and agriculture.

Colliaux David (koddda@gmail.com), Wintz Timothée, Lahlou Aliénor, Garlanda Lisa, Lahlou Aurèle, Hanappe Peter

Sony CSL, Paris, France

Introduction

In recent years, imaging has risen as a major source of development for plant phenotyping [King et al.]. Either for biology or agronomy, many infrastructures are providing scientists with a flow of data from set ups which are often complex and integrated in dedicated infrastructures. Those data are useful to uncover aspects of the architecture of the plants under study and the dynamics of their growth for example. It is crucial for crop modelling.
Although widely used, these infrastructures may not be appropriate for small research teams or small farms willing to collect images of their plants. Delays for using the infrastructure may be long and some laboratories may not have the possibility to bring their plant to the phenotyping platforms. For mobile platforms used in agronomy, it may be tedious and costly to set up the platform on a new field. There is thus a need for lightweight robotic platforms dedicated to data acquisition in the laboratory or in the field and that is what we propose [Colliaux et al.].

Material and Methods

A first platform is dedicated to the study of architecture of the plant and is targeted for use in laboratories. It is based around a robotic arm at the tip of which a camera is attached. From the collected images, the 3d structure can be reconstructed and analyzed using computer vision.
A second platform is targeted at field studies. It is based around a mobile robot with a camera on top taking pictures of the crops. After segmentation of the images into plants and ground, the robot is able to weed the crop field with a mechanical tool at the tip of the robotic arm avoiding the cultivated plants.

Results

In our application of the 3d scanner, for example, we measure the angles of fruits along the stem of Arabidopsis Thaliana to study its phyllotaxis. From the images collected by the robot and aggregated into a map of the field, we can determine the spatial density of weeds in the field. Plants in the field are tracked individually and the biomass for each plant is estimated from their projected leaf area. The growth curve can thus be obtained for each plant and we collected growth statistics for populations of radishes.

Discussion

Both platforms are developed in a open-source fashion so that it is easy to build and adapt. The data collected on such platforms may be shared on open databases so that it can contribute to open science initiative targeted at crop modelling.

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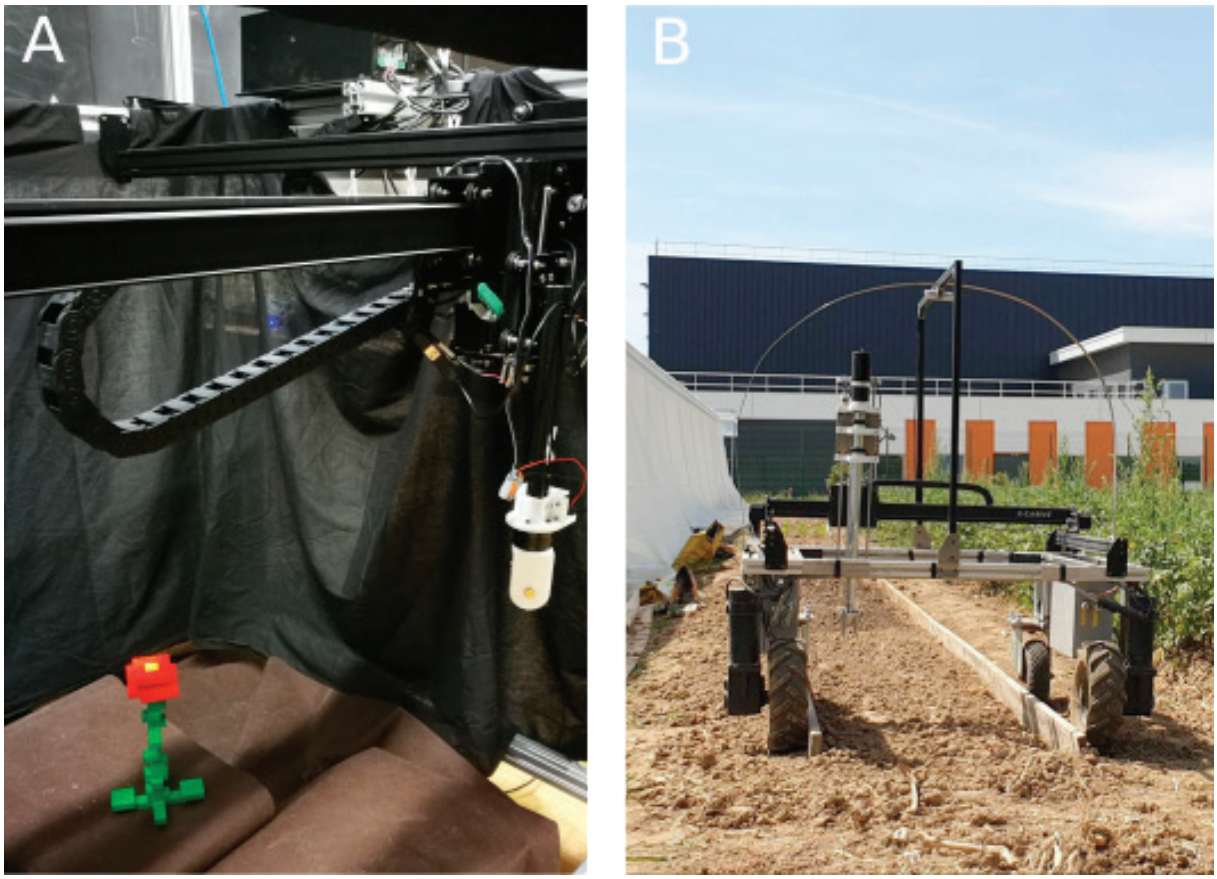

A- Static platform for 3d scanning of plants. B-Mobile platform for weeding and crop monitoring.

Keywords: robotics, computer vision, vegetables, growth curve, architecture.

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S4-P.03

A simple yet reliable system to support fertilisation decision making at farm level

Ferrise Roberto[1] (roberto.ferrise@unifi.it), Trombi Giacomo[2], Costafreda-Aumedes Sergi[2], Padovan Gloria[2], Pasqui Massimiliano[3], Di Giuseppe Edmondo[3], Moretto Johnny[4], Morari Francesco[4]

[1] *DAGRI, University of Florence, Firenze, Italy*; [2] *University of Florence, Firenze, Italy*; [3] *CNR-IBIMET, Roma, Italy*; [4] *University of Padua, Padova, Italy*

Agriculture, and so the cultivation of wheat as well, is increasingly affected by the effects of climate change, with repercussions on vegetative growth, phenology, as well as yields. This is worsen by a greater uncertainty related to the variability of the climate, which is complicating the decisions to be taken by sector operators (Iizumi et al. 2018). In this context, farmers are experiencing increasing difficulties to comply on the one hand with the qualitative and quantitative standards, as required by the agro-food chain, or by the industrial sector, and on the other to preserve the environment and, last but not least, their own revenue. In recent years, thanks to the development of new technologies, the proliferation of internet-related services, the increased and greater availability of computational capacity, as well as the spread of smartphones and tablets, decision support systems are spreading in agriculture. However, if on the one hand they are often having high complexity and reliability, such systems require large amounts of information, being highly time and energy consuming for the farmer, who often does not complete the process. For these reasons we have created an extremely simple system, which requires very little, known information from the farmer, but is able to provide useful, reliable and effective information for the user. The system integrates a mechanistic crop growth simulation model (SSM-Wheat, Soltani et al. 2013), weather generators (LARS-WG, Semenov & Barrow 1997), algorithms for NDVI calculation and nitrogen withdrawal.

The farmer must just indicate where the field is, the texture and depth of the soil, what cultivars he sowed and when, and any application (water and nitrogen, simply indicating the date and amount): the system will automatically find the further necessary information (observed weather data, seasonal forecasts, satellite images) to launch some thousands of simulations able to represent both the climatic variability and the different levels of fertilization, in order to obtain the best combinations that allow to ensure the yield by optimizing the nitrogen uptake, while reducing waste and pollution. The forecasts, produced on a ten-year basis by the US National Centers for Environmental Prediction, are provided as monthly anomalies with respect to a reference climatology. A climate generator transforms these anomalies into a bundle of possible daily weather patterns to feed the model up until the time of collection (Ferrise et al. 2015; Lawless & Semenov 2005). The result will be the likely distribution of the growth, and growth dynamics of the crop in relation to the expected climatic conditions.
Unlike the statistical models, the model used is able to reproduce the processes that underlie the growth and development of the crop and the complex interactions with the surrounding pedoclimatic environment. It is therefore able to provide highly detailed site-specific information that will be used for the localized distribution of the nitrogen fertilizer according to the real needs of the crop.
Finally, with little additional information (a vector file indicating the various parcels with homogeneous soils, with the related textural data) it is possible to use the system in precision farming: in case, the farmer will obtain a file that can be used on precision systems directly in the field.

This work was developed within and thanks to the AGER Project funding, n ° 2017-2194.

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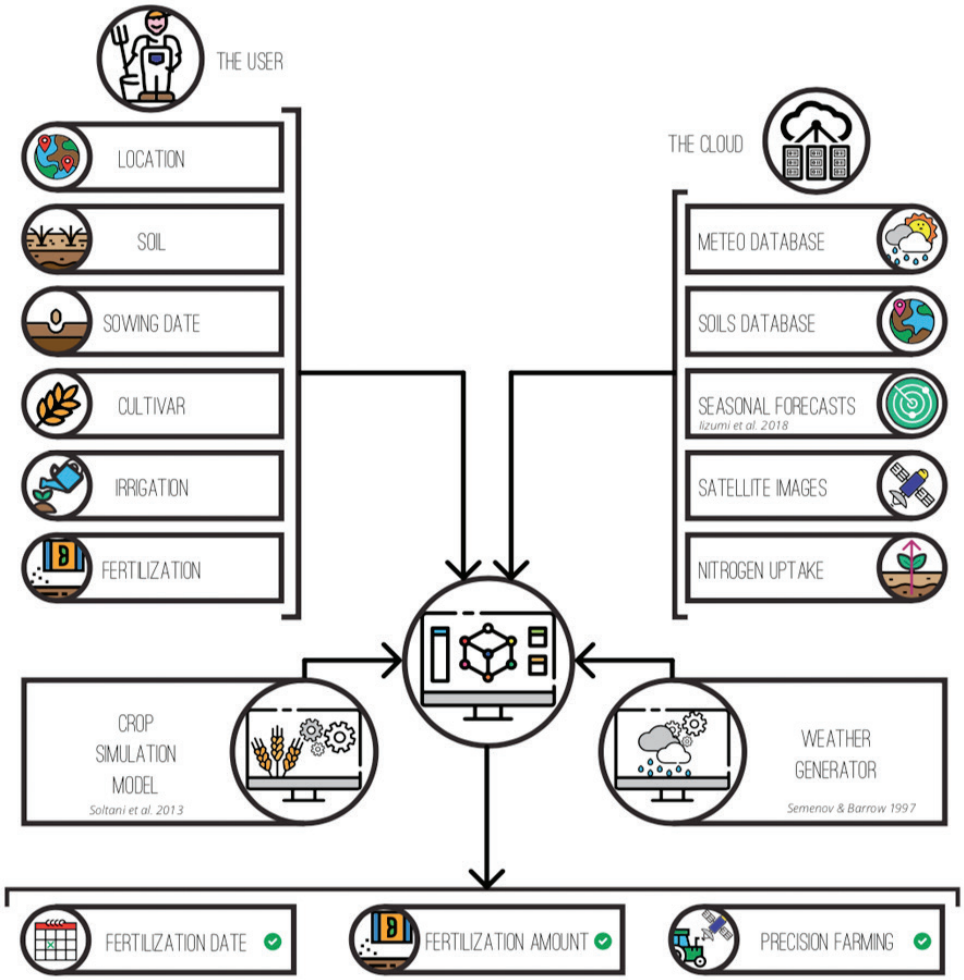

Scheme of the system.

Keywords: DSS, nitrogen fertilisation, seasonal forecast, precision agriculture, crop simulation model.

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S4-P.04

An operational crop yield forecast system in Castilla y Leon based on an agronomic model combining meteorological data.

Gutiérrez García Alberto[1] (ita-gutgaral@itacyl.es), Nafría Gracía David A.[1], Garrido del Pozo Nieves[2], Villarino Barrera Ignacio[2], Abia Llera Inmaculada[2]

[1] *GIS and Innovation unit, ITACyL, Valladolid, Spain*; [2] *AEMET, Valladolid, Spain*

Introduction

Castile & Leon (Spain) is the largest region in Spain (94.000 km2). About 35,000 km^2 are arable land. Rainfed crops, mainly wheat and barley, represent almost 83% of this area. The knowledge of how weather conditions along the season affect the final product becomes a very useful tool for general planification not only for the government but also to farmers. The Castile & Leon Agriculture Technology Institute (ITACyL) and the National Meteorological Agency of Spain (AEMET) collaborate to carry out this project on rainfed crops forecast system.
The main goal of this project is to give an overall view of the performing of the crops compared to the long-term average (LTA) in the region using an agronomic model (AquaCrop). AquaCrop, in this case, uses as meteorological input a combination of current data, ten days prediction, and thirty years of historical data.

Materials and Methods

The system is based on the systematic run of AquaCrop which is executed every day during the season in 23,559 geographic locations spanning all the region. AquaCrop is run with the minimum set of inputs that is, meteorological data, soil properties, and the phenological description of the crop.
As for meteorological inputs, daily Tmin and Tmax, daily rainfall, and daily ET_0 are required. This information is collected from two different meteorological networks: one belongs to AEMET and the other one is managed by ITACyL (Inforiego project). The total number of stations involved in this daily execution is about 200. Both AEMET and ITACyL also store the historical data recorded in every station.
Soil properties were retrieved from the Soil Sample Database of Castile and Leon. The translation from textural properties to hydraulic characteristics was made by using Pedotransfer Functions (PF).
Geostatistical methods were used to transfer both meteorological data and soil information to the regular grid defined in the project.
The methodology follows next guideline:
At the beginning of the season, the model is executed using 30 years of historical data as input. The average of the thirty results on every point in the grid configures the long-term average (LTA).
Every day throughout the season the model is run at each location. Since the model is meant to run to the end of the season, meteorological inputs are made up of current and historical data. Ten days of the mid-term prediction from the European Centre for Medium-Range Weather Forecast ECMWF is incorporated just before the historical part.

Results and Discussion

The outputs of the system are two maps for each crop: (i) One shows the percentage of the expected yield in the season over the long term average. (ii)The second one describes the advance or delay of the development of the crop in terms of days. Both at http://cosechas.itacyl.es/en.
The results from the historical execution were compared with the yield collected by the Crop Surface Area and Yields Survey in Spain (ESYRCE). The results show correlation at province level.

Conclusions

The daily execution of the system shows the general trend of crop development at regional level. It integrates, in just one product, meteorological data of the current season, ten days of weather forecast, and 30 years of historical data. The results of the execution with the historical data shows correlation at province level with the yield observed by external sources.
Finally, the system can also be used to analyze the impact on crop production under climate change scenarios.

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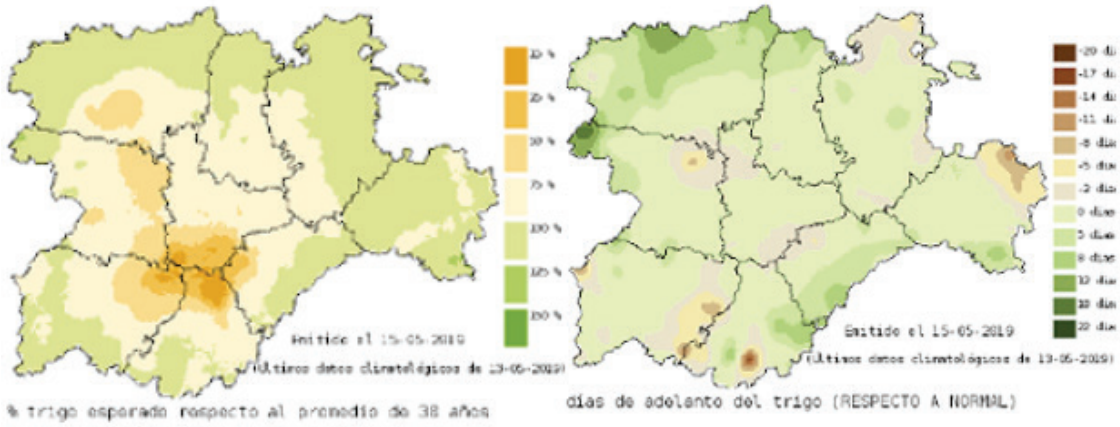

Figure 1. Precentage of expected yield over the long term average (left) Days of advance/delay in the season (right).

Keywords: agronomic model, weather forecast, ensemble, ITACyL, AEMET.

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S4-P.05

Data assimilation of crop models and drone images based on an iterative sensitivity analysis for precision fertilization

Haumont Jérémie[1] (jeremie.haumont@kuleuven.be), De Swaef Tom[2], Cool Simon[2], Diels Jan[3], Lootens Peter[2], Schrevens Eddie[1], Saeys Wouter[1]

[1] *Biosystems, MeBios division, KU Leuven, Leuven, Belgium*; [2] *ILVO, Merelbeke, Belgium*; [3] *Earth and Environmental sciences, KU Leuven, Leuven, Belgium*

Open air vegetable farming is influenced by many external factors like weather, soil conditions and pests. To ensure high yields farmers incorporate large safety margins. This involves using excessive amounts of resources leading to detrimental effects on the environment like nitrogen leaching to ground and surface water. Today, in Flanders, Belgium, nitrogen fertilization in open air vegetable farming is typically based on the KNS-expert system, which involves nitrogen analysis in soil samples (Vlaamse Landmaatschappij, 2014). However, this approach assumes a constant nitrogen uptake, thus ignoring the actual crop development and the corresponding nitrogen uptake. Furthermore, the fertilization recommendations are provided at field scale, even though large variation within a field is observed regarding soil conditions and yield in vegetable production.

To deal with the former problem, mechanistic crop models can be used to optimize farm management through simulation of the crop development. However, these models are typically used in decision support systems at field, regional or country scales, and thus cannot cope with the observed field variations. Novel crop monitoring techniques using UAV's and field robots allow to measure key crop parameters like LAI, biomass, green crop cover and nitrogen content at high resolution. This makes them very useful to adapt crop simulation models to capture within field variation. Based on the discrepancy between observed and simulated values the model can be updated using data assimilation to improve the accuracy for further simulation (Jin et al., 2018). However, the large number of parameters in mechanistic crop simulation models for describing the underlying biological processes make this challenging. Therefore, the aim of this study is to ease data assimilation using an iterative sensitivity analysis of a crop simulation model for application in a variable rate fertilization decision support system for open field vegetable production.

The developed crop model combines a crop module which simulates biomass accumulation and respiration on an hourly basis with a quasi-2D extension of the WAVE model to account for heterogeneous root development in vegetable cropping (Van Loon, Vansteenkiste, Diels, & Schrevens, 2011; Vanclooster, Viaene, Diels, & Christiaens, 1994). The model was calibrated at field scale using experimental data over three consecutive years.

Prior to any measurements, the Sobol sensitivity indices of the model parameters and the initial conditions were calculated as a function of time based on Monte Carlo samples within the full parameter space using weather data of five historic years. Subsequently, the identifiable parameters were determined using the method of De Swaef et al. (2019), limiting the number of parameters which can be updated from measurements and fixing the values of the others based on previous knowledge. Thereafter, the model was updated using an iterative sensitivity analysis and data assimilation for application at sub field scale. Once a measurement has been performed, the sensitivity analysis was repeated using only the identifiable parameters and the weather data until measurement. Next, the model was updated to better represent the current situation, capture zone specific crop development and reduce the parameter space. Because the sensitivity of the parameters varies over time, only those with a significant effect on the measured variable should be considered. Subsequently this method was repeated with every measurement using the parameter space which has been reduced iteratively. In this way, data assimilation is facilitated by limiting the considered parameters to those which are identifiable and active at the moment of new measurements.

Acknowledgement
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Keywords: data assimilation, sensitivity analysis, crop models, drone imaging.

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S4-P.06

Bias correction of regional climate model results for crop simulations: hidden pitfalls and possible solutions

Kis Anna[1] (kisanna@nimbus.elte.hu), Barcza Zoltán[1], Hidy Dóra[1], Hollós Roland[1], Kristóf Erzsébet[1], Kern Anikó[2], Fodor Nándor[3]

[1] *Excellence Center, Faculty of Science, Eötvös Loránd University, Martonvásár, Hungary*; [2] *Space Research Group, Eötvös Loránd University, Budapest, Hungary*; [3] *Agricultural Institute, Centre for Agricultural Research, Martonvásár, Hungary*

Introduction

Crop models coupled with bias corrected regional climate model (RCM) simulation results are widely used to estimate the possible impacts of climate change and management practices on crop production (Webber et al., 2018). The meteorological data needed for such experiments can be constructed using different techniques. One possible method for data construction is the combination of observation based gridded data for the past, and bias corrected RCM data for the future where bias correction is performed with the observation based dataset. The advantage of such approach is the straightforward validation of the model based on the subset of the observation based dataset. Here we focus on some unexpected artifacts of such approach and the possible solution for the issue.

Materials and Methods

In Hungary, within the frame of the AgroMo project, the Biome-BGCMAg (formerly known as Biome-BGCMuSo) biogeochemical model (Hidy et al., 2016) is used in combination with the FORESEE database (Dobor et al., 2014) to simulate maize and winter wheat production for the near (2021-2050) and distant (2071-2100) future. FORESEE is built on the E-OBS dataset and RCM results from the ENSEMBLES project (van der Linden and Mitchell, 2009), and contains observation-based data for 1951-2018, and 10 different projections for 2019-2100. The latest version of FORESEE is based on E-OBS 17.0 (Cornes et al., 2018). Given the stronger-than-expected warming in Hungary after 2000, inconsistencies were detected in some of the combined datasets after 2018. This inconsistency means that some RCMs predict temperature that is lower than the short term extrapolation of the observed data of the past 10-20 years. In some cases the sudden decrease of the projected temperature in the near future is remarkable as it takes about 30 years for the given RCMs to reach the observed 2010-2018 value (Fig. 1). The aim of our study is to demonstrate this discontinuity phenomenon based on FORESEE temperature data and introduce a novel statistical method for eliminating the inconsistency. The new method leaves the projections for the distant future mostly intact, while it adjusts the projections for the near future in a way that the final dataset will be consistent with the observed tendencies.

Results

Biome-BGCMAg based yield and carbon flux results are presented and evaluated utilizing the original and the adjusted RCM datasets. The introduced correction method is applicable to other datasets used for crop models and integrated assessment models as well.

Acknowledgements

The research has been supported by the Széchenyi 2020 programme, the European Regional Development Fund and the Hungarian Government (GINOP-2.3.2-15-2016-00028), and by the Hungarian Scientific Research Fund (FK-128709 and K-129118). Supported by grant «Advanced research supporting the forestry and wood-processing sector's adaptation to global change and the 4th industrial revolution», No. CZ.02.1.01/0.0/0.0/16_019/0000803 financed by OP RDE».

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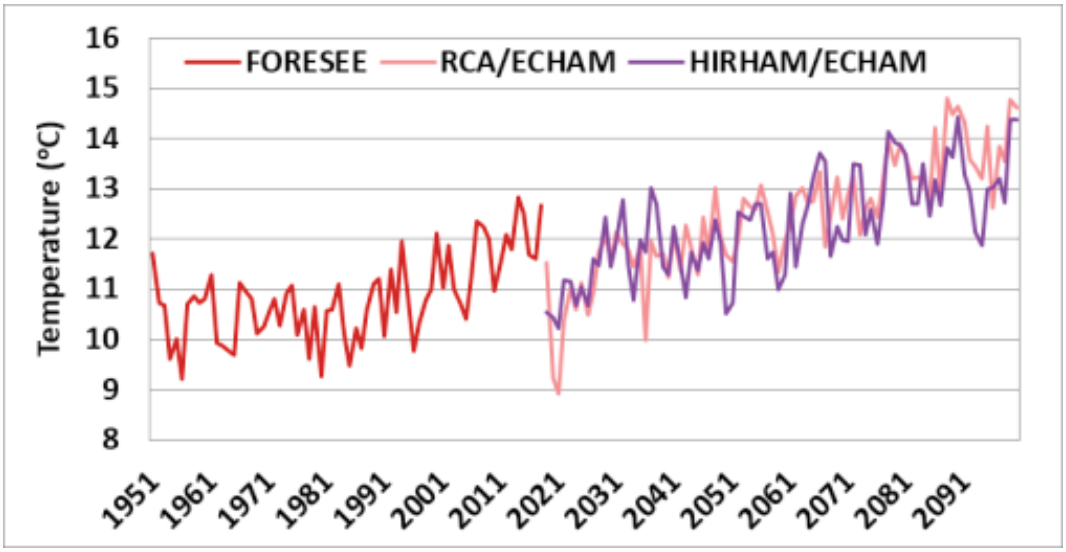

Figure 1. Mean annual temperature for Hungary for the 1951-2100 time period. The 1951-2018 time period is based on observations (FORESEE), while RCA/ECHAM and HIRHAM/ECHAM RCM results represent the 2019-2100 time period.

Keywords: Crop model, regional climate model, bias correction, discontinuity of time series.

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S4-P.07

Recurrent neural networks to model oil palm tree abortion

Beurier Grégory[1] (gregory.beurier@cirad.fr), Eberhardt Axelle[2], Perez Raphael[2], de Raissac Marcel[2], Cazemajor Michel[3], Nodichao Leifi[4], Impens Reinoult[5], Caliman Jean-Pierre[6], Rouan Lauriane[2], Larue Florian[2]

[1] *AGAP, CIRAD, Montpellier, France*; [2] *CIRAD, Montpellier, France*; [3] *PalmElit, Montferrier sur Lez, France*; [4] *INRAB, Pobè, Benin*; [5] *SIAT, Presco, Nigeria*; [6] *Smart-RI, Pekanbaru, Indonesia*

Introduction

Oil palm *(Elaeis guinnensis)* is a monoecious plant that produces sequentially phytomers, each phytomer being a leaf bearing either a male, a female, or an aborted inflorescence. Modelling oil palm yield at the plant scale thus requires accurate predictions of the number of female inflorescences becoming bunches. Previous studies highlighted the complexity of modeling oil palm abortion, since each phytomer takes 3 to 4 years to develop under specific conditions related both to climate and the trophic state of all the phytomers developing simultaneously (Combres et al., 2013; Pallas et al., 2013). The former statistical studies highlighted the influence of water stress and carbon source-sink relationships on abortion, but simple probabilistic formalisms make abortion prediction still inaccurate, mainly because of the time-lagged and the potential non-linear interactions among the biological processes involved.

Material and Methods

Over the past few years, deep learning has become a major asset when dealing with massive data (images, videos, sound, etc.) and thus has been widely adopted to interpret scientific data. Although still poorly represented, several crop science studies have proposed deep neural networks (DNN) and convolutional neural networks (CNN) for yield prediction and disease detection (Liakos et al., 2018). However, except some studies on soils and evapotranspiration, DNN and CNN related works use predominantly images as input data and do not address the problem of temporal data. In many fields (finance, physics, medicine, etc.), recurrent neural networks (RNNs) have been widely applied to process sequential data (text, audio, etc.). However, traditional RNNs - composed of sigma or tanh functions - are unable to learn meaningful information when the sequence is large. Long-short-term -memory neural network (LSTM) solves this problem by adding gates in the recurrent cells, allowing long-term dependencies to be considered. Since their introduction, LSTMs and their alternative (Gated Recurrent Unit - GRU) have been a major contributor to the success of Deep Learning and are now essential in the toolkit of time-series analysis techniques (Yu et al., 2019).

The present study aims at testing the potential contribution of LSTMs to better harness the driving factors of inflorescence abortions and predict accurately oil palm phenology. Individual phenological data and daily meteorological data were collected on genotypic trials located in three contrasted climatic sites (Benin, Nigeria and Indonesia) over seven years. This database was used to train RNNs to predict various phenological events using subsets of input meteorological and/or phenological data (see Figure).

Results and Discussion

Recurrent neural networks are interesting alternative to traditional statistical methods used to analyze times series. Although LSTMs are usually used as prediction tools, this study highlights how LSTMs can be efficient to detect relevant determinants useful for modelling complex biological processes. For instance, depending on the phenological events under study, we observed that different specific subsets of input were needed for an accurate prediction. Such a result emphasizes the potential existence of distinct biological processes related to oil palm phenology. Subsequently, this approach allows us to better consider these former processes when developing crop models.

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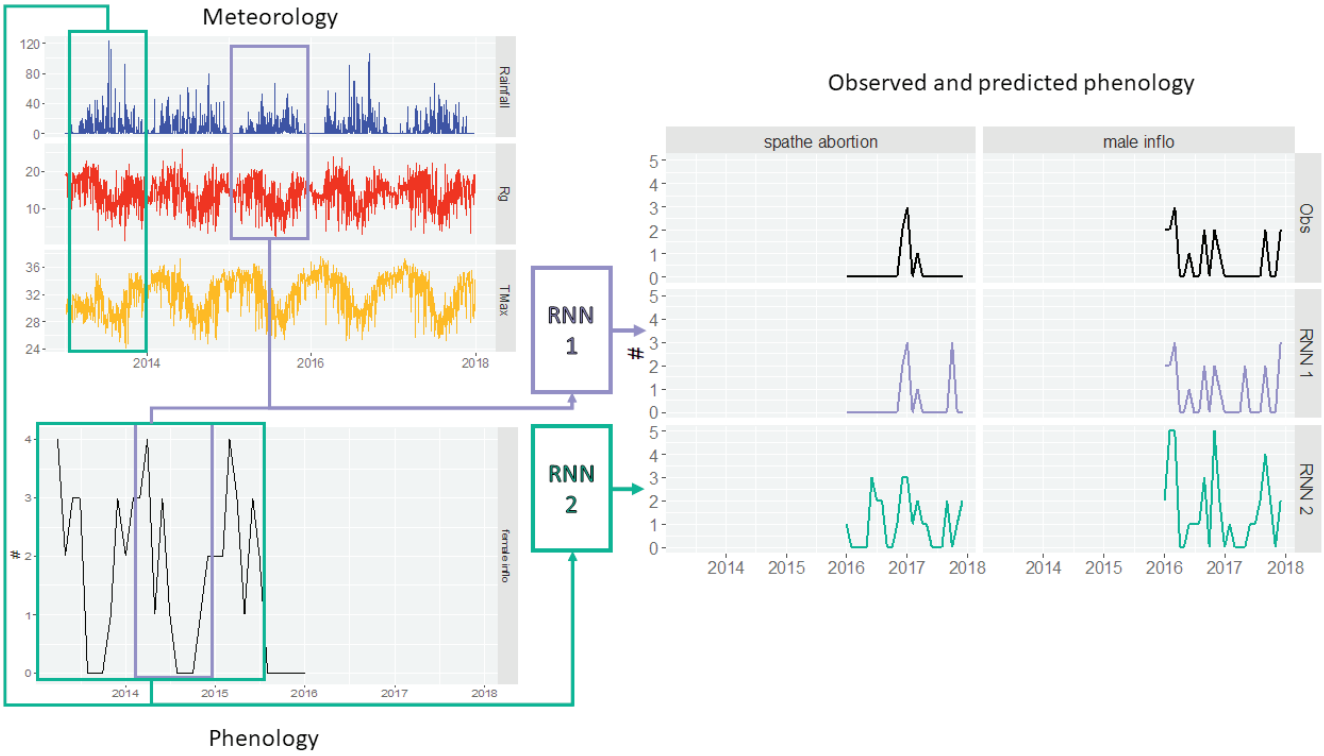

RNN training workflow: prediction of spathe abortion and male inflorescence are compared to predictions of recurrent neural networks (RNNs) trained on different meteorological and phenological entries.

Keywords: Palm tree, Deep Learning, Recurrent Neural Networks, Optimization, Prediction.

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S4-P.08

Nnnovative - Development and validation of information services for the optimization of Nitrogen use in agriculture

Kühl Kersten[1] (kersten.kuehl@lmu.de), Brohmeyer Franziska[2], Mauser Wolfram[1], Bach Heike[2], Hank Tobias[1]

[1] *Department for Geography, Ludwig-Maximilians-Universität Munich, Munich, Germany*; [2] *VISTA Remote Sensing in Geosciences GmbH, Munich, Germany*

Introduction

Excessive accumulation of nitrogen (N) in agricultural ecosystems diminishes biodiversity, drives climate change and results in potentially carcinogenic concentrations of nitrate levels in drinking water. Crop fertilization is one main source of nutrient oversupply, e.g. in the case of excess N not being incorporated into biomass but washed out into the groundwater or volatized into the atmosphere respectively (Erisman et al., 2018). The prospect of lowered and legally binding upper limitations of N usage increases the need for optimization and documentation of fertilization at the farm scale and opens a promising field for model developments (Muller and Martre, 2019). The research project Nnnovative, funded by the German Federal Ministry for Economic Affairs and Energy, aims at improving and validating the processes of a physically based dynamic crop simulation, aimed at describing spatio-temporal in-field variability of N dynamics in cropping systems, and applying this model to increase N use efficiency on the subarea scale.

Materials and Methods

Nnnovative applies the land surface processes model PROMET for the simulation of biomass accumulation and yield formation restricted by N availability (Hank et al., 2015; Mauser and Bach, 2009). The model describes the processes of N transport, transformation and translocation in the soil-vegetation-atmosphere continuum explicitly. Agricultural N input may be specified by time, location, quantity, parameterized fertilizer type and application technique. The variability of spatio-temporal crop development is driven by meteorological data on one hand and by the assimilation of leaf area and leaf chlorophyll content derived from ESA Sentinel-2 optical earth observation data on the other (Fig. 1). The physically based model allows calculating fertilization scenarios, which then can be analyzed for optimal N use efficiency.

For validation, biomass and nitrogen content of summer barley and winter wheat crops were sampled at harvest stage in August 2019 at 22 representatively selected points of an area of 100 hectares of agricultural land in Bavaria, Southern Germany. At the sampling locations, soil of the uppermost 90 cm of the soil column was analyzed for mineralized N content at the beginning of the vegetation period and a second time right after harvest. The collected biomass was partitioned by plant compartment and tested for N content individually. The collected in situ data thus allows for validating the model's capability of mapping the nitrogen cycle in the soil-vegetation continuum during the 2019 season.

Results and Discussion

The results of the validation experiment in Southern Germany will be presented at the conference. First analyses show that the model is capable of tracing the temporal dynamics very well, while the spatial heterogeneity could not fully be reproduced by the model.

Conclusions

Once the model developments and validation is finished, the system's capability of supporting nitrogen management decisions through N-application scenarios will be demonstrated on selected demo farms.

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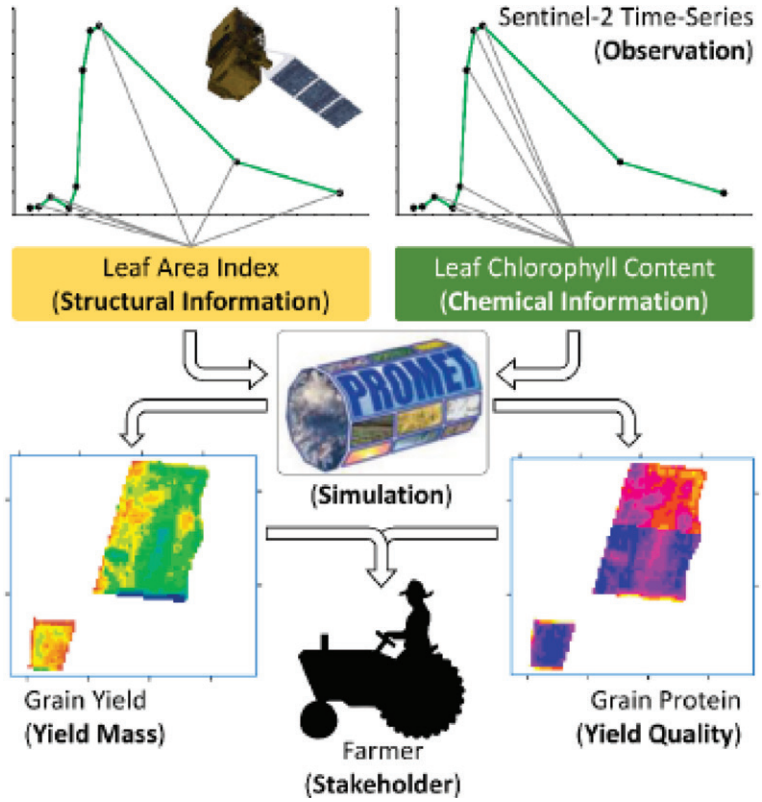

Fig. 1: Schematic representation of the parallel assimilation of structural and chemical information into the model PROMET for generating maps of the yield quantity and yield quality.

Keywords: N-management, N-emission, Sentinel-2, PROMET, food security.

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S4-P.09

DROLIVe: a platform for monitoring olive groves

Leolini Luisa[1] (luisa.leolini@unifi.it), Costafreda-Aumedes Sergi[1], Rossi Riccardo[1], Padovan Gloria[1], Trombi Giacomo[1], Dibari Camilla[1], Brilli Lorenzo[2], Di Gennaro Salvatore Filippo[2], Matese Alessandro[2], Bindi Marco[3], Moriondo Marco[2]

[1] *DAGRI, University of Florence, Florence, Italy*; [2] *CNR-IBE, Florence, Italy*; [3] *University of Florence, Florence, Italy*

Introduction

In the Mediterranean basin, olive groves represent one of the most important and valuable cultivation increasing local farming incomes and providing several ecosystems services. The largest olive oil production derives from Spain which produces about 1400k tons (t) followed by Italy 474.6k t and Greece 320k t in 2015–16 (IOOC, 2018). In Italy, Tuscany is the 6th ranked region for olive oil production but the land use changes restricted olive groves to marginal areas. In this context, precision agriculture and crop modelling may represent useful techniques and tools for monitoring the health status of olive groves, providing a support to farmers in applying management practices to make the cultivation more profitable. Building on these premises, the DROLIVe project (POR FSE 2014-2020) is focused to develop a monitoring platform of olive groves for a specific area of Tuscany by coupling remote sensing techniques with phenological modelling.

Materials and Methods

Two-olive grove status was monitored during 2018-2019 field campaigns conducted in Montalbano area (Tuscany). The use of different Vegetation Indexes (Vis, NDVI, GEMI, OSAVI), derived by Drone and Satellite imageries (Sentinel 2 and Landsat) and field measurements (ceptometer, SPAD), allowed to describe the overall trend of vegetation along the olive growing season and some important vegetative parameters (e.g. Leaf Area Index (LAI), Photosynthetically Active Radiation (PAR) and yield). Moreover, two weather stations were installed for recording (every 15 minutes) the main weather and soil variables (air temperature and humidity and soil moisture). Finally, two phenological models were implemented and calibrated for reproducing bud-break, flowering and 50% of veraison stages. The first phenological model is based on the GDH (growing degree hour) computation and it is used for estimating the vegetative bud opening, according to a specific temperature threshold. The second model (UNICHILL; Chuine, 2000) is based on the chilling-forcing approach and it is used for estimating flowering and veraison stages.

Results and Discussion

The results evidenced a strong decrease of the VIs average value during summer period in correspondence of grass cutting and drought conditions, which reduce the grass spectral reflectance. We also found a satisfactory correlation between LAI and PAR and the VIs value during the olive growing season (LAI: Average Pearson $\bar{r}$ = 0.71; PAR: $\bar{r}$ = 0.67). The phenology of olive tree was reproduced by calibrating two phenological models for budbreak and flowering of a standard olive tree variety (flowering: RMSE= 3.00, r= 0.82; Moriondo et al. 2019). Finally, we analyzed the relationship between NDVI and olive production (kg of olives) during six years. In this context, we found that the best correlation between these two variables is expected in July, according to the maximum decrease of grass cover in the inter-row.

Conclusions

The DROLIVe project shows how the use of new technology coupled with crop modelling may allow giving important information about olive groves growth and development also in marginal areas. The implementation of this software platform may represent the starting point for providing a useful support tool in agriculture.

Acknowledgements

We wish to acknowledge the DROLIVE project POR FSE 2014-2020 Prot. 13748-VII/16.4, 2018.

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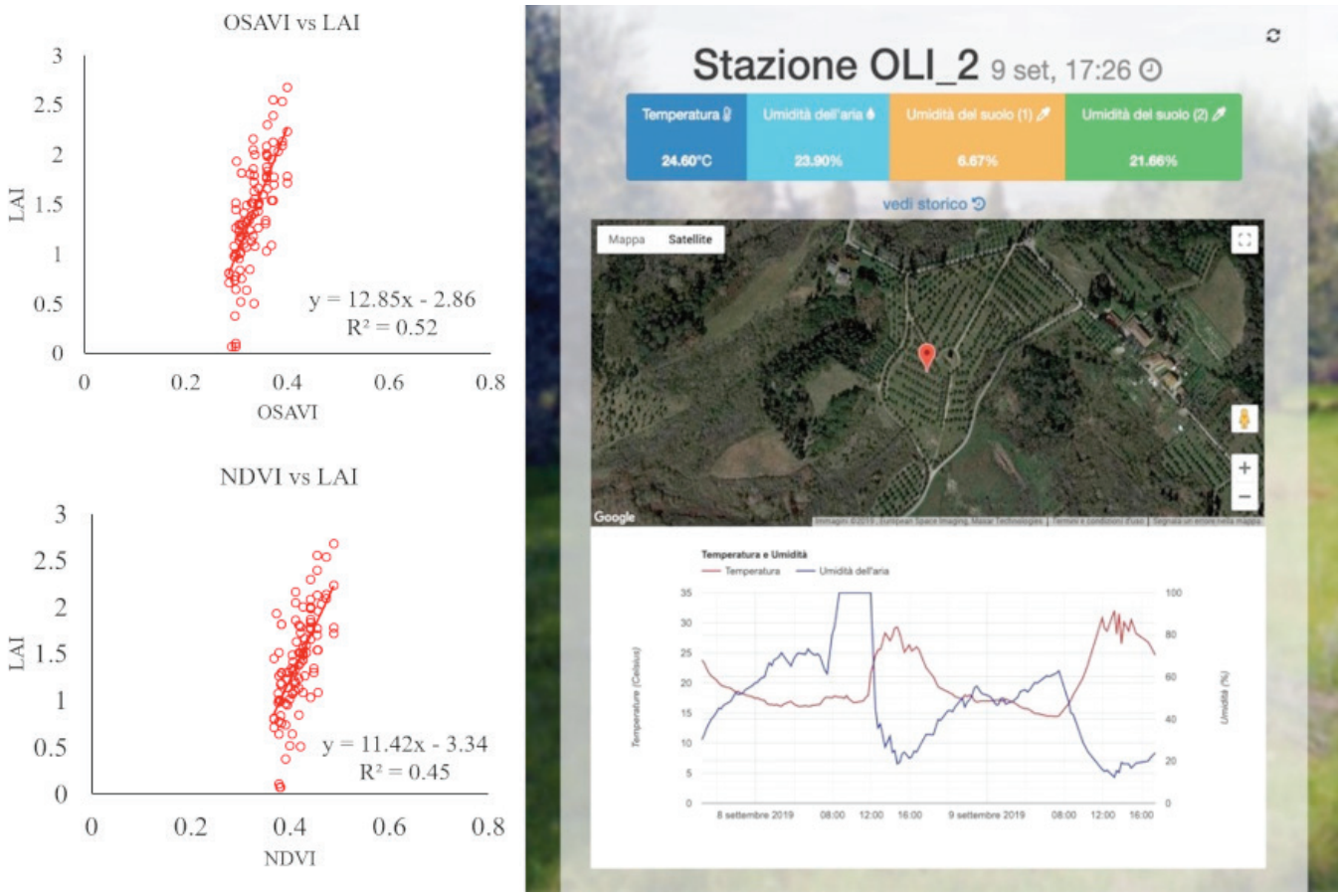

Figure 1. DROLIVe platform (right) and VIs correlations (left).

Keywords: Crop monitoring, Olive groves, Precision Agriculture.

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S4-P.10

Using assimilation techniques to predict yield in the DSSAT model

Soldevilla Maria (maria.soldevilla@yara.com), Brück Holger

Yara Research Center, Dülmen, Germany

Introduction

Timely and accurate estimation of crop yield before harvest is crucial for management decision-making. Remote sensing provide spatial information about important canopy state variables for crop models. The Sentinel-2 mission has been a great step forward for continuous crop monitoring. The fusion of satellite data and cropping systems modelling has been investigated for several agricultural applications. Thorp et al. (2010) developed two strategies for assimilating LAI data into CSM-CERES-Wheat (Jones et al., 2003). One is the updating method which adjusts the model only on the dates when LAI observations are available. The second is the forcing method which adjusts the model on a daily time step using linear interpolation to compute LAI between measurement dates. In this study comparisons have been made between DSSAT model runs with these two techniques; and without input of remote sensing satellite data. Simulations focused on yield prediction before harvest.

Materials and Methods

The research was carried out in Lückstedt, located in Saxony-Anhalt, Germany, in a 116 ha parcel.Winter wheat (*Triticum aestivum L.)* was sown on September 29th, 2018, and harvested on July 19th, 2019. Soil water availability was derived from soil conductivity map of the parcel and classified in 4 classes ranging from 1, lower soil water availability, to 4, higher soil water availability. Meteorological daily data was collected from the Deutscher Wetterdienst. The forecasted weather from the date of the model prediction until harvest, was estimated from the historical weather data of the region. The CERES 3.5 model, distributed with the DSSAT 4.6 software package, was used. The LAI estimated from Sentinel-2 data has been sequentially assimilated into the model. The model was reprogrammed according to Thorp et al. 2010 to be able to assimilate the Sentinel-driven LAI using either updating or forcing techniques. Final yield predicted by DSSAT-CERES at 4 different dates and the yield measured by the combine harvester at the end of the season were compared. The benefits of using assimilation techniques as compared to the stand-alone model were also studied.

Results and Discussion

The averaged observed yield of the field was 4911 kg/ha. The stand-alone model overestimated the final yield. The percentage of error between observed and simulated yield was reduced by 17% when updating technique were used and by 20% when forcing technique were used compared with the simulation of the stand-alone model. The RMSE between predicted and observed yield for all soil classes decreased with the time of prediction and was slightly higher in the updating technique than in the forcing technique. When the analysis was done for the different soil classes separately, it was observed that the RMSE in both techniques was lower for soils with higher water availability (soil classes 3 and 4), meaning a better performance of the model when water supply is not a limiting factor (Figure 1).

Conclusions

The assimilation of satellite data into the DSSAT-CERES model significantly increased the accuracy of the predicted yield when compared with the stand-alone model. No significant differences were found when using the updating or the forcing technique in terms of yield prediction. The prediction of yield by the model was better in the soil classes with higher availability of water in the soil meaning a better performance of the model when water supply is not a limiting factor.

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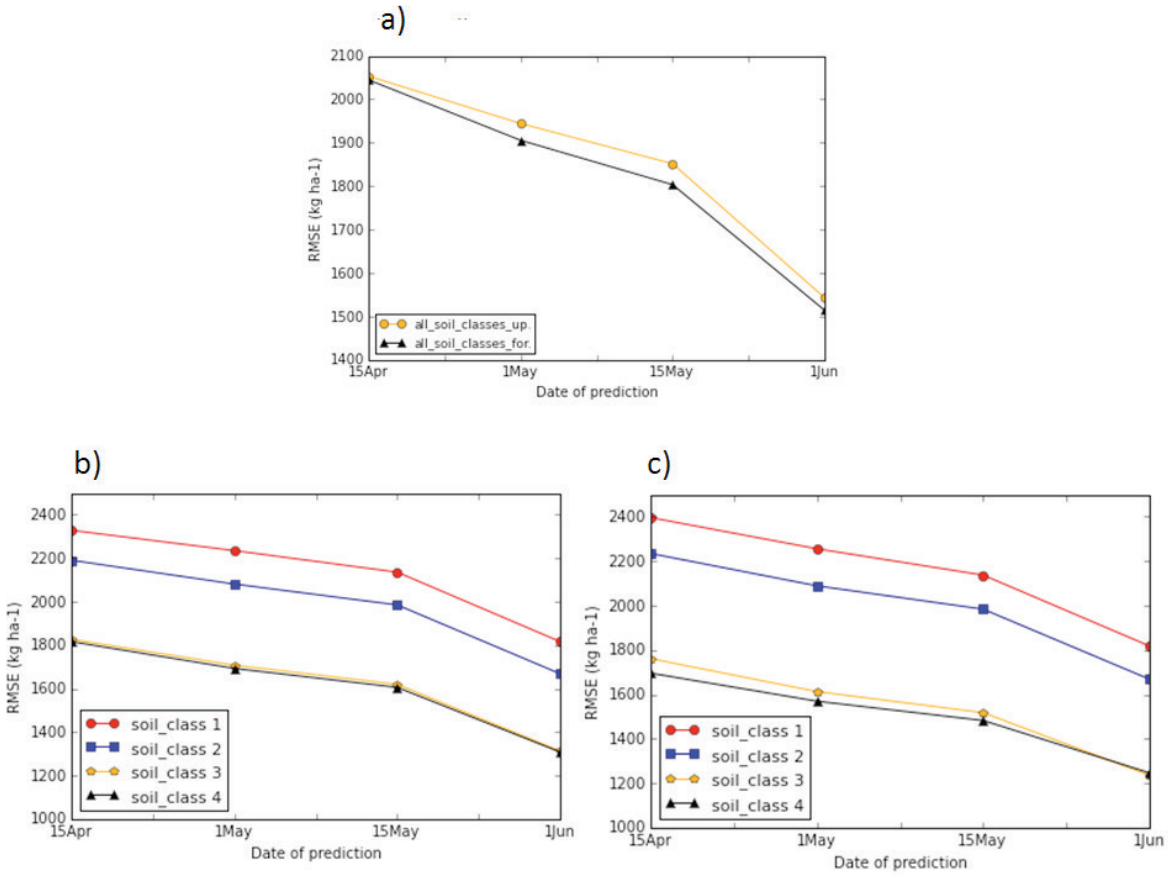

Figure 1. RMSE between predicted yield at different dates and final observed yield for: a) all soil classes using updating technique (up.) and forcing technique (for.); b) different soil classes using updating technique; c) different soil classes using forcing technique.

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S4-P.11

Assimilation of Leaf Area Measurements Into A Crop Model to Improve Sub-Field Wheat Biomass Estimations

Tewes Andreas[1] (atewes@uni-bonn.de), Hoffmann Holger[2], Schäfer Fabian[2], Kerkhoff Christian[2], Krauss Gunther[1], Gaiser Thomas[1]

[1] *INRES, Crop Science Research Group, University of Bonn, Bonn, Germany*; [2] *xarvio BASF Digital Farming GmbH, Köln, Germany*

Introduction

The assimilation of LAI measurements could help dynamic crop simulation models to account for within-field heterogeneity of crop growth. Updating methods such as the Ensemble Kalman Filter (EnKF) commonly rely on ensemble model runs to update state variables every time new observations becomes available (see Jin et al. (2018) and Huang et al. (2019)). This might threaten the model's integrity, as not the entire table of model states is updated. We developed the Weighted Mean (WM) approach, relying on a model ensemble that runs from simulation start to end without sequential updating; a subsequent calculation of the weighted mean accounts for the observations. We tested if a) the WM approach outperformed the EnKF approach, b) the WM and EnKF approaches improved accuracy over standard model runs (SR) and the ensemble mean (EM), and c) the performance of the assimilation approaches depended on the composition of the ensemble generation variables (EGV).

Material and Methods

Winter wheat was grown on commercial fields in locations across the countries DE, FR and NL during the growing periods of 16/17/18. LAI measurements using the LI-COR LAI-2200C (LI-COR Inc., Nebraska, U.S.A.) were repeatedly conducted in 40-60 points across each field. We collected soil texture, weather data and biomass yield.
We employed the generic <LINTUL5> model (Wolf, 2012) in the modelling framework SIMPLACE, considering water-limited conditions. Only pre-flowering measurements were included.
Two sets of EGVs in combination with the assimilation approaches were tested:
The crop component (CC) set perturbed the three parameters ScaleFactorSLA, ScaleFactorRUE and the maximal relative increase in LAI (RGRLAI). ScaleFactorSLA scaled all development stage-dependent SLA values uniformly, ScaleFactorRUE all development stage-dependent RUE values accordingly. RGRLAI described the maximal relative increase in LAI during the juvenile stage of the plant.
The soil and crop component set (SCC) approach comprised the three parameters that scaled 1) the soil water content at simulation start (SoilWaterInit), 2) the maximal rooting depth that could be reached by the plants (MaximalRootDepth), and 3) a scaling factor for the development stage-dependent specific leaf area (ScaleFactorSLA). By perturbing the first two parameters at initialization, the model induced water stress at varying points in time.
The model was run for each point in each field, in combination with the assimilation approaches, and subsequently compared to measured biomass. We also included the standard run and the ensemble mean in the analysis.

Results

Our findings comprised that a) the performance of the WM approach was very similar to the EnKF approach when soil and crop related variables were used for the ensemble generation, but outperformed the EnKF approach when crop related variables were considered only (see Figure 1), b) the difference in site-specific performance largely depended on the choice of the EGV set, with the combination of SCC-based variables outperforming the the CC set with regard to biomass, and c) EnKF and WM improved accuracy over SR and EM.

Conclusions

When taking into account that the EnKF approach violates the integrity of the model runs because only a small part of the states is updated, the WM approach should be preferred when assimilating observational data into crop models.

Acknowledgements

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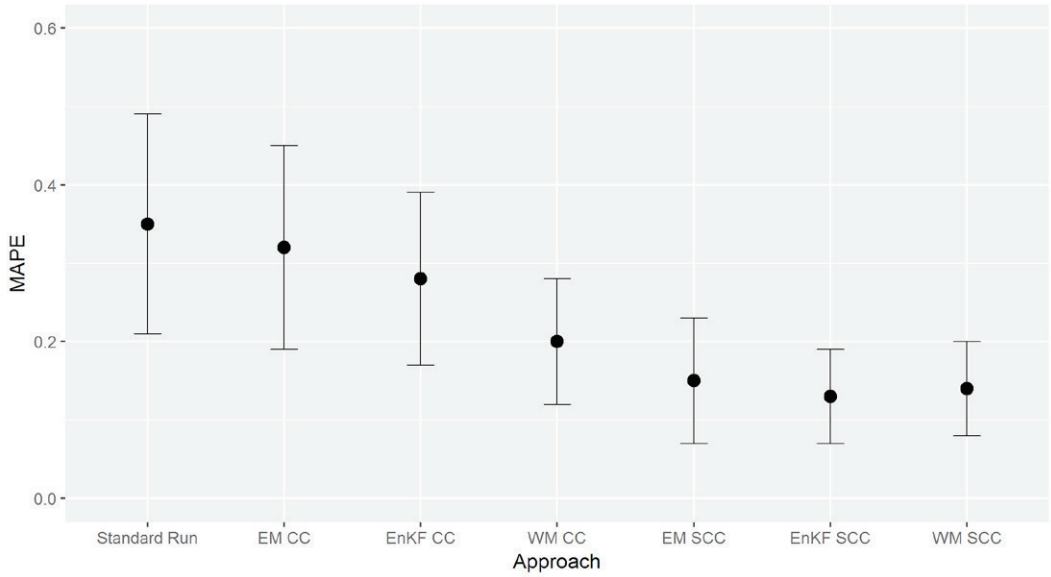

Figure 1: Mean and standard deviation of total aboveground biomass mean absolute percentage error (MAPE in decimal-%) for tested approaches. SR: Standard Run, EM: Ensemble Mean, EnKF: Ensemble Kalman Filter, WM: Weighted Mean, CC: Crop Component Set, SCC: Soil and Crop Component Set.

Keywords: Data Assimilation, Leaf Area Index, Ensemble Kalman Filter, Weighted Mean, Ensemble Generation.

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S4-P.12

Calibration of a crop model using data from a commercial potato farm

Van Evert Frits K.[1] (frits.vanevert@wur.nl), Riepma Jits[2], Van Oort Pepijn A.J.[1], Janssen Arni P.H.M.[2]

[1] *Agrosystems Research, Wageningen University & Research, Wageningen, Netherlands*; [2] *Farm Technology, Wageningen University & Research, Wageningen, Netherlands*

Introduction

Precision agriculture is the art of applying the right amount of the right substance (fertilizer, water, biocide), at the right time, and at the right place. In many cases, farmers practising precision agriculture rely on recommendations generated by a decision tool. Such recommendations are typically based on empirical models, for example when a nitrogen application rate is calculated from a drone or satellite image. In the future such recommendations will be generated using dynamic crop growth models in addition to satellite and drone imagery. Unfortunately, it is a challenge to calibrate crop growth models to the specific conditions of each cultivar, each farm, and each farm field. The aim of our work was to operationalize the estimation of crop (cultivar) and soil parameters via inverse modelling, using yield data from all the crops in the rotation on a commercial farm.

Materials and Methods

We calibrated the WOFOST model (de Wit et al., 2019) using five years of data from ten fields selected on a commercial potato farm on sandy soil in the southern part of The Netherlands where sugar beet, maize, and spring barley were grown in non-potato years. Default parameters provided with WOFOST were taking as starting values for crop parameters. Starting values for soil parameters were taken from the Dutch national soil map BOFEK (Wösten, 2001). Soil field capacity, wilting point and water content at saturation were strongly correlated on the sandy soils in the study area. An exponential relationship was developed which was used to control the correlation during the optimization of the parameters. We used remote sensing data from several satellites to estimate aboveground biomass and LAI throughout the growing season. Additionally, for potatoes we had access to between four and six destructive samples taken during the growing season. Final yield was available for sugar beets and potatoes. Soil water data were available only for one field.

Results and Discussion

Simulation results were much improved by calibrating crop parameters (Fig. 1). Simulations were much less improved by calibrating soil parameters; of the soil parameters, field capacity and depth of the soil were the most important ones. Overall, inverse modelling resulted in improved accuracy of simulated LAI and crop yield.

Conclusions

If WOFOST is to be used for precision agriculture recommendations on the sandy soils in the southern part of the Netherlands, proper calibation of crop parameters is more important than calibration of soil parameters. For our study, the soil parameters of the BOFEK soil map are sufficiently accurate to make predictions with the WOFOST model.

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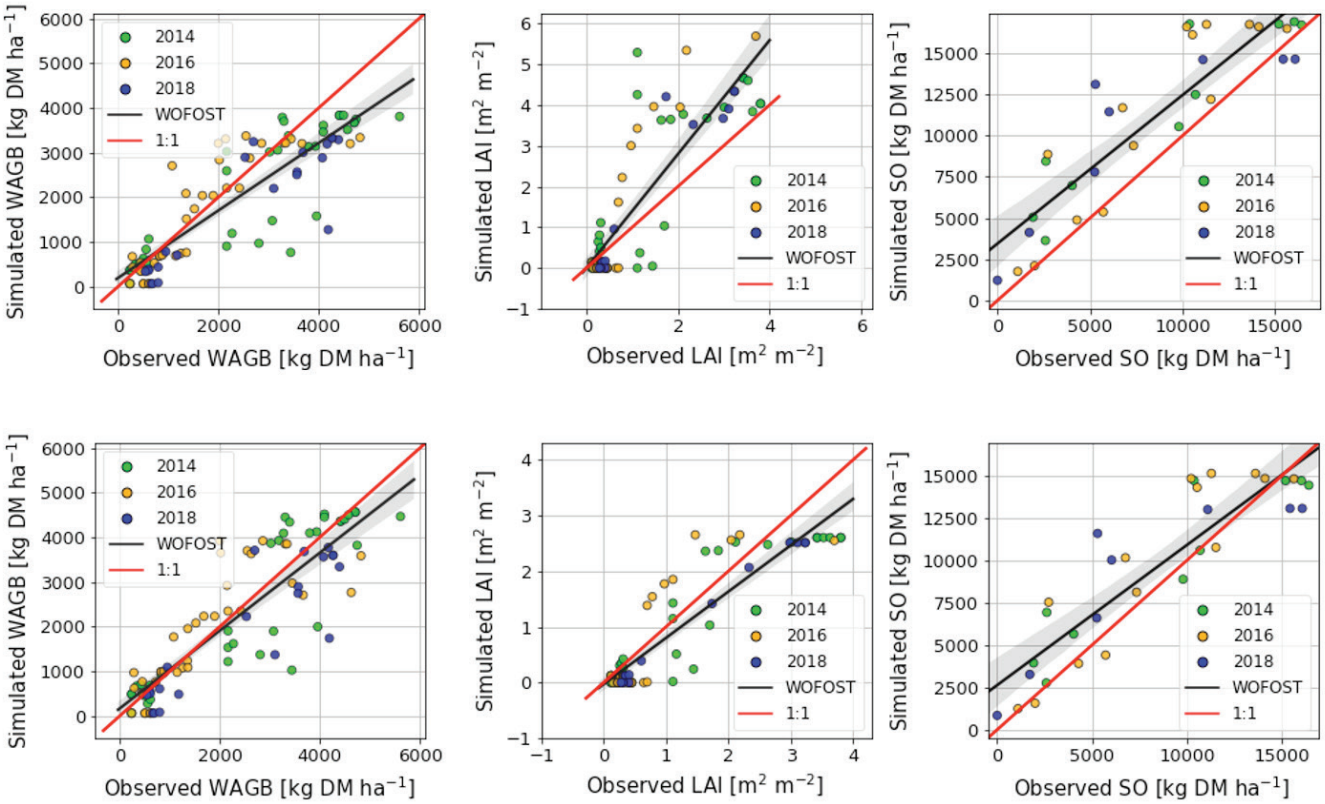

Model simulations versus observations for potato, for aboveground weight (WAGB), leaf area index (LAI, and tuber weight (SO). Top row shows results before calibration of crop parameters. WAGB: model efficiency (EF) = 0.71, RMSE = 835 kg/ha; LAI: EF = 0.03, RMSE = 1.21 m2/m2; SO: EF = 0.53, RMSE = 3565 kg/ha. Bottow row shows results after calibration. WAGB: EF = 0.75, RMSE = 2629 kg/ha; LAI: EF = 0.78, RMSE = 0.56 m2/m2; SO: EF = 0.74, RMSE = 2629 kg/ha.

Keywords: potato, water, remote sensing.

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S4-P.13

9 years of multi-site measurements in the SVAT continuum: A comprehensive dataset from contrasting regions in Germany

Weber Tobias KD[1] (tobias.weber@uni-hohenheim.de), Ingwersen Joachim[1], Poyda Arne[1], Wizemann Hans-Dieter[2], Högy Petra[3], Kremer Pascal[1], Eshonkulov Ravshan[1], Imukova Kristina[1], Witte Irene[1], Laub Moritz[1], Scott Michael[4], Cadisch Georg[4], Müller Torsten[5], Fangmeier Andreas[3], Wulffmeyer Volker[2], Streck Thilo[1]

[1] *Inst of Soil Science and Land Evaluation, University of Hohenheim, Stuttgart, Germany*; [2] *Institute of Physics and Meteorology, University of Hohenheim, Stuttgart, Germany*; [3] *Institute of Landscape and Plant Ecology, University of Hohenheim, Stuttgart, Germany*; [4] *Inst of Agr. Sciences in the Tropics, University of Hohenheim, Stuttgart, Germany*; [5] *Institute of Crop Science, University of Hohenheim, Stuttgart, Germany*

Introduction

Predicting the impact of climate change on agroecosystems and *vice versa* requires process models to understand land-atmosphere feedbacks. Process models enable testing hypotheses concerning the governing processes and identifying the need for further investigations. Validation is commonly carried out by comparing simulation results with measured state variables or fluxes. Properties of interest at the field level may be grain and biomass yields, soil organic carbon and nitrogen fluxes and turnover as well as the water, carbon dioxide and energy fluxes between land surface and atmosphere.

For this, high quality and extensive measurements are required. For this, two climatically contrasting study regions were selected: the warmer and drier Kraichgau region with a mean temperature of 9.7°C and annual precipitation of 890 mm, and the cooler and wetter Swabian Jura, where the mean temperature is 7.5°C and the annual precipitation 1042 mm. In each region, measurements were conducted over a time period of ten years from 2009 to 2018. The backbone of the measurements were three fully equipped eddy-covariance stations in agricultural fields in each region (Figure 1). This contribution presents the set-up of the measurement stations and the mean statistics of the dataset.

Materials and Methods

The 9-year data set is composed of crop-related data on phenological development stages, canopy height, leaf area index, vegetative and generative biomass as well as carbon and nitrogen content. Fluxes of energy and water in soil were monitored at 30-min resolution. Moreover, more than 1200 soil samples were taken to study changes of carbon and nitrogen contents. Finally, half-hourly fluxes of water, energy and carbon dioxide between land surface and atmosphere and the ground heat flux were determined at each of the six sites.

Results and Discussion

The dataset provide formidable opportunities for crop model calibrations in standard farming practice and using crop rotations. A large database of high precision data are made available. In particular, since 2015 and 2018 were very dry growing seasons, with pronounced water stress

Conclusions

Currently, the final data curation is underway, the post-processing and data quality and plausibility checks have been completed, full metadata describing the dataset were created. A peer-reviewed publication is in preparation, submission planned for early 2020.

Acknowledgements

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Fig 1 (left) Overview of research site location (center), research fields embedded in an intensely managed agricultural landscape, (right) fact sheet on Kraichgau and Swabian Jura.

Keywords: eddy-covariance measurements, agroecosystems, climate change, multi-modelling, crop model comparison.

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S4-P.14

Comparison of process model predicted LAI to real-time data assimilation and a simple model

Zare Hossein[1] (hossein.zare@uni-hohenheim.de), Weber Tobias[1], Ingwersen Joachim[1], Gayler Sebastian[1], Nowak Wolfgang[2], Streck Thilo[1]

[1] *Soil science, University of Hohenheim, Stuttgart, Germany*; [2] *Modelling Hydraulic, University of Stuttgart, Stuttgart, Germany*

Introduction

The leaf area index (LAI) of crop canopies plays a dominant role in evapotranspiration, energy partitioning and carbon exchange, and significantly affects crop yield formation. Process-based crop models are valuable tools for simulating LAI dynamics, provided that many input data are available to run, calibrate and validate these models. Although well-calibrated process-based models are expected to provide proper predictions, uncertainty in inputs can have significant impacts on predictions, leading to considerable deviations. An example is uncertain weather forecasts in real-time applications of crop models. An alternative is to use simpler models that require less input information. One of these simpler empirical crop models is the PILOTE model (Khaledian et al., 2009). It simulates LAI dynamics as a function of growing degree day (GDD) and water availability. As PILOTE is computationally extremely fast, its prediction can be easily assisted by Data Assimilation (DA). A specific DA technique suitable for non-linear dynamic systems like the soil-crop system is particle filtering (PF; Linker and Ioslovich, 2017). We hypothesize that PILOTE assisted by DA can provide more accurate and useful predictions than process-based crop models. Therefore, we compare LAI predictions of the PILOTE model assisted by DA with LAI simulations performed with process-based crop models using stochastically generated future weather data (GWD).

Materials and Methods

Data from six wheat fields located in southwest Germany (2010-2016) were used to calibrate CERES-Wheat, GECROS and SPASS in Expert-N. For this, nine site-year datasets were used to calibrate the models and six for validation. The Choudhury method (Choudhury et al., 1994) was applied to estimate LAI from NDVI, derived from cloud-free Sentinel 2 images. The stochastic weather generator MarkSimGCM (Jones and Thornton 2000), together with the RCP 4.5 scenario were applied to generate weather data.

PF was applied on a simple empirical LAI model (PILOTE). PF is a recursive Bayesian Monte Carlo algorithm to sequentially update a prediction (in form of a probability distribution), based on previous predictions and new observations. Once an observation (a satellite image) arrives, particles (samples from the distribution) are weighted based on their likelihood, i.e. how good their states (LAI) fit with the latest observations. To counteract extreme contrasts in particle weights, an acceptance/rejection sampling procedure is applied at every time step when an observation comes using importance sampling.

Results and Discussion

The GWD showed nonlinear effects on the models output. CERES overestimated LAI in early growing periods and underestimated LAI for the rest of period. GECROS showed a similar pattern but with a lower uncertainty. GECROS proved to be very robust under uncertain weather. SPASS underestimated LAI during growing period.

LAI simulated by PILOTE + DA showed a very low uncertainty in both situations (LAI from measured data and NDVI-derived LAI). When NDVI-derived LAI is assimilated into PILOTE, an overestimation is seen due to the overestimation in LAI estimated by NDVI.

Conclusion

Under uncertain weather conditions, when measured/observed LAI data are available, PILOTE assisted by DA is more reliable than complex process-based models. The accuracy of PILOTE + DA also depends on the accuracy in the LAI assimilated into the model.

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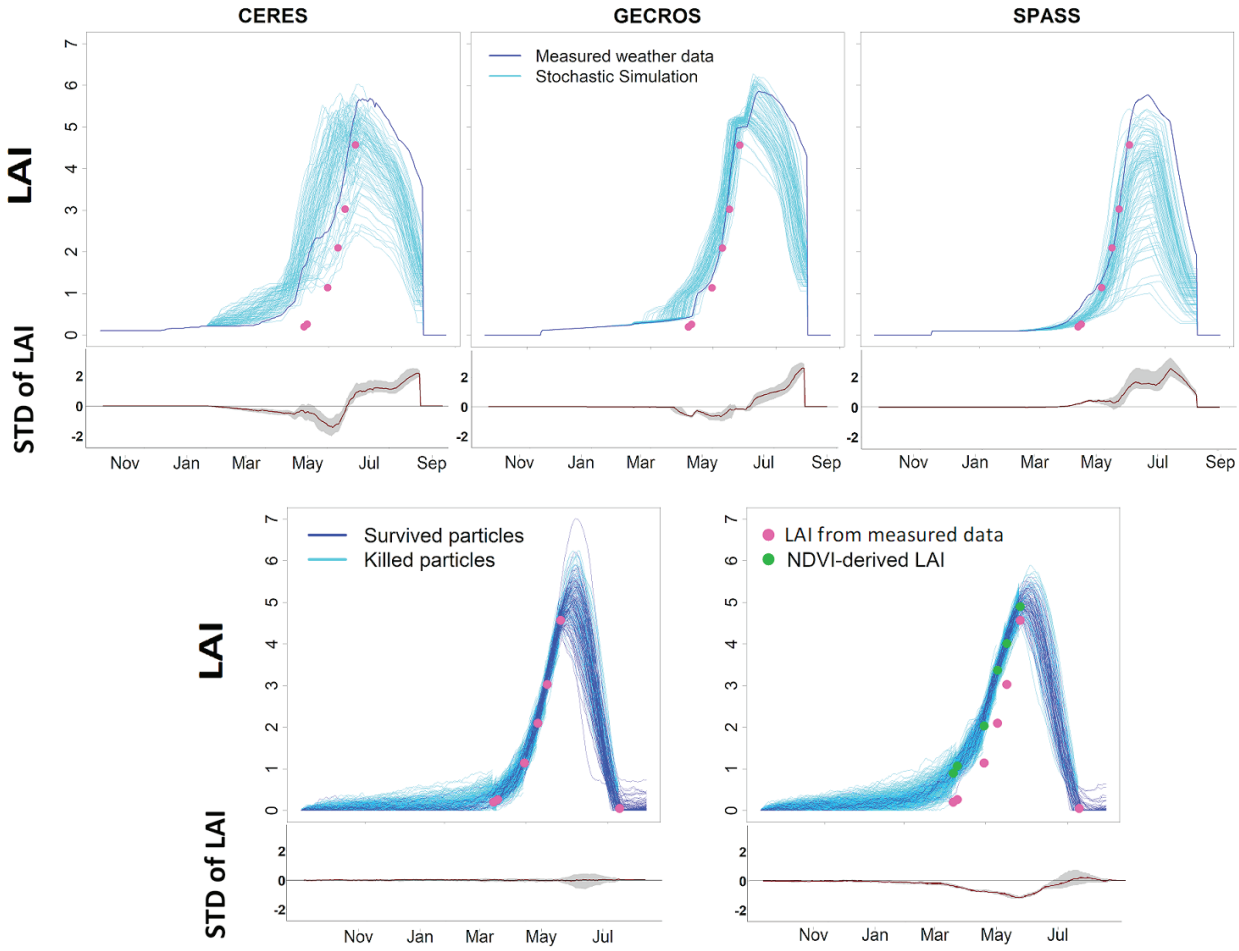

Figure 1- LAI simulated with crop models and its uncertainty (upper row) and LAI assimilated into PILOTE model (lower row) under uncertain weather condition. The lower subplots show the standard deviation (STD) of the stochastic simulations with reference to the calibrated LAI (CERES, GECROS and SPASS) and the Median LAI (PILOTE + DA). The gray shadow in the uncertainty plots show the upper 75 % and lower 25 % quantiles.

Keywords: Data Assimilation, Crop Modelling, Stochastic Simulation, Crop Growth Predictions.

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Enhancing Regional Yield Forecasting of Five Major Crops in Canada using Earth Observation

Zhang Yinsuo[1] (yinsuo.zhang@canada.ca), Champagne Catherine[1], Chipanshi Aston[2], Daneshfar Bahram[1], Davidson Andrew[1]

[1] *Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada*; [2] *Agriculture and Agri-Food Canada, Regina, Saskatchewan, Canada*

Introduction

Predicting crop yield ahead of the harvest date provides early warning information for markets, grain transportation, policy and program activities. Traditional operational yield estimations in Canada are mostly based on farm survey or ground observed climate information. Using both climate data and Earth Observation (EO) derived crop health indices, integrated with a physical process based model and statistical algorithms, Agriculture and Agri-Food Canada (AAFC), in collaboration with Statistics Canada (STC) have developed a functional model for crop yield forecasting, i.e. the Canadian Crop Yield Forecaster (CCYF) (Chipanshi et al. 2015). The CCYF uses observed climate information from meteorological stations and remote sensing Normalized Difference Vegetation Index (NDVI) as predictors in a regression-based model. While these two sets of indicators provide robust prediction for most crops in most regions, improving in those areas where prediction accuracy is weaker requires a broader range of predictors than is traditionally used. Newer sources of agronomic information from microwave and thermal satellite sensors can provide spatially explicit information on soil moisture and evapotranspiration, in addition to more advanced methods of extracting vegetation condition information from optical satellites. The objectives of this study are 1) to evaluate the effectiveness of three EO based datasets in forecasting the regional and national yield for five major crops in Canada and 2) to develop a suitable ensemble algorithm to optimize production estimates under variable weather conditions using this broader range of crop predictors.

Materials and Methods

The CCYF uses climate based predictors estimated from a simple process-based Versatile Soil Moisture Budget (VSMB) model, such as measures of crop water demand (water deficit index) and crop heat accumulation (crop heat unit). Both the VSMB climate indicators and EO indices are integrated at a Census Agricultural Region (CAR) unit using EO derived crop masks (Zhang et al., 2019). Statistical algorithms such as robust least angle regression and robust cross validation are used in CCYF to rank and select the most relevant predictors that explain the majority of the crop yield variance.

Three EO datasets are assessed in this study: 1) an Evaporative Stress Index (ESI) derived from the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor (Anderson etal. 2011), 2) an Accumulative Seasonal Greenness Index (ASGI) derived from MODIS NDVI (Tadesse et al. 2017) and 3) a composite Satellite Soil Moisture (SSM) dataset derived from active and passive microwave data (Gruber et al. 2019). The three new datasets are each assimilated into the model with the climate based indices and compared with the climate indices and the three-week-averaged MODIS NDVI alone. A Leave-One-Out-Cross-Validation (LOOCV) process as applied in previous CCYF evaluations (Chipanshi et al. 2015, Zhang et al. 2019) are used to assess the effectiveness of the new datasets.

The study area covers most of the agricultural regions of Canada, which encompasses a vast area from 42 ˚N to 60 ˚N and from 60 ˚W to 130 ˚W. Five major crops (spring wheat, canola, barley, corn for grain and soybean) with different agronomic properties grown in variable agroclimatic regions were modelled in order to assess the effectiveness of the EO datasets as predictors in these different environments.

Results and Discussion

At the CAR level, all three new EO inputs increased the chance of EO based inputs to be selected as top yield predictors in all the CARs for most of the crops compared to the currently used NDVI input. With the MODIS NDVI, about 60-75% of all CARs selected NDVI as one of the yield predictors, while the yield predictors for the remaining CARs based purely on climate indices. With the three new EO inputs, the percentage of CARs with EO inputs as predictor increased to 80-90% except ESI for corn for grain and soybeans.

Improvements to yield forecasting skill were demonstrated by aggregating the CAR level yield to provincial and national scales. Using the three datasets decreased the mean percentage absolute error by 0.5-2% for all five crops at the national level. However, large variations were observed at provincial and CAR level. More efforts are required to further assess the selection of predictors for different regions and for different crops.

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Conclusions

Assimilation of a diverse set of EO datasets was effective in improving the regional crop yield forecasting skill. Including all EO data sets into the model did not achieve the best performance, with some datasets effective for specific crops in specific regions. An effective ensemble approach would potentially mitigate this problem and provide a range of model predictor sets that best describe crop conditions for a given agroclimatic region and crop type. Sensitivity analysis with crop growth models may advance this understanding.

Keywords: Crop Yield Forecast, Earth Observation, Evaporative Stress Index, Seasonal Greenness Index, Satellite Soil Moisture.

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ABSTRACTS POSTERS

SESSION V

CROP MODELLING FOR RISK AND IMPACT ASSESSMENT

S5-P.01

Multimodal ensemble approach to study elevated CO_2 effects on wheat productivity

Ahmed Mukhtar[1] (ahmadmukhtar@uaar.edu.pk), Stöckle Claudio[2], Nelson Roger[2], Higgins Stewart[3]

[1] *Agronomy, PMAS Arid Agriculture University, Rawalpindi, Pakistan*; [2] *Biological Systems Engineering, Washington State University, Pullman, United States*; [3] *Biological Systems Engineering, Washington State University, Pullman, Pakistan*

Introduction

Carbon dioxide is an important substrate of photosynthesis and its elevated concentration results in metabolic changes in crops directly through photosynthesis (A) and stomatal conductance (gs). Theoretically, a change in [CO_2] from 380 ppm to 550 ppm could increase C3 photosynthesis by 38% compared to C4 crops (Long *et al.*, 2004). Many researchers have used crop modeling under different climatic scenarios but most of the earlier crop modeling work was more focused on studying and quantifying the impact of temperature on crop growth, development and yield.They, in general concluded reduction in grain yield with some level of uncertainties under higher temperature (Asseng *et al.*, 2011). Similarly, earlier modeling studies focused on the combined effect of climatic parameters i.e. [eCO_2], temperature, nitrogen and drought. Some of the earlier work focused on the interactive study of increased temperature and CO_2 (Luo and Kathuria, 2013). Few studies have focused on carbon dioxide alone. Therefore, it is necessary to focus on quantification of CO_2 when dealing with projections of impacts of future climate conditions, it is important to evaluate differences arising from the different approaches and parameterization of modeled responses of crops to CO_2. Therefore, present study was designed to evaluate the performance of different process based crop models under different level of [eCO_2]. The objectives of the present study were to (i) quantify impact of [eCO_2] on winter wheat biomass and yield and (ii) bring/suggest accuracy in the models response to [eCO_2].

Materials and Methods

The five process based crop models i.e. APSIM-Wheat, CropSyst, DSSAT_CERES_Wheat, EPIC and STICS were evaluated in present study under [eCO_2] using observed field data at three variable study sites of PNW USA. The focus of this evaluation is on biomass and yield responses to [eCO_2], with attention to changes in stomatal conductance, crop transpiration, biomass and grain yield gain. These process based models were chosen because of their wide used in climate change studies and easily availability.

Results and Discussion

The simulated results by all models showed (Figure) that elevated CO_2 resulted to the significant variability among models to simulate biomass at three different sites with highest (44%) production at water stress conditions i.e. Lind while under irrigated conditions (Moses Lake) increase in biomass was 22%. Similarly, average yield increase under water stress among all models from ambient CO_2 concentration to 1000 µmol mol-1 was 45 % comparatively higher than high rainfall site where it was 34 % while under irrigated conditions it remained 22 % which was almost 50 % less then dryland site (Lind). Rosenzweig *et al.*, (2014) results indicated strong negative effect of climate change particularly at higher temperature. However, they pointed further research to minimize uncertainties related to the representation of carbon dioxide, nitrogen, and high temperature which we elaborated in our studies by considering impact of elevated CO_2 only.

Conclusions

We concluded from our study that process based crop models have variability in the simulation of crop response to elevated CO_2 with greater difference under water-stressed conditions which recommend use of ensembles approach to bring accuracy in the models response to elevated CO_2.

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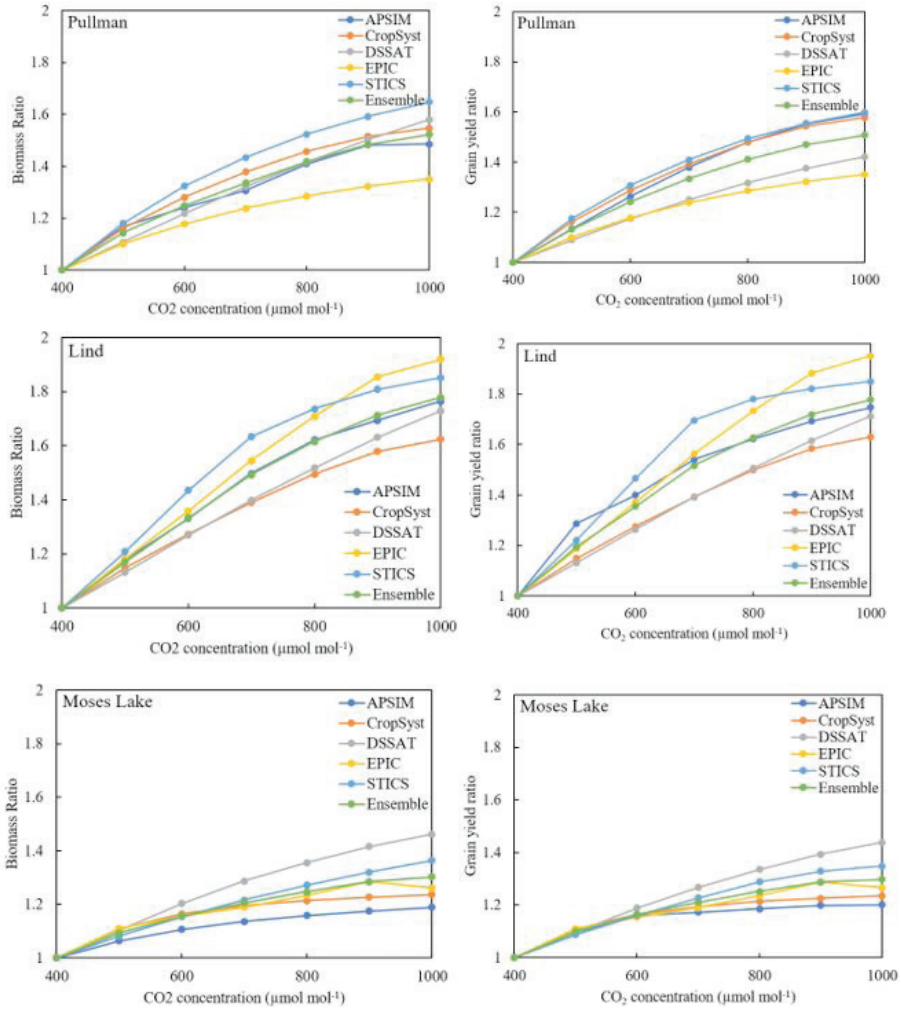

Biomass and yield ratios of wheat under elevated carbon-dioxide concentration [eCO_2] for APSIM, CropSyst, DSSAT, EPIC, STICS and ensemble at three Pacific Northwest sites.

Keywords: Ensemble, Elevated CO_2, Wheat, Productivity.

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S5-P.02

Vulnerability of cassava yield to climate change in Brazilian Semi-arid region

Bongiovani Paola de Figueiredo (paola.f.bongiovani@gmail.com), Sentelhas Paulo Cesar, Bender Fabiani Denise

Department of Biosystems Engineering, University of São Paulo (ESALQ/USP), Piracicaba, SP, Brazil

Introduction

Cassava is one of the most important crops for tropical countries. Due to its tolerance to adverse weather and soil conditions, it has been cultivated as a strategic crop in semi-arid regions, as in Brazilian Semi-arid (BS). Within the predictions of climate change, it is crucial to understand in which ways cassava production might be affected in this region, since any change in its yield might be critical for food security. In this context, crop simulation models are effective tools to quantify the future climate impact on crop yields. Thus, the objective of this study was to apply the DSSAT CSM-CROPSIM-Cassava model to elaborate a climate change vulnerability index for cassava at BS.

Materials and Methods

The CSM-CROPSIM-Cassava model, previously calibrated (r^2 = 0.85, d = 0.93) and evaluated (r^2 = 0.82, d = 0.94), estimated cassava cultivar BRS Formosa attainable yield (AY) for 50 locations in BS. Soil profile data was obtained from soil analyzes. Weather data from 1980 to 2010 composed the current historical series (CHS). Rain data were obtained from the National Water Agency (ANA) databases and other weather data, from the grid database of Xavier et al. (2016).

The weather series under future projections were created from the CHS through the delta method (Rosenzweig et al., 2015), based on the projections of global climate models (GCMs) from CMIP5/IPCC/AR5. Projections were considered under scenarios of intermediate (RCP4.5) and high (RCP8.5) greenhouse gases emission, for medium (2040-2070) and long (2070-2100) terms, using seven GCMs, as recommended by Bender (2017). The simulations for all GCMs were presented as mean values of their ensemble.

With the average AY values for 29 cycles performed for the 50 locations, for current and future scenarios, a vulnerability index (IV) was created. The IV served to identify the most vulnerable areas for cassava AY reduction due to climate change, the greater the vulnerability the lower the IV. For the preparation of the VI maps, the 50 sites in BS were divided into two different groups, one with 35 sites for the development of the linear regression models, aiming at VI spatialization, and the other, with 15 locations, for map evaluation. Mapmaking was performed applying statistical analysis.

Results and Discussion

IVs estimation by the linear equations was efficient, with very low errors compared to the calculated IVs (MAE from 5.0 to 8.4%), and consistent results, with d indexes from 0.86 to 0.93.

Climate change is likely to increase BS's vulnerability to cassava production, with predominating reductions in AY (Figures 1a to 1d). Areas already vulnerable will become even more critical for cassava production, while most non-vulnerable areas will show some degree of vulnerability in the future.

Conclusions

The cassava production vulnerability to climate change in BS was greatest in the long term (2070-2100) in both GHG emission scenarios (RCP4.5 and RCP8.5). The most vulnerable region was located at Southwest of BS and the less vulnerable, at North and Northeast. Thus, studies of adaptation measures are essential to minimize the vulnerability of such important crop to food security in BS.

Acknowledgements

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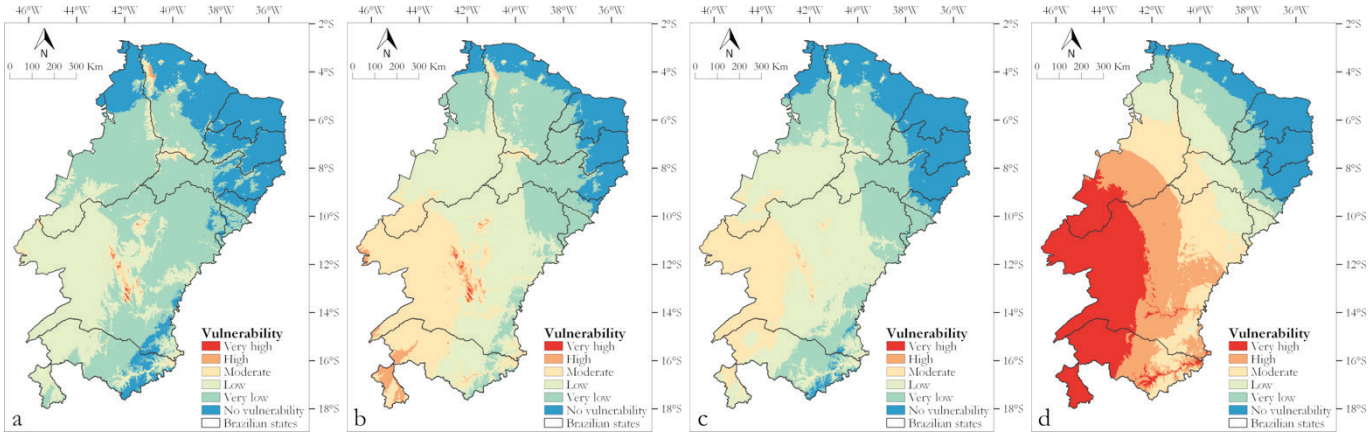

Figure 1. Cassava vulnerability in Brazilian Semi-arid region on climate change scenarios, with moderate GHG emission (RCP4.5), for medium (a) and long (b) term, and high emission (RCP8.5), for medium (c) and long (d) term.

Keywords: Manihot esculenta, Crantz, DSSAT CSM-CROPSIM-Cassava, Global warming, Future scenarios.

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S5-P.03

A method for simulating risk profiles of wheat yield in data-sparse conditions

Bracho-Mujica Gennady[1] (gennady.brachomujica@uni-goettingen.de), Hayman Peter T.[2], Sadras Victor O.[2], Ostendorf Bertram[3]

[1] *TROPAGS, Georg-August-Universität Göttingen, Göttingen, Germany*; [2] *SARDI, Urrbrae, South Australia, Australia*; [3] *School of Biological Sciences, The University of Adelaide, Adelaide, South Australia, Australia*

Introduction

Crop simulation models can be used to generate risk profiles (i.e. probability curves of crop yield) for multiple genotype, environment and management combinations. However, robust simulations of risk is limited when high-quality weather data is sparse. In this study, we aimed to determine whether and to what extent a simple method for scaling daily weather data (Liddicoat et al., 2012) could be applied to estimate robust risk profiles of modelled crop yield in data-sparse conditions. To do this, we examined an extreme situation of having one single location with high-quality weather data (reference site), and a number of locations of varying distance to the reference site with only averaged data available (study sites). Weather data from the reference site was adjusted using a simple delta method, using delta factors (adjustment factors) to represent the difference between the reference and each study site. We explored the effect of the record length of averaged climate data on (i) the accuracy of adjustment factors, and (ii) the matching of simulated risk profiles curves of wheat yield.

Materials and Methods

We focused on 49 wheat-growing sites within the Australian grain-belt. Risk profiles were generated using wheat yield simulated with APSIM model (Holzworth et al., 2014). At each study site, two weather data sets were used as model input: measured and adjusted. Both data sets included daily values for the variables: precipitation, maximum and minimum temperatures, and solar radiation. Adjusted data refers to perturbed weather values from the reference site using a delta method. For each climate variable, adjustment factors represent the difference of averaged data from the reference and a study site. Snowtown (South Australia) was used as reference site due to the availability of high-quality data and its agricultural importance. To mimic the problem of short climate series, adjustment factors were computed using a variable record length (i.e. 10, 20, …, 100 years) for the long-term period 1901-2000. Risk profiles were built using a combination of adjustment from the most simple (adjusted series of precipitation only) to the most detailed (adjusted series of all climate variables).

Results and Discussion

Overall, all adjustment factors were sensitive to the record length of the averaged climate data. Adjustment factors for precipitation were the most sensitive, with departures ranging from -10 to 10% for record lengths of 40 or more years. Adjustment factors for both temperatures were mostly underestimated, but departures remained within -0.5 and 0.5 ºC with record lengths of 20 or more years. Adjustment factors for solar radiation was the less sensitive to the record length. The proportion of test sites in which the risk profiles were estimated with biases within -10% and 10%, consistently increased as the number of climate variables adjusted increased (Fig. 1).

Conclusions

Results indicated that although record length of climate data have an impact on the accuracy of adjustment factors, adjustment of all climate variables (i.e. precipitation, temperatures and solar radiation) produced the most reliable estimations of simulated risk profiles of crop yield across a large area, encompassing a diversity of climates.

Acknowledgement

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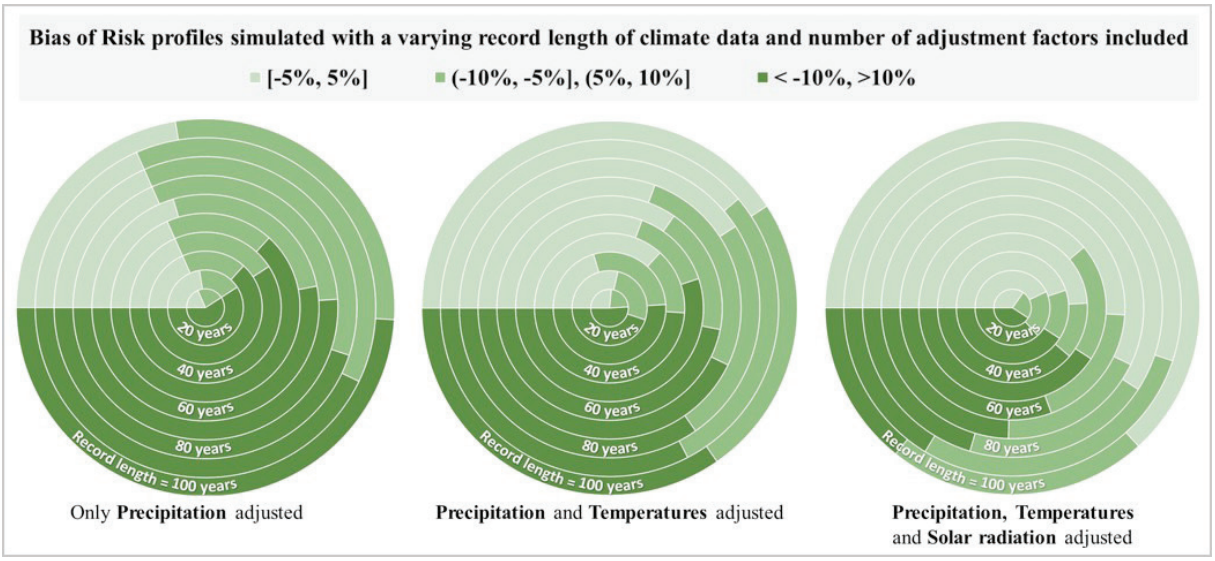

Effect of record length on the matching of risk profiles modelled with measured weather data and those modelled with adjusted data. Number of adjustments increases from left to right. Bias is expressed in percentage.
Each ring represents the bias for a given record length, starting in the center with a record length=10 years until the last ring of 100-years (period 1901-2000).

Keywords: climate risk, weather data, APSIM, delta method.

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S5-P.04

AdaptaOlive: A tool for assessing the impact of climate change on olive crop

Cabezas-Luque José Manuel[1] (josem.cabezas@juntadeandalucia.es), Gabaldón-Leal Clara[2], Ruiz-Ramos Margarita[3], Santos Cristina[2], De la Rosa Raúl[2], Belaj Angjelina[2], León Lorenzo[2], Soriano María Auxiliadora[4], Lorite Ignacio[2]

[1] *Agriculture and Environment, IFAPA - Junta de Andalucía, Córdoba, Spain*; [2] *IFAPA - Junta de Andalucía, Córdoba, Spain*; [3] *UPM, Madrid, Spain*; [4] *Universidad de Córdoba, Córdoba, Spain*

Introduction

Olive crop constitutes the main economic and social crop in numerous areas of the Mediterranean basin. However, recently there is a growing concern about the future sustainability of this crop due to the limited profit and the increasing frequency of climatic hazards as droughts and heat events.

The tool AdaptaOlive integrates different simplified physically-based models and has been developed to assess the behavior of Mediterranean olive orchards under future climate conditions (Lorite et al., 2018). The objective of this study is to assess the impact of climate change on this crop to facilitate adaptation.

Material and Methods

Adaptaolive integrates specific functions for assessing crop behavior under current and future weather conditions. Thus, response functions considering the transpiration efficiency increase associated to the increased atmospheric [CO_2] and water stress, the effect of water stress during flowering stage on yield (Lorite et al., 2018) and the impact of lack of chilling requirements (Gabaldón-Leal et al., 2017) have been added to the simulation model.

Weather data were sourced from an ensemble of 11 climate model outputs and from perturbed observed climate and impact response surfaces (IRS) based on methodology by Pirttioja et al. (2015). As result of the use these weather data with AdaptaOlive, phenology, yield and irrigation requirements were projected for olive orchards located at Southern Spain.

Results and Discussion

Simulations with AdaptaOlive considering an ensemble of 11 climate models for near future (NF) and far future (FF) showed olive yield increases of 14.8 and 7.1%, respectively under rainfed conditions (Figure 1a), and under deficit irrigation strategies, increases of 12.6 and 21.5%, respectively.

Analyzing perturbed climate under NF conditions (NF-RCP4.5) large differences in response were found depending on location, with an average olive yield increase of 19% and reductions of 34% for cold and warm locations, respectively (Figure 1b). In addition, yield response showed abrupt changes even for limited changes in weather variables when critical temperature thresholds were exceeded.

These results confirm the necessity to conduct an additional sensitivity analysis to weather, as provided by perturbed climate and IRS, for developing site-specific adaptation strategies of the Mediterranean olive orchards (Cabezas-Luque et al., 2020).

Conclusions

The development of a simulation model as AdaptaOlive, combined with the use of an ensemble of climate models, perturbed climate and IRS methodologies, has provided an excellent tool for assessing impact of climate change and identifying adaptation strategies to increase the sustainability of Mediterranean olive orchards under future weather conditions.

Acknowledgements

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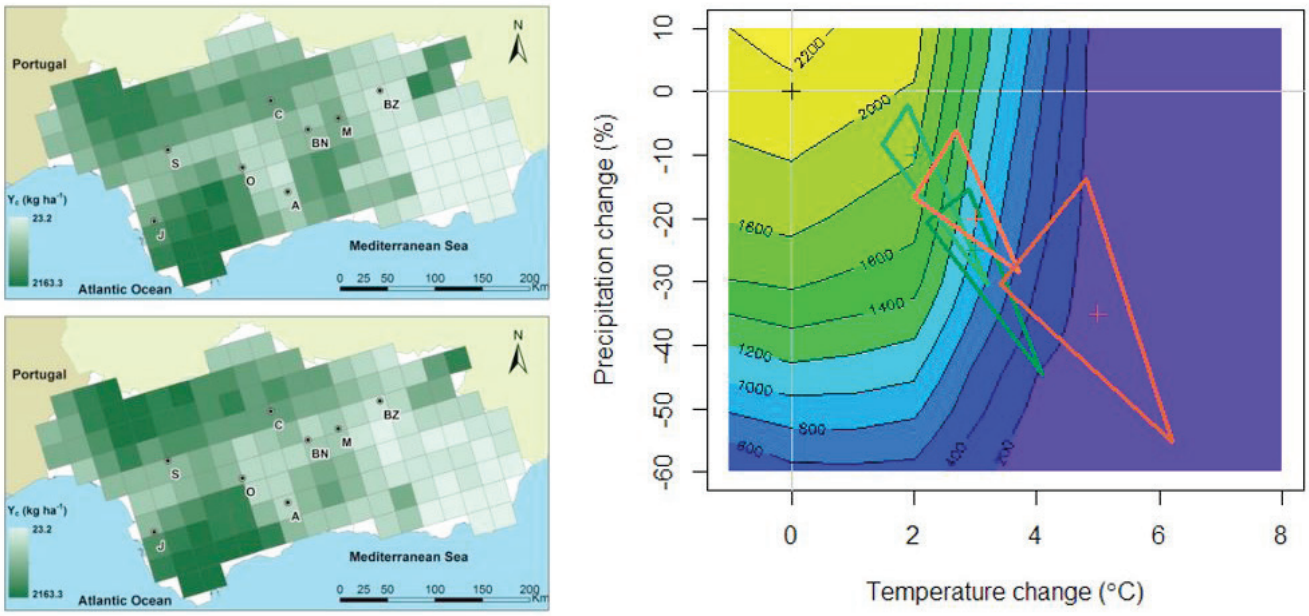

Figure 1. Olive yield impact of future weather conditions under rainfed conditions provided by AdaptaOlive considering an ensemble of climate models (a), and perturbed climate and IRS in Córdoba (b)

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S5-P.05

Impact of climate sensitivity on agriculture systems in West Africa: Case of Senegal

Faye Babacar[1] (babacar.faye@ird.fr), Sultan Benjamin[1], Affholder François[2], Gérard Françoise[3]

[1] *IDR, ESPACE-DEV, Montpellier, France*; [2] *CIRAD, UPR AIDA, Montpellier, France*; [3] *CIRAD, UPR GREEN, Montpellier, France*

Introduction

Weather parameters are the main limited factors for simulating yield for the crop growth models. It is well known the effect of single weather parameters on crop development but the interaction remains uncertain in condition of high variability of climate such as West Africa. This region is characterized by a continuous increase of temperature and a high uncertainty in the projections of the precipitation change. Nevertheless, in the particular case of Senegal mean precipitation is expected to decrease in the future.

This study analyses the sensitivity of parameters: temperature, water and [CO_2] on crop yield with a single response of each parameters on one hand and on the other hand a combination of parameters based on the response of temperature for each [CO_2] level combine with six levels of water in each [CO_2] x temperature combination.

Materials and Methods

Two cereals: maize (improved maize and local maize) and pearl millet were simulated in two different soil types and two zones under different mineral and organic fertilizer applications. The simulations are performed with CELSIUS crop growth model couple with ANDERS economic model. The two models were calibrated and validated previously for maize and pearl millet in the given area (Ricome et al 2017). Two virtual experiment were setup with observed data as baseline from 1991 to 2010: (i) with no interaction for a total of 54 climate scenarios (11 Temperature levels + 8 water levels + 7 [CO_2] levels + baseline) * 2 zones, (ii) with interaction (table1).

Results and Discussion

Preliminary results showed that improved maize had a higher response to the variability of climate with and without interaction in both zones irrespective of the soil type and fertilizer application. The response of the crop to the parameters considered is more uncertain under soil with low nitrogen content under the interaction case. Yield change remains constant under low fertilizer application compare to high fertilizer application, while losses were higher of about 50% when temperature increase from 0 to 6°C for maize improved and 20% for local maize and pearl millet. In the economic perspective results from Anders showed that producers with low income are more subject to be affected to the variation of climate than producers with higher income based on the level of risk tested.

Conclusions

In summary, results indicated that producers with low income will be more vulnerable to climate variability than producers with high income as they have resources to purchase inputs to counteract the effect of climate. This in fact depend on the assumptions about the allocation of the amount of income per worker in the model. The assumptions about the economic factors need implication of the stakeholders and decision makers that could help farmers to sustain the production system.

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Table1: Combined factors (interaction) for the reference period (1991-2010). 156 climate scenarios (6S1 + 18S2 + 12S3 + 12S4 + 12S5 + 18S6)*2 zones.

Interaction	Factor levels
T x CO2 x H2O	S1= (T0) * (C360)* (W70,W80,W90 W100, W120,W150)
	S2= (T2,T3,T4) * (C450)* (W70,W80,W90 W100, W120,W150)
	S3= (T3,T4) * (C550)* (W70,W80,W90 W100, W120,W150)
	S4= (T3,T4) * (C630)* (W70,W80,W90 W100, W120,W150)
	S5= (T4,T5) * (C720)* (W70,W80,W90 W100, W120,W150)
	S6= (T4,T5,T6) * (C800)* (W70,W80,W90 W100, W120,W150)

Table1: Combined factors (interaction) for the reference period (1991-2010). 156 climate scenarios (6S1 + 18S2 + 12S3 + 12S4 + 12S5 + 18S6)*2 zones.

Keywords: agriculture systems, climate change, Senegal, West Africa.

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S5-P.06

Sowing date and precocity evolution on maize biomass and water availability in France in a climate change context

Deudon Olivier[1] (o.deudon@arvalis.fr), Gendre Sophie[2]

[1] *Arvalis, Boigneville, France*; [2] *Arvalis, Baziege, France*

Introduction

Maize in France represents 3 million hectares to produce grain, seeds and biomass. Due to its summer seasonality, it is sensitive to water scarcity and heat. Due to climate change, a lot of studies looked at the climate change effect on maize water needs for one sowing date and one variety. The limit of these studies is that they don't consider farmers adaptability. Indeed, since 1960's, French farmers adapt their crop management to climate by sowing earlier and changing their varieties. We propose here to study evolution effect of sowing date and precocity for maize with climate change scenario, using CHN model. The aim of this study is to compare different sowing/precocity pairs and see their effects on soil water availability and maize biomass production.

Materials and Methods

This study is based on CHN model. CHN is a dynamic crop model developed by ARVALIS Institut du vegetal (Soenen, 2015). It simulates water and nitrogen stress on biomass and plant development. It is currently available for wheat and maize. As it does not have decision rules for irrigation, the study is on rain-fed maize.

Simulations were made on all French territory by defining homogeneous agronomic and climate areas. This segmentation represents the main French arable field crop production areas. Then we calculate centroid of each region to make the calculations.

Two scenarios were studied: RCP 4.5 and RCP 8.5, and the datas are provided by the DRIAS portal. Three type of soils were considered (low, medium and large water storage capacity). Six different sowing dates were selected between March 1st and May 10th which are representative of French sowing dates. For maize precocity seven classes were considered from very "early varieties" to very "late varietes". All these combinations lead us to create 252 maps (1 model, 2 climate scenario 3 soil types, 6 sowing dates and 7 precocities).

We look at water deficit between ten leaf and flowering then between flowering and grain humidity up to 32%. Water deficit is defined as the difference between maximum evapotranspiration and real evapotranspiration. We also focus on flowering biomass then final biomass.

Results and Discussion

Figure 2 shows and increase in water deficit whether this for RCP 4.5 or RCP 8.5.

When we look at sowing dates paired with precocity, whatever the scenario, it seems that precocity has more impact on water deficit or biomass than sowing dates.

Conclusions

First results show a comparison for different couples of sowing dates and precocity. As we could sense, climate change increase maize water needs in France, with likely consequences on biomass production. Next steps would be to optimize this couple for each segment defined in the methodology.

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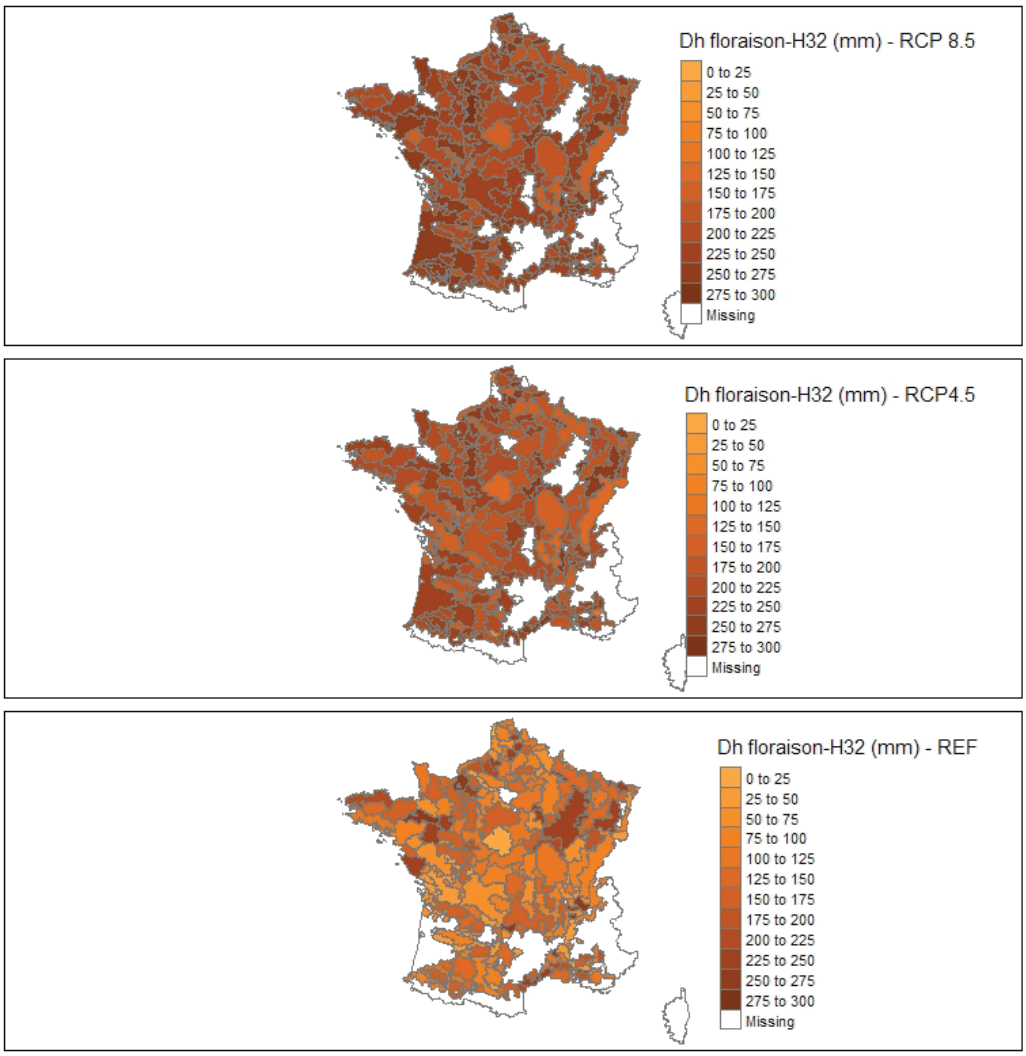

Figure 2. Results of hydric deficit simulated between flowering and grain humidity up to 32%for a low soil and a sowing date at 01/03 between 1971-2000 for the reference, 2021-2050 for RCP 4.5 and 2071-2100 for RCP 8.5.

Keywords: agronomy, meteorology, variability, adaptation.

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S5-P.07

Testing a crop model with extreme low yields from historical district records

Guarin Jose[1] (jguarin@ufl.edu), Asseng Senthold[1], Martre Pierre[2], Bliznyuk Nikolay[1]

[1] *Agricultural & Biological Engineering, University of Florida, Gainesville, FL, United States*; [2] *LEPSE, Universite Montpellier, INRA, Montpellier SupAgro, Montpellier, France*

Introduction

Extreme weather events across the world cause large variations in daily seasonal temperature and precipitation, potentially reducing grain yield and negatively affecting global food security (Lesk et al., 2016). Additionally, these extreme weather events are becoming more frequent and variable (Sheffield and Wood, 2008). Thus, it is important to assess if crop growth models can simulate the yield losses caused by these extreme weather events.
The objective of this study was to test the ability of the Decision Support System for Agro-technology Transfer (DSSAT) wheat model, DSSAT-NWheat v.4.6.1.003, to reproduce historical extreme low-yielding years, based on a calculated low-yielding threshold, at three global agricultural districts from the 1920s – 2015, and determine possible causes for similarities and differences between the observed and simulated yields of the extreme low-yielding years.

Materials and Methods

Three districts were chosen for simulation based on known wheat-producing areas located in differing global climates at: Hays, Ellis County, Kansas, USA; Orléans, Loiret District, France; and Merredin, Merredin Shire, Western Australia, Australia. The historical weather data and historical observed yield records were collected from well-maintained databases ranging from 1926–2015 at Hays, 1950–2013 at Orléans, and 1924–2014 at Merredin. The observed yield data was temporally trend-corrected and normalized, and the simulated yields from the DSSAT-NWheat model were also normalized for proper comparison for each location. The extreme low-yielding threshold was chosen to be the 15th percentile of the observed yield data per location/district based on the definition of moderate-extreme droughts of the Self-Calibrating Palmer Drought Severity Index (SC-PDSI) scale (Wells et al., 2004).

Results and Discussion

The NWheat model correctly reproduced 37% of all extreme low-yielding years in total. The model reproduced 70% of the driest and hottest extreme years on record at all three locations. Additionally, the model simulated extreme low yields in some years that were not extreme low yielding in the observed records, but surprisingly, some of the driest and hottest years did not show up as observed extreme low-yielding years in the district records. This discrepancy could be explained by reporting yields, or in this case "not reporting extreme low yields" in district records, as indicated by large drops in harvested areas in extreme dry and hot seasons. Other discrepancies exist because crop models do not often consider many factors under farmer-field conditions that lead to extreme low yields in district records, including frost, hail and lodging, pests and diseases, and excess water. Historical district yield records are also limited for model testing due to unknown and changing aggregation across a district, possible omission of extreme low-yielding fields in some years, and unknown spatial and temporal varying cultivars and crop management, particularly in initial soil water conditions.

Conclusions

We do not recommend using historical district yield records for model testing of extreme low yields because of the many uncertainties within the environment, crop management, and observed data reporting over an extended historical period.

Acknowledgements

We thank Z. Hochman for supplying some of the historical data for Merredin, Australia.

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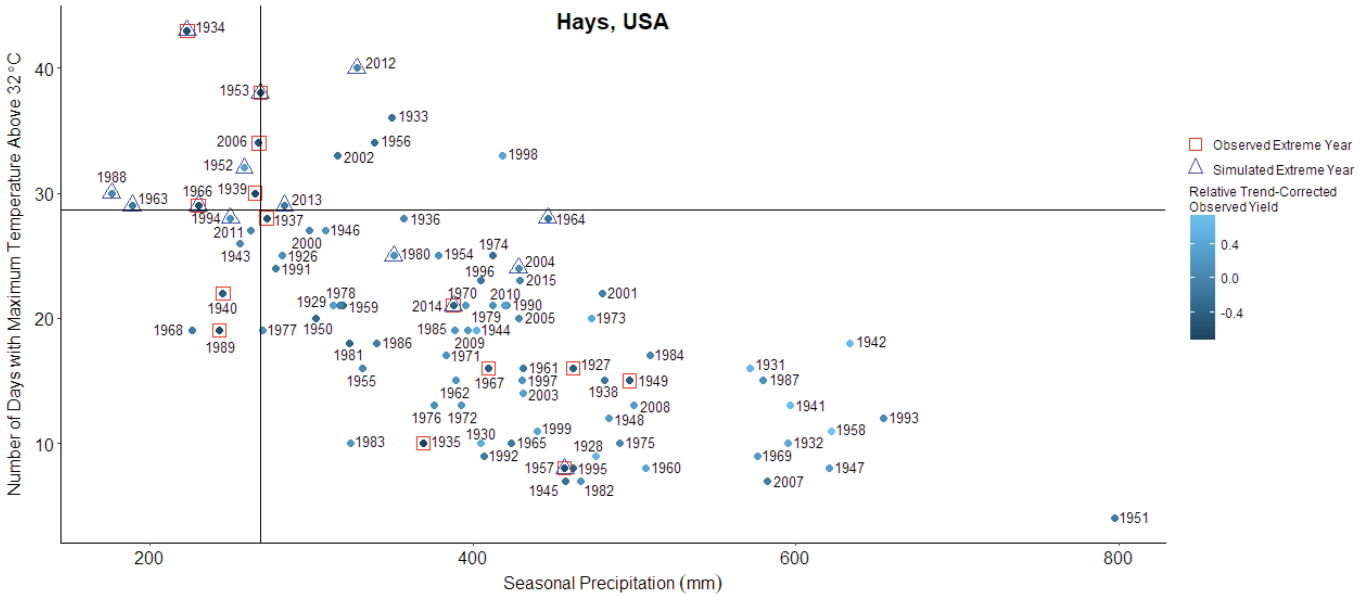

Figure 1. Hays, Kansas, USA seasonal precipitation vs number of days with maximum air temperature above 32°C from 1926 to 2015 (labeled). Red squares indicate when observed yield is in 15th percentile; blue triangles indicate when simulated yield is in 15th percentile. Black lines indicate 15th percentile of seasonal precipitation (vertical) and 85th percentile of the number of days with maximum air temperature above 32°C (horizontal). Gradient of relative trend-corrected observed yields illustrates the deviation of yields, i.e., severity of extreme years. Source: Guarin et al., (2018).

Keywords: Crop model, extreme events, food security, historical district yield records, model testing.

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S5-P.08

Estimating the Potential Impact of Climate Change on Sunflower Yield in the Konya Basin of Turkey

Gurkan Hudaverdi[1] (hudaverdigurkan@hotmail.com), Bayraktar Nilgun[1], Yesilekin Nebi[2], Gunduz Arzu[3], Yildirim Yusuf Ersoy[1], Boote Kenneth[2], Shelia Vakhtang[4], Porter Cheryl[2], Hoogenboom Gerrit[4]

[1] *Faculty of Agriculture, Ankara University, Ankara, Turkey*; [2] *Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, United States*; [3] *Ataturk Horticultural Central Res. Inst., Ministry of Agriculture and Forestry, Yalova, Turkey*; [4] *Institute for Sustainable Food Systems, University of Florida, Gainesville, Florida, United States*

Introduction

Sunflower is the most important crop for domestic herbal oil consumption in Turkey. However, Turkey has been importing more than 50% of the vegetable oil industry's raw material demands. Increasing the efficiency of sunflower production is the absolute necessity in order to reduce import. Turkey is in the eastern Mediterranean region and is the one of the most vulnerable regions for climate change. According to the projections the temperature will increase by 1.5°C-2.5°C and 2.5°C-3.6°C based on RCP4.5 and RCP8.5 scenarios by end of the century (Gurkan et al., 2017). Projections published by the World Food and Agriculture Organization (FAO), due to climate change, after the first quarter of the century (2030-2100) there will be a decreasing trend in the crop yield in the developing countries (included Turkey) (Anonymous, 2017). In this study, it is aimed to estimate the effects of different climate change scenarios on sunflower yield productivity in the future periods with using DSSAT crop simulation model.

Materials and Methods

The CSM-CROPGRO-Sunflower model of DSSAT4.7 was used in this study (Hoogenboom et al., 2019). The soil, weather, field management and crop parameters data were obtained from an experiment that was conducted in the Konya region during 2015 and 2016 (Gunduz et al., 2018). Two different treatments, including rainfed and irrigated treatments, were used for model analysis. Daily climate projections dataset of 3 Global Climate Models, including HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M, based on RCP4.5 and RCP8.5 scenarios provided by Turkish State Meteorological Service. The CSM-CROPGRO-Sunflower model was calibrated and evaluated with using observed and measured values in 2015 and 2016. For the climate change impact assessment, 3 different periods including 2019-2040, 2041-2070 and 2071-2098, were used.

Results and Discussion

The CSM-CROPGRO-Sunflower model was calibrated and evaluated with data of 2015 and 2016. It is achieved good yield simulations results for first year both rainfed and irrigated and second year irrigated treatments respectively relative error (RE) with 0.08 %, 1.40 %, -1.05 %. We could not obtain perfect yield simulation RE 28.07 % for second year rainfed treatment. Phenological stages were calibrated as perfectly. According to the obtained results, it is expected that sunflower yield decreases between 19-31 % based on RCP4.5 and decreases between 3-36 % based on RCP8.5 under rainfed conditions during the period of 2019-2040. According to the analysis results of irrigated treatment, it is expected that increases between 11-13 % based on RCP4.5 and increases between 7-13 % based on RCP8.5 during the period of 2019-2040.

Conclusions

Sunflower can be grown under rainfed conditions but according the analysis of impacts of climate change, yield is expected to decrease under rainfed conditions in Konya-Turkey. On the other hand, according to the analysis results; if irrigated agriculture method is applied, it is possible to adaptation of expecting climate conditions.

Acknowledgements

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Parameter	YIELD CHANGES (%)											
Treatment	Rainfed						Irrigated					
Scenario	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
GCM	HadGEM	GFDL	MPI	HadGEM	GFDL	MPI	HadGEM	GFDL	MPI	HadGEM	GFDL	MPI
2019-2040	-19.3	-23.3	-30.6	-2.9	-23.4	-36.3	10.6	10.6	13.4	12.9	7.4	8.5
2041-2070	-14.6	-31.2	-21.3	-24.2	-25.0	-33.3	23.5	17.5	16.7	33.7	25.4	24.0
2071-2098	-14.8	-19.3	-33.5	-21.4	-39.6	-36.6	28.3	22.9	18.5	54.2	38.5	31.7

Table 1 Sunflower yield changes based on rainfed and irrigated conditions.

Keywords: Sunflower, climate change, agricultural productivity, DSSAT, CSM-CROPGRO.

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S5-P.09

Simulating the two heat-tolerant wheat varieties grown in Sudan using CYGMA global gridded crop model

Iizumi Toshichika[1] (iizumit@affrc.go.jp), Tsubo Mitsuru[2], Ali Babiker Imad-eldin A[3], Tahir Izzat[4], Kurosaki Yasunori[5]

[1] *NARO, Tsukuba, Ibaraki, Japan*; [2] *Arid Land Research Center, Tottori Unive, Tottori, Japan*; [3] *Dry Lands Research Center, Agricultural Research Corporation, Khartoum, Sudan*; [4] *Gezira Research Station, Agricultural Research Corporation, Wad Medani, Sudan*; [5] *Arid Land Research Center, Tottori University, Tottori, Japan*

Introduction

Imports have accounted for a dominant portion of wheat consumption in Sudan (2.5 million tons or 86% in 2018). The population would increase from 33 millions to 80 millions by 2050, requiring national food agencies strengthening the capacity of domestic wheat production to meet increasing demand. However, wheat production in Sudan has suffered from cyclic fluctuation associated with economic factors (e.g., exchange rates reforms). Recent climate change poses an additional burden for production goals. An assessment of production capacity under projected climates is therefore crucial. As the first step, we modified the process-based global gridded crop model CYGMA (Iizumi et al., 2017) to enable it capturing major observed differences in wheat responses to temperature across two heat-tolerant varieties grown in Sudan.

Materials and Methods

Wheat in Sudan is produced by growing spring wheat varieties in colder season (November to March) with irrigated condition. The field experiments conducted at Wad Medani (14.40°N; 33.52°E) reported sowing dates, days from sowing to maturity and yield for two varieties –Debeira and Imam– from 2008/09 to 2017/18 with two replications. In the model, the crop total thermal requirement, the maximum temperature for growth, the fraction of growing season at which flowering occurs, the maximum temperature for yield formation were determined for each variety. The observed sowing dates were used. We assumed the recommended nitrogen application rate of 86 kgN ha-1 yr-1 throughout the simulation period. The bias-corrected 55-year Japanese Reanalysis (JRA-55; Kobayashi et al., 2015) was used as the daily weather inputs.

Results and Discussion

The field experiment data confirmed the general recognition among breeders that Imam is more heat-tolerant than Debeira. The model successfully reproduced this varietal difference. For both varieties, the days from sowing to maturity and yield decreased with temperature increased (Fig. 1 a and c). However, Imam had longer crop duration and higher yield than Debeira under hot condition (the average temperature >26 °C). These varietal differences were well reproduced by the model (Fig. 1 b and d), indicating that the model is acceptable for subsequent analysis. Note however that some discrepancies between the observations and model emerged. Particularly, under hot condition (>27 °C), the observed crop duration of Imam seemed to become insensitive to temperature (Fig. 1a), whereas the modeled one monotonically decreased (Fig. 1b). More observations are necessary to conclude whether the Imam's growth stagnation under high temperatures is robust and the phenology submodel needs be revised.

Conclusions

The crop model is well calibrated to describe the observed differences in wheat responses to temperature and varietal differences. Using the model, potential effects of utilizing these varieties and shifting sowing dates under warming will be examined.

Acknowledgements

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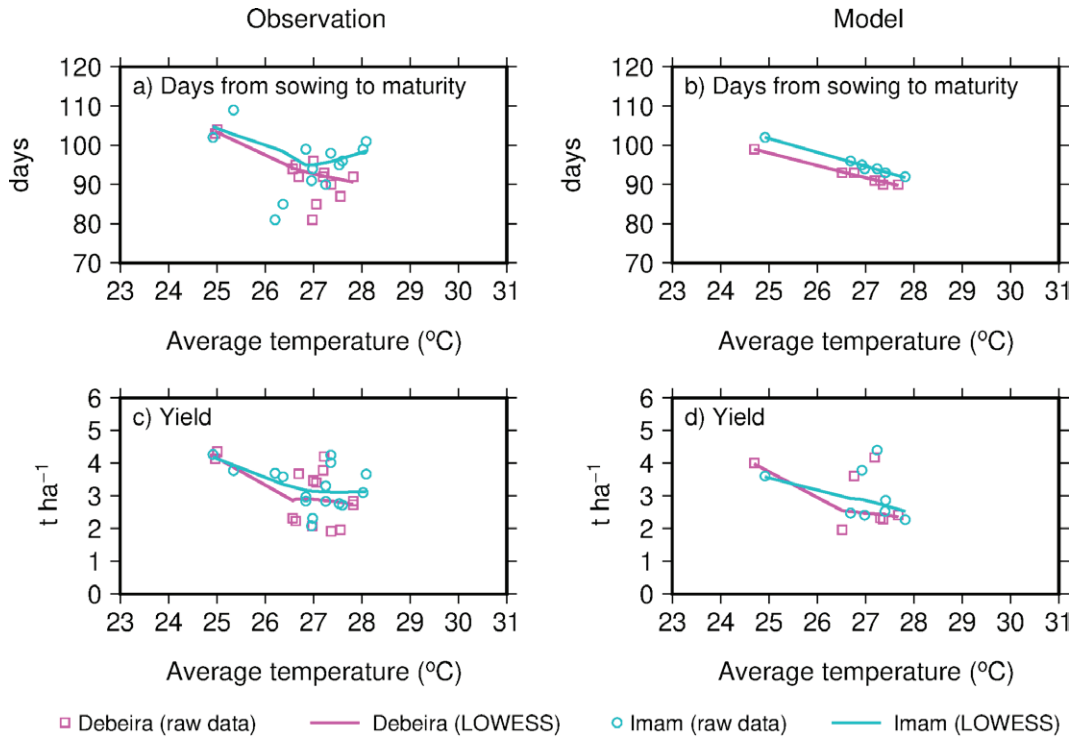

Figure 1. Observed and modeled responses of the two varieties (Debeira and Imam) to growing-season average temperature at Wad Medani. Symbols (squares and circles) indicate individual year-replication samples. Lines indicate the average responses derived using the locally weighted scatterplot smoothing (LOWESS).

Keywords: adaptation, climate change, food security, irrigated wheat, regional crop simulation.

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S5-P.11

A spatial assessment of climate change impacts on the productivity and irrigation requirements of olive orchards

López-Bernal Álvaro[1] (g42lobea@uco.es), Mairech Hanene[2], Moriondo Marco[3], Dibari Camilla[4], Regni Luca[5], Proietti Primo[5], Villalobos Francisco[6], Testi Luca[7]

[1] *University of Cordoba, Córdoba, Spain*; [2] *University of Perugia & IAS-CSIC, Perugia, Italy*; [3] *IBE-CNR, Florence, Italy*; [4] *IBE-CNR & University of Florence, Florence, Italy*; [5] *University of Perugia, Perugia, Italy*; [6] *University of Cordoba & IAS-CSIC, Córdoba, Spain*; [7] *IAS-CSIC, Córdoba, Spain*

Introduction

Covering more than 10 Mha in the countries surrounding the Mediterranean, olive orchards represent a key agricultural system with huge economic and environmental relevance. Climate change scenarios foresee an increase in temperature, a decrease on average annual rainfall and an increase in extreme events over the Mediterranean (IPCC, 2014), which is seen as a major threat for the sustainability of this strategic tree crop. This study assesses the impacts of future climate scenarios on the productivity and irrigation requirements of different types of olive orchards across the main olive-farming regions in the Northern shore of the Mediterranean using the process-based model OliveCan (López-Bernal et al., 2018).

Materials and methods

Meteorological data over olive tree cultivated area in southern Europe were clustered into 22 sub-climates over 1980-2010 applying the High Dimensional Data Clustering approach. Future climate data of CCLM regional circulation model was used. These data were produced according to RCP4.5 and RCP8.5 for two time-slices (2041-2070 and 2071-2100). Simulations were performed for 100 (LD) and 200 trees ha^{-1} (MD) olive orchards under three irrigation treatments: full irrigation (replacing 100 % of the maximum crop evapotranspiration, ET), deficit irrigation (replacing 30 % of maximum crop ET) and rainfed. Results were used to compare the relative variations in yield in relation to the baseline scenario (1980-2010). Similarly, relative changes in irrigation requirements (irrigation supplied in the full irrigation treatments) were compared between scenarios.

Results and discussion

According to our simulations, changes in productivity under future scenarios were cluster-dependent and highly influenced by the irrigation treatment and RCP considered, while little qualitative differences were found between LD and MD orchard typologies. Yield responses to future scenarios in the wettest clusters (in the northern part of the study area) were more positive than those in the driest ones. Under rainfed conditions, the driest clusters exhibited yield reductions of up to 30 % by 2071-2100, whereas slight yield increases were found for the wettest clusters (Figure 1). By contrast, our results showed no yield penalties for the full irrigation treatment irrespective of the cluster, with relative yield increases being quite significant in some cases. Irrigation requirements for maximum productivity only increased by 5-25 % (depending on the cluster and RCP) in the future scenarios in relation to the present. Apparently, the increase in CO_2 considered in the future scenarios resulted in an enhancement of water use efficiency that partly compensated for the negative impacts of higher temperatures, higher reference evapotranspiration (ET_0) and lower rainfall.

Conclusions

Our results suggest that climate change could lead to either lower, neutral or higher productivities in relation to the present, depending on the balance of water supply (rainfall + irrigation), evaporative demand and atmospheric CO_2.

Acknowledgements

The research leading to these results has received funding from Ministerio de Economía y Competitividad (AGL2015-69822) and from ERA-NET FACCE SURPLUS (Grant No: 652615, project OLIVE-MIRACLE), the latter cofunded by INIA (PCIN-2015-259).

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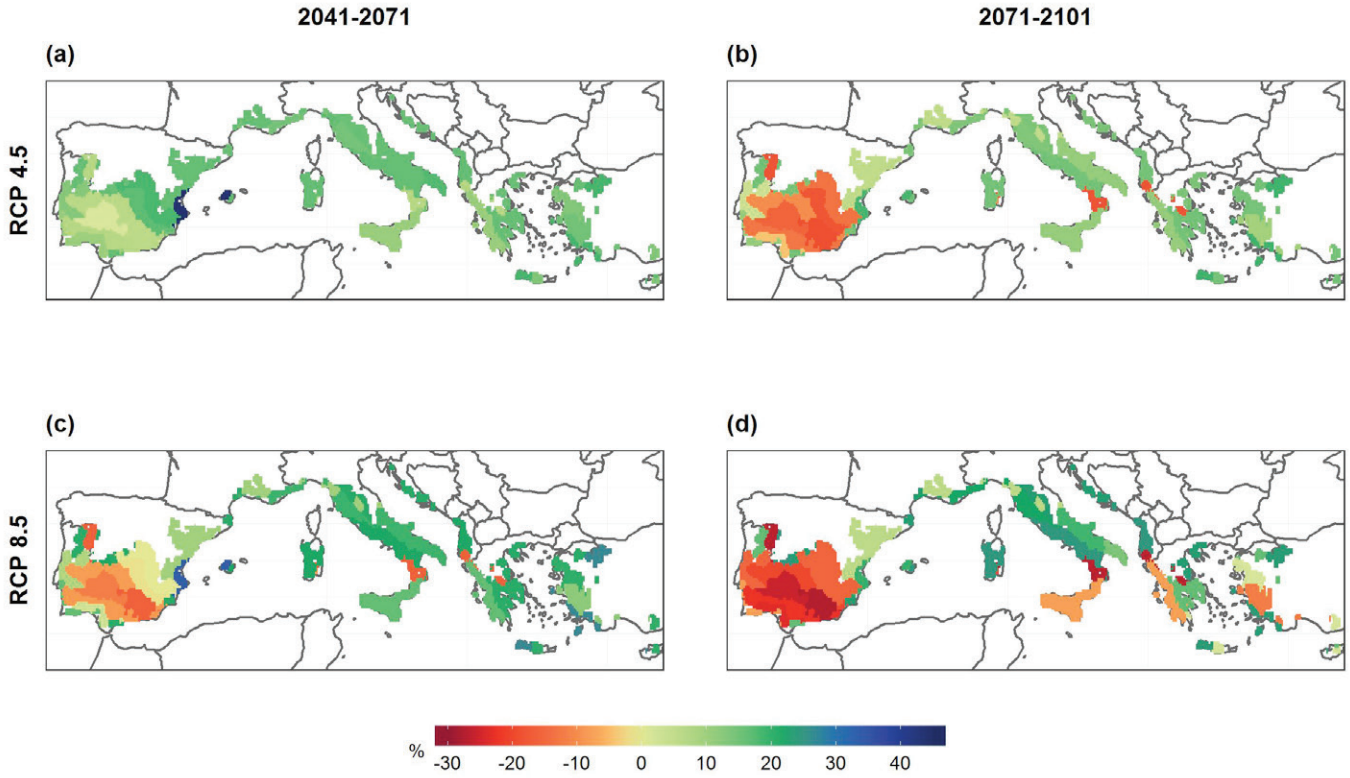

Figure 1. Relative changes in the productivity of the rainfed MD orchard in the future scenarios expressed in percentage (%) in relation to the values in the present scenario

Keywords: Olea europaea L., future climate scenarios, irrigation, Mediterranean basin.

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S5-P.12

AdaptaNuts: A tool for assessing the impact of climate change on almond crop

Lorite Ignacio[1] (ignacioj.lorite@juntadeandalucia.es), Cabezas-Luque José Manuel[2], Ruiz-Ramos Margarita[3], Lovera Maria[2], Espadafor Mónica[2], Gabaldón-Leal Clara[2], Santos Cristina[2], Rodríguez Alfredo[4], Arquero Octavio[2]

[1] *Agriculture and Environment, IFAPA - Junta de Andalucía, Córdoba, Spain*; [2] *IFAPA - Junta de Andalucía, Córdoba, Spain*; [3] *UPM, Madrid, Spain*; [4] *Universidad de Castilla La Mancha, Toledo, Spain*

Introduction

Almond constitutes one of the main woody crops of the Mediterranean basin. Recently a significant expansion to fertile and new productive areas has been identified. This fact and the uncertainty associated to climate change generate the necessity to develop a tool for assessing the behavior of almond crop in those new cultivation areas and under future weather conditions. A tool named AdaptaNuts integrates several models, introducing in this study the phenological module for assessing flowering date under current and future weather conditions (Lorite et al., 2020).

Material and Methods

The current version of AdaptaNuts integrates a module for assessing flowering date based on experimental data (Lorite et al., 2020). This flowering approach is based on the Dynamic and ASYMCUR models, described by Pope et al. (2014). In this methodology, the fulfillment of chilling requirements is one of the critical components for almond flowering. Thus, the lack of chilling could generate flowering failure and severe yield reductions.

The French late-flowering cultivar 'Lauranne', widely cultivated in the Mediterranean basin, was selected for evaluating its behavior in the Iberian Peninsula under current and future weather conditions. Weather data corresponded to the outputs from 5 GCMs under 2 forcing scenarios (RCP4.5 and RCP8.5) for near future (NF) and far future (FF) periods (Fronzek et al. 2019).

Results and Discussion

The combination of AdaptaNuts tool with weather data from an ensemble of 5 climate model outputs allowed to identify those areas affected by low chilling accumulation. Thus, for 'Lauranne' with RCP8.5-FF scenario, the Guadalquivir Valley and the Mediterranean and South Atlantic coast areas, characterized by warm winter temperatures, could be seriously impacted in terms of lower chilling accumulation, with failure in meeting chilling requirements in some areas to the 100% of the years (Figure 1a).

For those areas where correct flowering happened, the flowering date for 'Lauranne' showed advances (in cold regions) or delays (in warm areas) in flowering date, depending on the location/weather conditions provided by RCP8.5-FF scenario (Figure 1b). This date has a high relevance for assessing the impact of climate change on almond, as flowering is the beginning of a critical period for almond when frost damages or unfavorable conditions for pollination may impact on final yield (Lorite et al., 2020).

Conclusions

The combination of a phenological model for almond tree crop based on experimental data with weather data from an ensemble of 5 climate model outputs, allowed identifying the vulnerable regions within the Iberian Peninsula for this crop. Vulnerability was assessed in terms phenological failures induced by climate change.

Acknowledgements

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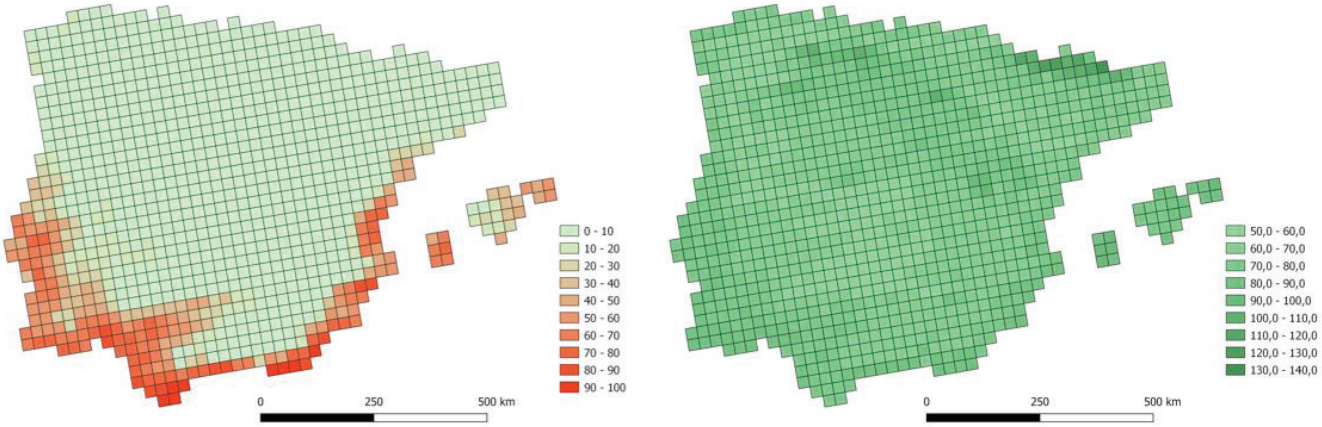

Figure 1. Probability of occurrence of flowering failure due to lack of chilling requirements (a) and flowering date (b) for 'Lauranne' under weather conditions provided by RCP8.5-FF scenario

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S5-P.13

Comprehensive global climate impact assessment for crop yields

Müller Christoph[1] (cmueller@pik-potsdam.de), Franke James[2], Jägermeyr Jonas[3], Ruane Alex C.[3], Elliott Joshua[2], Moyer Elisabeth[2], GGCMI Team[4]

[1] *Potsdam Institute for Climate Impact Res, Potsdam, Ger*; [2] *University of Chicago, Chicago, United States*; [3] *NASA, New York, United States*; [4] *various, various, various*

Introduction

Climate change impacts on agriculture are subject to large uncertainties from a variety of sources. One of the most important sources of uncertainty is the uncertainty in the realization of climate change itself. In the absence of clear climate mitigation strategies and substantial uncertainties on population growth, economic development, technology and lifestyles, a very broad set of greenhouse gas emission scenarios has been developed to inform climate modeling. Climate models often differ in the spatial patterns of projected changes in particular with respect to changes in precipitation. The upcoming new set of climate projections from the Coupled Model Intercomparison Project (CMIP6) is set up to more comprehensive than ever, providing a broad range of future climate change projections.

Materials and Methods

Crop models are often applied at selected sites or with global coverage, as in the Global Gridded Crop Model Intercomparison (GGCMI) of the Agricultural Model Intercomparison and Improvement Project (AgMIP). Global crop model applications have been shown to have some skill, but also add additional uncertainty, given that many processes cannot be calibrated properly for the lack of suitable reference data and because management information is largely absent (Müller et al., 2017).

However, already the computational power required to compute the comprehensive set of climate projections prohibits such applications. Instead, typically, small and largely random selections of climate scenarios are used to project impacts, such as agricultural crop yields. McSweeney and Jones (2016) find that a selection of 5 climate models as often applied, is insufficient to cover the range of projections in all regions.

Results and Discussion

Here we present initial results of a comprehensive global climate impact assessment for crop yields that explores the full range of the CMIP6 climate projection archive. For this, we use a set of 9 global gridded crop model emulators (Franke et al., 2019b) that were trained on a very large systematic input sensitivity analysis with up to 1404 global-coverage, 31-year simulation data sets per crop and crop model (Franke et al., 2019a). The training domain includes variations in atmospheric carbon dioxide (CO_2) concentrations (4 levels from 360 ppm to 810 ppm), air temperature (7 levels from -1 to +6°C), water supply (8 levels from -50 to +30% and full irrigation), nitrogen fertilization (3 levels from 10 to 200 kgN/ha) and adaptation (2 levels: none and regained growing seasons) and thus represents an unprecedented rich data base for emulator training. The emulators, in form of grid-cell specific regression models with 27 coefficients, are computationally light-weight and can thus be applied to the full CMIP6 data archive.

Conclusions

We here present first results from this analysis, breaking down the different sources of uncertainty (emission concentration pathways, climate model, crop model). Results will help to interpret crop model simulations in general: the unstructured reduction of the uncertainty space from selecting a small number of climate scenarios by e.g. first availability and/or individual crop models has so far hampered to quantify the uncertainty in crop model projections.

Acknowledgements

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Keywords: emulator, global, uncertainty, climate change, AgMIP.

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S5-P.14

High Yield Regions Move Poleward Less Than Expected Under Climate Change in Globally-Gridded Crop Simulation

Franke James[1] (jfranke@uchicago.edu), Müller Christoph[2], Josua Elliott[3], Jonas Jägermeyr[4], Alex C. Ruane[4], Elizabeth Moyer[1]

[1] *Department of the Geophysical Sciences, University of Chicago, Chicago, United States*; [2] *Institute for Climate Impact Research, Potsdam, Germany*; [3] *Department of Computer Science, University of Chicago, Chicago, United States*; [4] *Goddard Institute for Space Studies, NASA, New York, United States*

Introduction

Crop yields on currently cultivated land are projected to decline under climate change as conditions shift away from optimal. It has been assumed that some of these losses can be recovered by shifting areas of cultivation, i.e. that «breadbasket» zones may move polewards. While changes in temperature and precipitation distributions will reduce agricultural favorability in some areas, they may increase it in others, leading to shifting spatial patterns of optimum yield. The recent Global Gridded Crop Model Intercomparison (GGCMI) Phase II experiment under AgMIP allows testing for geographic shifts in maximum yield regions under possible future climate states, for all major grains and soybeans.

Materials and Methods

We employ nine state-of-the-art, globally gridded at 0.5o, **process-based crop models** for maize, rice, wheat, and soybeans (pDSSAT, JULES, LPJmL, PEPIC, PROMET, EPIC-TAMU, LPJ-GUESS, CARAIB, GEPIC). Models are run over a wide range of climate and management conditions resulting in 12 billion simulated yields. We compare historical (1980-2010) emulated yields to those at the end of century (2070-2100) under high-end climate change (RCP 8.5) or artificially applied warming up to 6 K. CO_2 effects are held fixed in this analysis and no dynamic nitrogen inputs are considered (where applicable: 200 kg ha-1).

Results and Discussion

While most GGCMI Phase II models show some previously uncultivatable land at high latitudes becoming viable for agriculture, in all models the peak yield centers barely shift. Max yields found in the corn belt in North America disappear by 2100 under warming (RCP-8.5) and are not replaced in other locations in northern latitudes. For example, by 2100 the center of the North American maize belt moves only 80 km poleward in the mutli-model mean, less than 10% of the distance required to maintain constant mean growing-season temperatures. As a result, mean growing-season temperatures increase by 5 K, and the zone of highest potential yield shrinks while remaining relatively fixed in location (Figure 1). This stasis may be the result of other latitudinally-varying factors that affect crop yields, such as seasonality or solar insolation. Although yield losses can be mitigated somewhat by adaptations that allow crops to maintain growing season length under warming, cultivar adaptations also do not significantly shift optimum yield zones.

Conclusion

Globally-gridded crop models therefore robustly concur that climate-driven production losses cannot be offset via a shift in cultivation areas.

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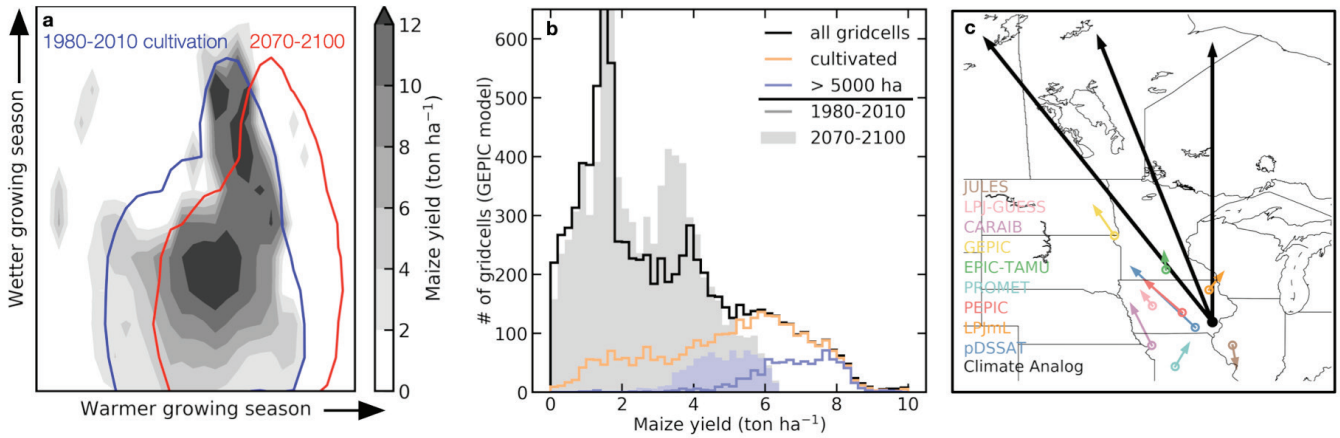

Figure 1: (a) Current North American maize yield heatmap by growing season temperature and precipitation from the GGCMI model ensemble median. Cultivation contour today and at the end of the century if cultivation does not shift. (b) Maize yields in the GEPIC model. Under warming, all of the highest yields --those in the corn-belt-- are lost. The distribution in yields across all simulated area contracts under warming. (c) Shifting yield patterns lag behind the poleward temperature shift. In the US midwest, constant growing season temperatures at the centroid of current cultivation moves poleward at a rate of nearly 200 km/K (HADGEM2-ES model), while peak yields move north 10x slower or not at all.

Keywords: AgMIP, GGCMI, climate change, breadbasket, emulation.

S5-P.15

Impact of climate change on irrigated maize production in Mexican subtropical conditions

Noriega José Luis[1] (luisnoriegan@hotmail.com), Salazar Raquel[1], López Irineo L[1], Burgueño Juan Andrés[2], Dhliwayo Thanda|[3], Petroli César Daniel[4]

[1] *IAUIA, Universidad Autónoma Chapingo, Texcoco, Estado de México, México*; [2] *BSU, CIMMYT, Texcoco, Estado de México, México*; [3] *CIMMYT, Texcoco, Estado de México, México*; [4] *SAGA, CIMMYT, Texcoco, Estado de México, México*

Introduction

Maize cultivation, the main crop in Mexico, is likely to decrease yields and reduce grain quality due to the negative effects of global climate change, as it is the main cause of changes in normal weather conditions, which have a direct effect on maize. To estimate yield in climate change scenarios, various mechanistic models of growth and yield simulation have been implemented, such as CERES Maize incorporated into the DSSAT (Decision Support System for Agrotechnology Transfer -DSSAT-) model. The objective was to estimate the impact of climate change on maize production in the subtropical region of Morelos, Mexico.

Materials and Methods

To achieve this, the DSSAT v 4.7.5 model was implemented to simulate the effects of climate change in 27 white maize hybrids planted in the Spring-Summer 2018 cycle under irrigation conditions in the experimental station of the International Maize and Wheat Improvement Center (CIMMYT) in Tlaltizapan, Morelos. Data were used with the physical, chemical and morphological properties of the soil at different depth levels. Data from the experimental field (1983-2013) was used as base climatology, and were coupled by means of the REA (Reliability Ensemble Averaging) weighted assembly to develop the near (2015-2039), medium (2045-2069) and distant (2075-2099) horizon in the scenarios of low emissions RCP 4.5 and high emissions RCP 8.5. Calibration was performed using the Bayesian GLUE method and sensitivity analysis.

Results and Discussion

For white maize hybrids, the average yield for the baseline was 11.174 kg ha-1. In the RCP 4.5 scenario, yield in the short, medium and distant horizons decreased by 2.14%, 5.09% and 1.78%, while for the RCP 8.5 scenario, yield decreased by 13.75%, 28.16% and 33.97%. Growth variables such as days to anthesis (DA) and days to physiological maturity (DPM) reduced in all the horizons of the scenario of high emissions RCP 8.5, which reduced the time of permanence of the crop in field, reason to which can be attributed the negative effect in the accumulation of dry matter (DM) and, consequently, in the decrease of the yield. With the information obtained by means of the simulation, it is possible to establish diverse measures of adaptation to the cultural practices in the cultivation of maize, with the objective to reduce to the minimum the negative effects of the climatic change in the production of maize in Mexico.

Conclusions

In a low emission scenario (RCP 4.5), corn production is expected to decrease by 2.14% in the near horizon. In the high emissions scenario (RCP 8.5), it is estimated that the reduction will reach a decrease of 33.97% in the same period.

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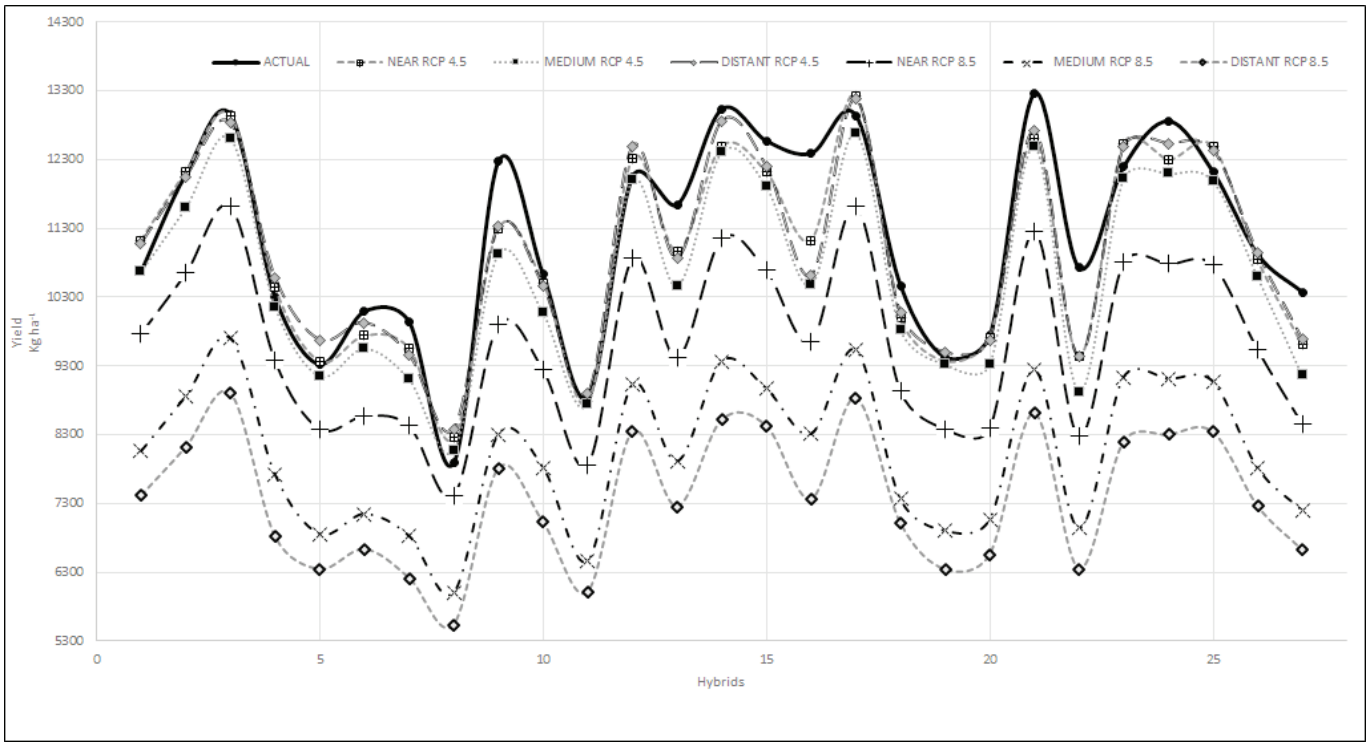

Maize yield under climate change scenarios in Mexico.

Keywords: Zea mays, DSSAT, RCP, REA, Modelling yield and growth.

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S5-P.16

CROPGRO-Tomato model for simulating impact of compound climate events on tomato grown

Potopová Vera (potop@af.czu.cz), Tűrkott Luboš, Muntean Nina, Možný Martin

Agroecology and crop production, Czech University of Life Sciences Prague, Prague, Czech Republic

Introduction

Compound climate events (CEs) have a huge impact on yield, speed of ripening and the presence of vitamins in the grown product. Modelling the interactions between a number of competing events is much more complex than modelling the drivers of individual events (Zscheischler et al., 2017). Dynamic crop simulation models can be useful tool to simulate the wide-ranging effects of CEs on vegetables production where impacts depend on multiple dependent weather-soil variables and crop management. The crop models calculate expected growth and development based on equations that describe how a crop, as a community of plants, responds to soil and weather conditions (Hoogenboom et al., 2010). Tomato has been a pioneer vegetable species for crop modelling. Theoretical and experimental researches on the use of CROPGRO to predict vegetables growth using the example of tomato (*Solanum lycopersicum* L.) have been carried out.

Materials and Methods

This paper focuses on the modelling the impact of CEs on the growth, development and yield of the hybrid field tomato variety LSL Thomas F1 on the locality Prague Suchdol using the BBCH phenological phases and growth analytical characteristics (RGR: Relative Growth Rate, LAI: Leaf Area Index) during the period 2014 - 2018. We used two compound climate extreme joint modes: Tmax85/P35 and Tmax85/P85, indicating combinations of extreme hot-dry and hot-wet events for the 1961-2018, respectively. The sampling plants were collected once in 14 days for analysing basic physiological parameters. Results of the weekly phenology (%) were calculated as a ratio between the number of plants occurrences in each phenological stages and the total number of plants counted in a given field. LAI was determined by the semi-empirical method, and this was followed by an infrared image analysis. Parameters affecting leaf growth, dry biomass production, and dry biomass of leaves, stem, and generative organs from planting to harvest were calibrated against the measured data.

Results and Discussion

The cold and wet events during the tomato growing season of 2014 led to high BBCH phase variability, low LAImax 0.5075 $m^2.m^{-2}$ and a low yield of 22.2 $t.ha^{-1}$. A beneficial effect of hot and dry events on the tomato fruit was noted during the entire growing period of 2018 (Fig. 1). The CEs in 2018, in comparison to the other years of the study, led to the formation of significantly more LAImax 4.1334 $m^2.m^{-2}$ and yield of 72.1 $t.ha^{-1}$. According to Scholberg et al. (1997), tomatoes growing in open field reached a maximum LAI equal to 3.8 in about 11 weeks after transplanting. However, experimental results show that fruit formation in the tomato cultivar decreases as both extreme temperature and drought frequency increase (Potopová et al., 2016). Drought-heat stress during fruit formation reduces the yield by 30% (each 1°C above 28°C reduced the yield by 10%).

Conclusions

The leaf area development was compared, and although the modelled values were higher than the measured values, they were still within a reasonable range. The model fitted the observed LAI data with an average RMSE of 0.89.

Acknowledgements

MZe NAZV: QK1910269 „Adaptation potential of common wheat in response to drought and extreme temperatures“. COST Action CA17109 “Understanding and modeling compound climate and weather events.

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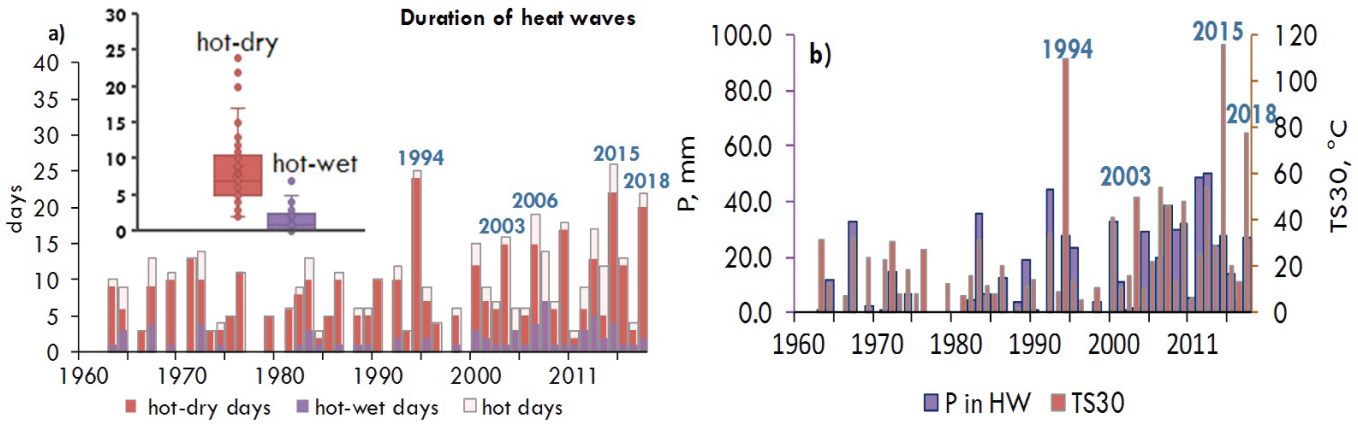

years	RGR, g g^{-1} day^{-1}	LAI$_{max}$, m^2 m^{-2}	LAI$_{max}$, day	Yield, t ha^{-1}	HD/DD, days	TS30, °C	DH/HW days
2014	1.94	0.5075	254.	22.2	13/67	28.4	5/2
2015	3.51	1.4831	257.	49.0	30/85	115.8	22/4
2016	4.71	1.7846	251.	41.7	13/70	20.3	12/1
2017	5.00	2.5393	221.	69.8	14/79	12.8	3/1
2018	4.26	4.1334	241.	72.1	33/96	77.1	20/1

Figure 1. The frequency of hot days, hot-dry and hot-wet days in the heat waves. Analysis of RGR, LAI and CEs (hot days [HD], heat stress index [TS30], dry days [DD], dry-hot/hot-wet days [DH/HW]) from transplanting to harvest of Thomas.

Keywords: crop growth model, DSSAT, heat waves, hot-dry, hot-wet.

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S5-P.17

Chilling accumulation in fruit trees for evaluating their viability in Spain under climate change

Rodriguez Alfredo (alfre2ky@gmail.com), Pérez-López David, Centeno Ana, Ruiz-Ramos Margarita

CEIGRAM, Universidad Politécnica de Madrid, Madrid, Spain

Introduction

Fruit trees are vulnerable to cold temperatures. They enter a dormancy state during the coldest time of the year to avoid damages. Then, an amount of chilling accumulation, different among varieties, should be accumulated to break the dormancy. In this way, fruit trees synchronise with environmental factors and can tolerate cold temperatures. In a global warming context, the chilling accumulation fulfilment for some tree crops and varieties in some regions could be compromised. Spain is one of the largest producers of fruits in Europe, being fruit trees an important source of income for farmers and representing a significant part of the national economy. Therefore, high confidence projections about the viability of the main fruit trees are needed.

Materials and Methods

Four models were used to estimate chilling accumulation: the Dynamic model (Fishman et al., 1987), the Utah model (Richardson et al., 1974) and two of its later modifications. As input, they use hourly temperatures. These were derived from the daily temperatures for peninsular Spain and Balearic Islands from an ensemble of 10 models from the CORDEX EUR-11 RCM simulations. Two RCP scenarios (RCP4.5 and RCP8.5) were considered. Temperatures from the RCM models were bias-adjusted using the Spain02 dataset, validation of the bias-adjusted temperature was done against observations. After literature revision of chilling requirements of different varieties of the main fruit tree crops in Spain, chilling requirements levels (low, medium and high) were defined for each crop. Finally, for each chill model, chilling accumulation projections for near and far future were calculated (see Rodríguez et al., 2019a) and then the EOA index (Rodríguez et al., 2019b) was applied to them for calculating the regions were chilling requirements would guarantee a Safe Winter Chill (SWC, Luedeling et al., 2009) with high confidence, allowing a viable production. Also, the EOA level of having a SWC for representative varieties of each crop in the most productive locations was calculated.

Results and Discussion

A future reduction of the SWC for representative varieties of the considered fruit tree crops is projected over the studied region. It will affect more harshly to the South-West of Spain, the Tagus and Ebro valleys and the Mediterranean coastal areas. A high confidence SWC is expected at the most productive location for most varieties for almost all the considered crops in the future under RCP4.5. Under RCP8.5, the number of viable varieties is reduced, with popular varieties threatened. This works evidences that 1) local adaptation will be needed; 2) adaptation is possible. The application of mitigation measures is essential to avoid the RCP8.5 or similar scenarios to contain the negative impact over crop production and food security.

Conclusions

Remarkable differences in terms of viability were found between RCP4.5 and RCP8.5. Varieties with low chilling requirements would be still viable in the future under an RCP4.5 scenario, but they may not reach SWC in some of the largest production areas under RCP8.5. At the locations with the largest production in Spain, almond, apple and plum would be the most affected crops, being olive, vineyard and cherry the less affected ones. Adaptation through variety change is possible in most locations.

Acknowledgements

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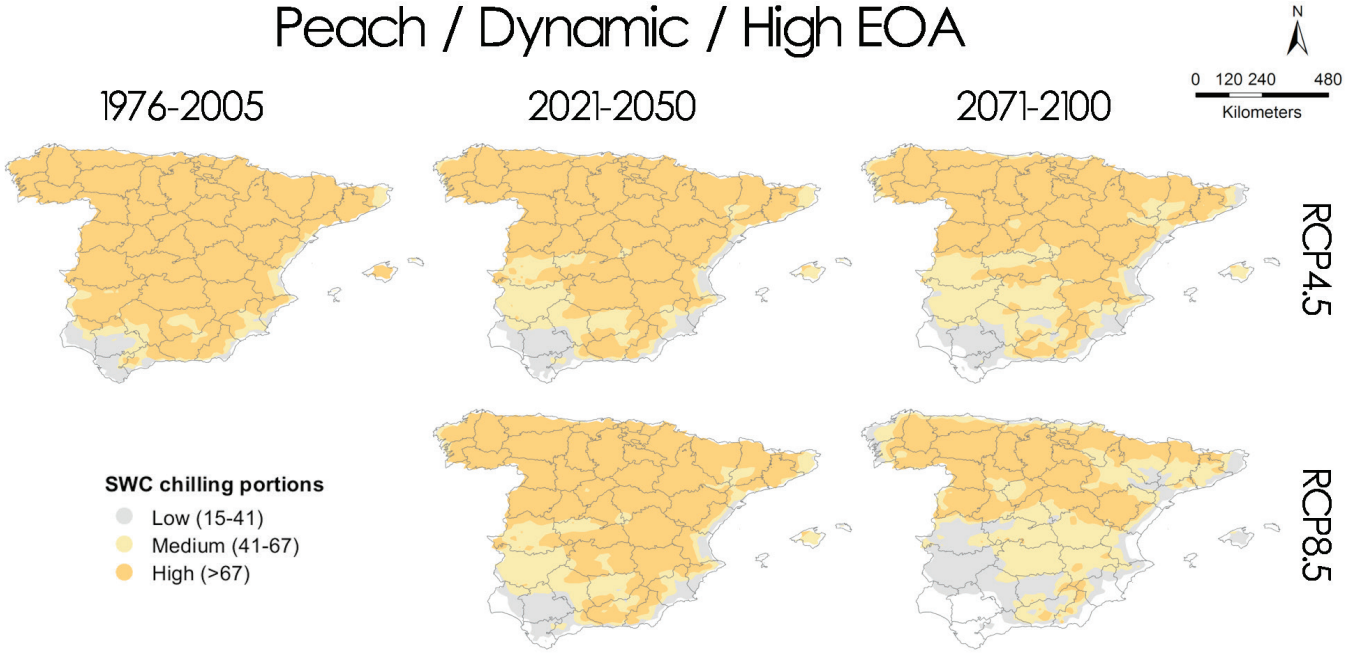

Safe winter chill areas with high confidence (EOA equal or higher than 0.5) for three chilling requirements' ranges limited by thresholds expressed as chilling portions calculated by the Dynamic model. Please notice that gray areas contain yellow ones, which in turn contain the orange ones. Maps were created for the baseline period (1976-2005, first column), near future period (NF, 2021-2050, second column) and far future period (FF, 2071-2100, third column), and for both RCP4.5 (first row) and RCP8.5 (second row). White areas do not present safe winter for peach with high confidence.

Keywords: Chilling requirement, Chill model, Bias adjustment, Ensemble Outcome Agreement, Safe Winter Chill.

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S5-P.18

Influence of climate variability on the forage production of a permanent grassland in the French Massif Central

Gómara Iñigo[1] (i.gomara@upm.es), Bellocchi Gianni[2], Martin Raphaël[2], Rodríguez-Fonseca Belén[3], Ruiz-Ramos Margarita[1]

[1] *Ceigram, Universidad Politécnica de Madrid, Madrid, Spain*; [2] *UMR UREP, INRA, Clermont-Ferrand, France*; [3] *Física de La Tierra y Astrofísica, Universidad Complutense de Madrid, Madrid, Spain*

Introduction

Climate Services (CS) provide support to decision makers across socio-economic sectors. In the agricultural sector, one of the most important CS applications is to provide timely and accurate yield forecasts based on climate prediction.

Materials and Methods

In this study, the Pasture Simulation model (PaSim) was used to simulate, for the period 1959-2015, the forage production of a mown grassland system (Laqueuille, Massif Central of France) under different management conditions, with meteorological inputs extracted from the SAFRAN atmospheric database. The aim was to generate purely climate-dependent timeseries of optimal forage production, a variable that was maximized by brighter and warmer weather conditions at the grassland.

Results and Discussion

A long-term increase was observed in simulated forage yield, with the 1995-2015 average being 29% higher than the 1959-1979 average. Such increase seems consistent with observed rising trends in temperature and CO_2 and multi-decadal changes in incident solar radiation. At interannual timescales, sea surface temperature anomalies of the Mediterranean (MED), Tropical North Atlantic (TNA), equatorial Pacific (El Niño Southern Oscillation) and the North Atlantic Oscillation (NAO) index were found robustly correlated with annual forage yield values. Relying only on climatic predictors, we developed a stepwise statistical multi-regression model with leave-one-out cross-validation. Under specific management conditions (e.g., three annual cuts) and from one to five months in advance, the generated model successfully provided a p-value<0.01 in correlation (t test), a root mean square error percentage (%RMSE) of 14.6% and a 71.43% hit rate predicting above/below average years in terms of forage yield collection.

Conclusions

This is the first modelling study on the possible role of large-scale oceanic–atmospheric teleconnections in driving forage production in Europe (Gómara et al., 2019). As such, it provides a useful springboard to implement a grassland seasonal forecasting system in this continent.

Acknowledgements

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Grassland site of Laqueuille. French Massif Central. Source: INRA.

Keywords: climate variability, grasslands, forage production, seasonal forecasts, climate services.

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S5-P.19

Modeling of the production of Mediterranean natural grassland facing climate change scenarios

Toro-Mujica Paula (paula.toro@uoh.cl)

Institute of Agricultural and Veterinary, Universidad de O›Higgins, San Fernando, San Fernando, Chile

Introduction

In the semi-arid zone of Central Chile exists large areas of natural grassland that are used through direct grazing by cattle, sheep, and goats. The climate projections associated with the greenhouse effect indicate that the precipitation will show more significant interannual variability along with a tendency to decline (Rojas *et al*., 2019), affecting the pattern of grasslands growth. Thus, with the aim of evaluating the effect of climate change on the production of grasslands in the central zone of Chile, simulations of the natural grassland growth rate were carried out in climatic scenarios.

Materials and Methods

Central Chile extends between latitudes 32° S and 36° S. The average annual temperature is 13.5 °C, with the warmest month averaging 20.5 °C and the coolest 7.3 °C. The grasslands in this area are commonly naturalized or natural annuals with a growing season that usually begins in April and ends in December (Ovalle and Squella, 1996). The grassland growth simulation model proposed by Castellaro and Squella (2006) and adapted by Toro-Mujica *et al*., (2016) was used to estimate the monthly growth rates of the natural grasslands. To obtain climatic data, the climate simulation visualization platform developed by the Centro de Ciencia del Clima y la Resiliencia was used (CR2, 2018). The information obtained corresponded to monthly average data of the following variables: precipitation, mean temperature, minimum temperature, maximum temperature, zonal and southern wind speed, and relative humidity. Three climatic scenarios were evaluated, an average past scenario (1985-2005) and two representative concentration paths scenarios (RCP 2.6 and RCP 8.0). In the representative concentration paths scenarios two periods were evaluated: a near future (2020-2044) and a distance future (2045-2069). Two evaluation points were selected within the study area, both with 34°24’5” latitude South and 71°29’58” and 71°54’22” longitude West, to represent the coastal and interior drylands, respectively (Z1 and Z2). In order to include randomness to the model and thus statistically compare the results obtained, a random component was included to the monthly average rainfall obtained in each simulated scenario, using the random () and inv.lognorm () functions available in Excel. For each simulated scenario 50 repetitions were performed.

Results and Discussion

A decrease close to 15% in total precipitation was appreciated when comparing the RCP8.5 scenario (2045-2069) with the past scenario (1985 to 2005) in both zones (Z1 and Z2). In mean temperatures, an average increase of 1.8°C and 1.7°C was observed for zones 1 and 2, respectively. Changes in total precipitation and temperatures conditioned total natural grassland production. Figure 1 shows the growth rates for Zone 1 obtained for the past scenario and scenarios RCP2.6 and RCP8.0 (2045-2069). In both scenarios of climate change, there is a significant decrease ($p < 0.01$) in the growth rate in each month within the growing season. Additionally, it is observed that in scenario RCP8.5 the onset of growth was delayed until May.

Conclusions

Changes in precipitation and temperature patterns will affect the production of natural grassland in the central zone of Chile, with a marked trend towards the decrease in production. The RCP2.6 scenario to a distance future would influence grasslands productivity, while an RCP8.0 scenario to a distance future would also delay the growing season.

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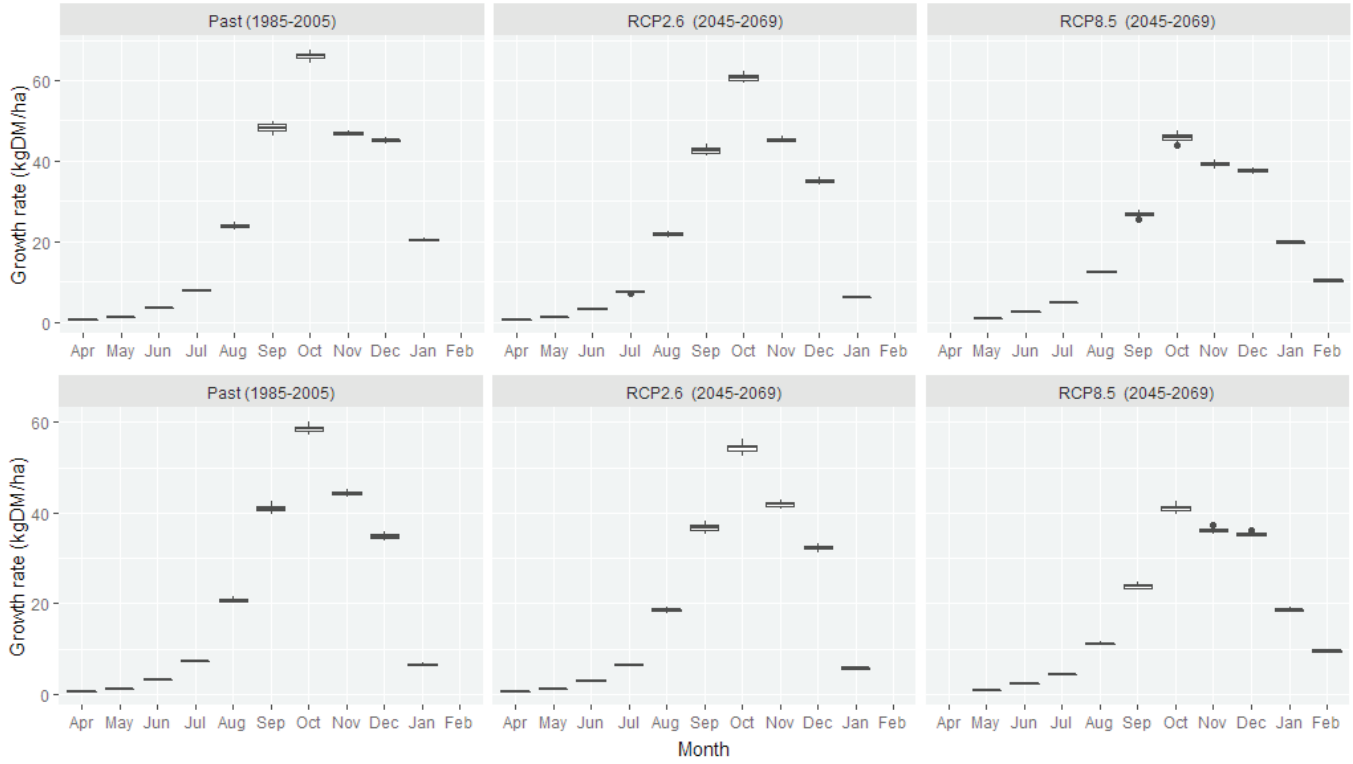

Figure 1. Growth rate of Mediterranean natural grassland in three climatic scenarios.

Keywords: Grassland, model, climate change.

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S5-P.20

Model-assisted evaluation of yield stability in wheat

Wang Tien-Cheng[1] (tien.wang@gem.uni-hannover.de), Chen Tsu-Wei[1], Stützel Hartmut[1], Casadebaig Pierre[2]

[1] *Leibniz Universität Hannover, Hannover, Germany*; [2] *Institut national de la recherche agron, Castanet-Tolosan, France*

Introduction

Discovering crop variety with stable and high yield performance across different environments is crucial for crop production, especially under the extreme climatic regimes. However, it is difficult to test thousands of genotypes in multiple environments. So we use crop model to analyze the relationships between physiological, phenological and yield-related traits, environmental scenario and stability indices of wheat.

Materials und Methods

APSIM-Wheat model was used to simulate 9100 virtual genotypes grown under 9000 environmental scenarios (4 sites × 125 years, management practices 3 sowing dates × 3 nitrogen fertilization levels and two CO_2 levels, Casadebaig et al., 2016). This dataset was processed by a self-developed R package "toolStability", which calculates 11 stability indices. In order to observe the impact of environments on the stability of trait, stability of a genotype under different environmental scenarios was calculated and normalized for further comparison.

Results and Discussion

Relationship of trait and different stability indices enable the screening of stable and high trait performance indices. Significantly and negatively correlation coefficient was found between genotypic superiority measure index and multiple traits, including flowering time (-0.84), grain number (-0.8), grain protein (-0.98), biomass (- 0.75), and yield (-0.61). Dependency of stability indices on environment was clear across environments. Among them environmental scenarios, "site" and "nitrogen" had the strongest impact on both distributions of trait and stability indices.

Conclusions

Stability index of crop trait depend on the classification of environments. Among all stability indices, genotypic superiority measure was found to be highly and negatively correlated with wheat yield component and yield, which is a potential tool for selecting the high yield and stable genotypes. Variance of stability indices across environmental groups may be used as a novel indicator of the impact of environments on stability of specific trait.

Acknowledgements

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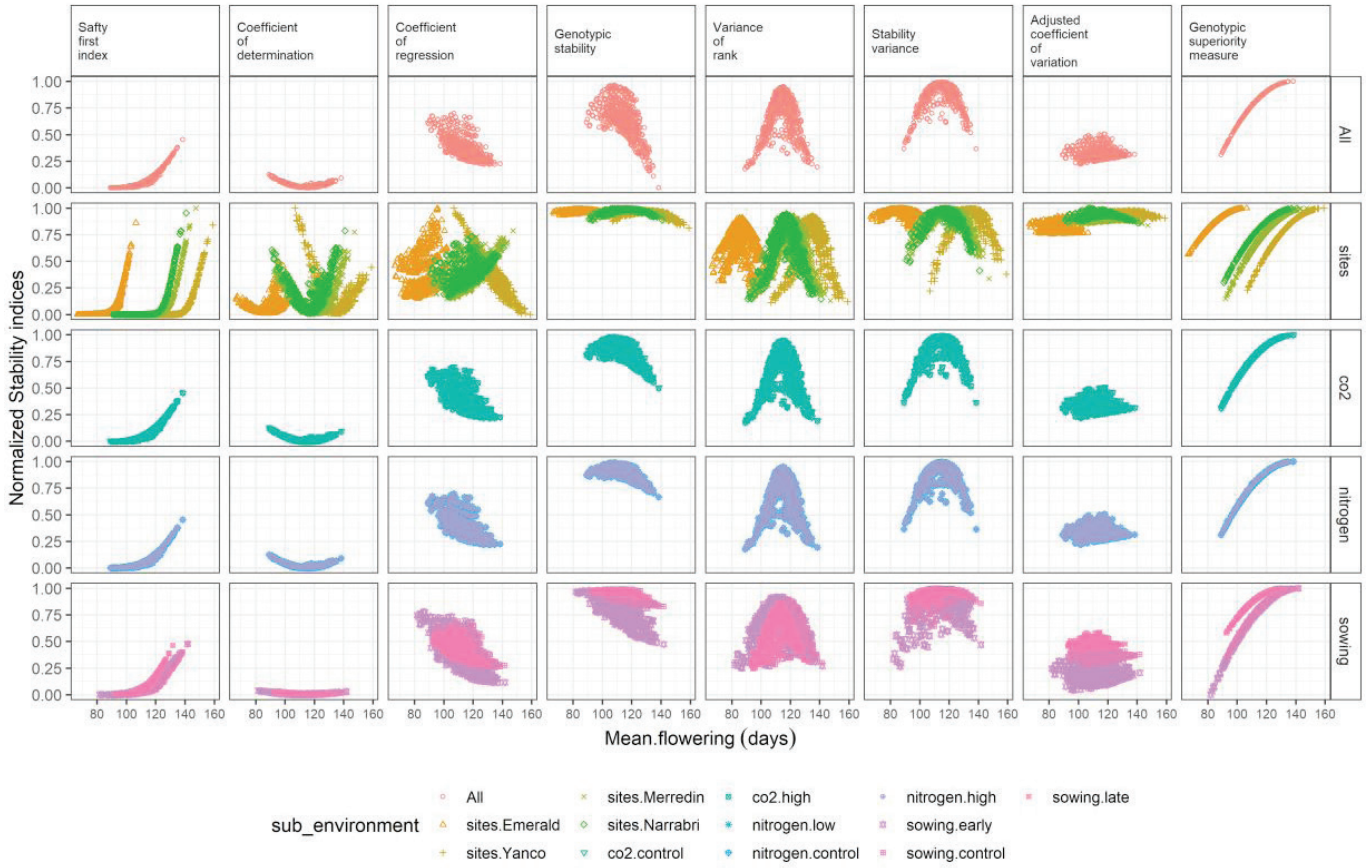

Figure 1. Scatterplot of normalized stability indices and flowering days across different environmental groups.

Keywords: Stability-indices, R-package, APSIM.

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S5-P.21

Impact of regional climate model input and soil map resolution on projected winter wheat production in SW Germany

Gayler Sebastian (sebastian.gayler@uni-hohenheim.de), Bajracharya Rajina, Weber Tobias, Streck Thilo

Institute of Soil Science, Biogeophysics, University of Hohenheim, Stuttgart, Germany

Agricultural ecosystem models, driven by climate projections and fed with soil information and plausible management scenarios are frequently used tools to predict future developments in agricultural landscapes. For performing simulations on the regional scale, the required soil parameters must typically be derived from soil maps that are available in different spatial resolutions, ranging from grid cell sizes of 50m up to 1km and more. The typical spatial resolution of regional climate projections is currently around 12km. Given the small-scale heterogeneity in soil properties, using the most accurate soil representation could be of importance for high quality predictions of crop growth. However, simulation with very highly resolved soil data requires greater computing time and a higher effort for data organization and storage. Moreover, the higher resolution may not necessarily lead to better simulations due to redundant information of the land surface. In addition, it could be that the impact of climate forcing dominates over the effect of different soil properties. This leads to the question if the use of high-resolution soil data leads to significantly different predictions of future yields and grain protein trends compared to simulations in which soil data is adapted to the resolution of the climate input.

This study investigated the impact of weather and soil input on simulated crop growth in Kraichgau, an intensively used agricultural region in Southwest Germany. For all areas classified as 'arable land' (CLC10), winter wheat growth was simulated over a 44-year period (2006 to 2050) using weather projections from three different regional climate models (http://reklies.hlnug.de) and soil information at two different spatial resolutions. The simulations were performed with the model system Expert-N 5.0 (Priesack, 2006), where the crop model Gecros (Yin and Laar, 2005) was combined with the Richards equation (Hydrus 1D v3.0; Simunek et. al., 1998) and the CN turnover module of the model Daisy (Hansen et al. 2012). Soil hydraulic parameters as well as initial values of soil organic matter pools were estimated from BK50 soil map information on soil texture and soil organic matter content, using pedo-transfer functions (ROSETTA) and SOM pool fractionation following Bruun and Jensen (2002). The coarser soil map is modified from the original soil map (50m x 50m) by selecting only the dominant soil type in a 12km × 12km grid to be representative for that grid cell ('winner-takes-all' approach). The crop model was calibrated with field data of crop phenology, leaf area, biomass, yield and crop nitrogen, which were collected at a research station within the study area between 2009 and 2018.

The predicted increase in temperatures during the growing season correlated with earlier maturity, lower yields and a higher grain protein content. The regional mean values varied by +/- 0.5 t/ha or +/-0.3 percentage points of protein content depending to the climate model used. On the regional scale, the simulated trends (yield decline, protein content increase) remained unchanged using high-resolution or coarse resolution soil data. However, there are strong differences in both the forecasted averages and the distribution of forecasts. The need for a high-resolution soil description is highlighted, as the coarser resolution captures neither the small-scale heterogeneity nor the average of the high-resolution results.

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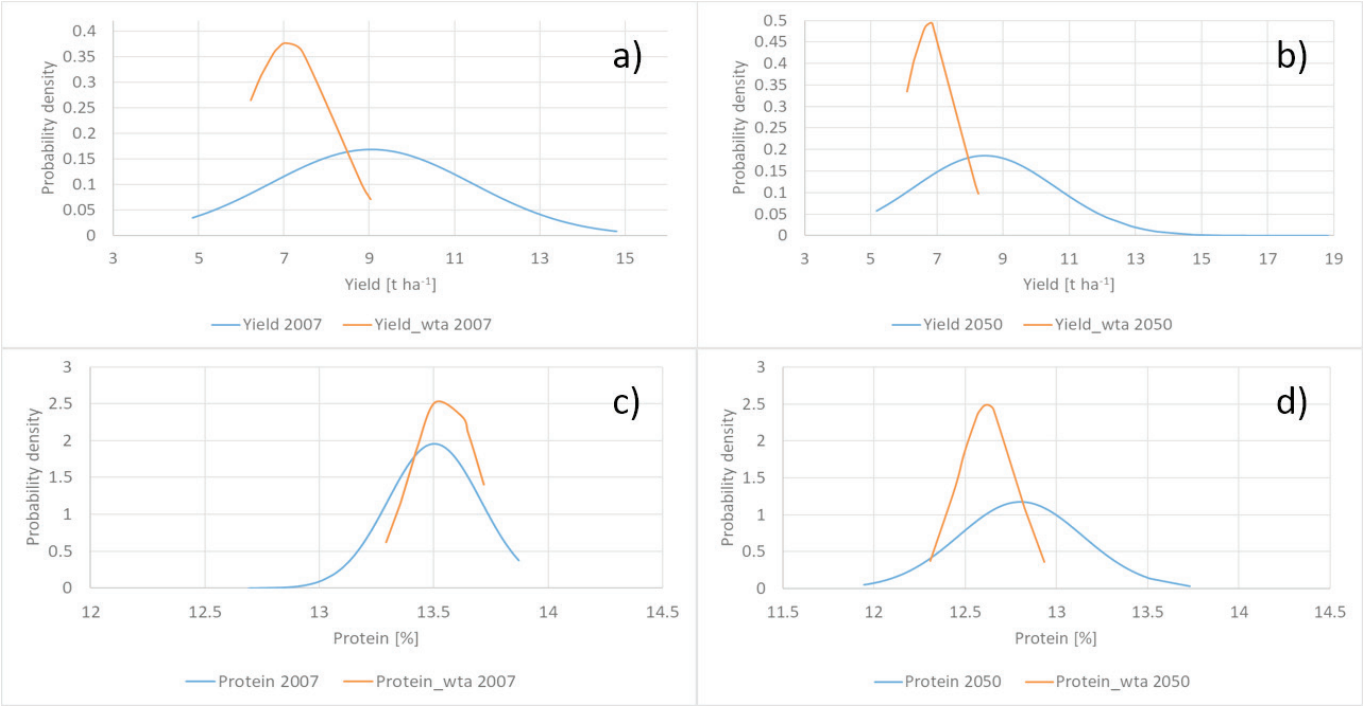

Simulated distributions of winter wheat yields (a, b) and grain protein contents (c, d) in Kraichgau region for 2007 (a, c) and 2050 (b, d) using high resolution soil data (blue lines) and "winner-takes-all" approach 'wta' (orange lines).

Keywords: regional model, yield projection, soil hydraulic parameters, soil oranic matter, climate forcing.

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S5-P.22

Evaluation of maize growing periods in the eastern Free State region, South Africa using DSSAT crop model

Moeletsi Mokhele (moeletsim@arc.agric.za), Tongwane Mphethe

Soil, climate and water campus, Agricultural Research Council, Pretoria, South Africa

Introduction

Agriculture is the one of the main economic activities in the Free State contributing significantly in the production of cereal in South Africa. Climate variability is the main factor that affect crop production in the semi-arid region of the eastern Free State, South Africa (Moeletsi et al. 2011). This calls for studies on the investigation of the effects of climate and agricultural productivity. Many studies deploy crop models to determine how climate variability impact crop production (Challinor et al. 2014). The aim of the study was to investigate the variability of the maize yields using DSSAT crop model for different planting windows.

Materials and Methods

This study was conducted in the Eastern Free State region of South Africa in the vicinity of Bethlehem, Harrismith and Reitz. Climate data (rainfall, temperature and radiation) were obtained from the Agricultural Research Council climate database. The study employed a 30-year daily data from 1980 to 2010. Missing data was patched using the ARC standalone patching program using inverse distance weighting method for rainfall and multiple regression method for the other parameters. Evapotranspiration was estimated using Hargreaves and Samani method. The Decision Support System for Agrotechnology Transfer (DSSAT) software was used to simulate yields for each of the agricultural seasons with varying planting dates. Nine different planting dates were used starting from October for every ten days till December. The PAN6479 cultivar which is considered a medium-late maturing was utilized for all the simulations.

Results and Discussions

Crop yield varied mainly due to the weather conditions prevailed during each of the growing season as shown in figure 1. The main restrictive factor in all the growing periods was drought conditions which had impact on the maize production as shown by dip in yields during seasons of strong El Nino. There were no significant differences of yields in different planting windows but planting in December generally resulted in lower yields. The average ranking of the yield data also show that the last 20 days of December are less suitable for maize production in the eastern Free State. This is mainly due to high vulnerability to frost during those growing periods (Moeletsi and Tongwane, 2016). The simulated yield data did not show high variability with the coefficient of variation ranging from 19% during October planting period to 35% during late December planting. Generally, planting in November yielded high with the average of 2.5 tons per hectare for Bethlehem and Harrismith while Reitz average yields were 2.3 tons per hectare.

Conclusions

DSSAT crop model was used to simulated maize yields for the three areas over the eastern Free State province of South Africa. Maize yields in the eastern Free State varied from year to year as well as from one growing period to another. The best yields were obtained during the November planting dates thus indicating that farmers would be encouraged to plant in these periods to ensure optimum productivity.

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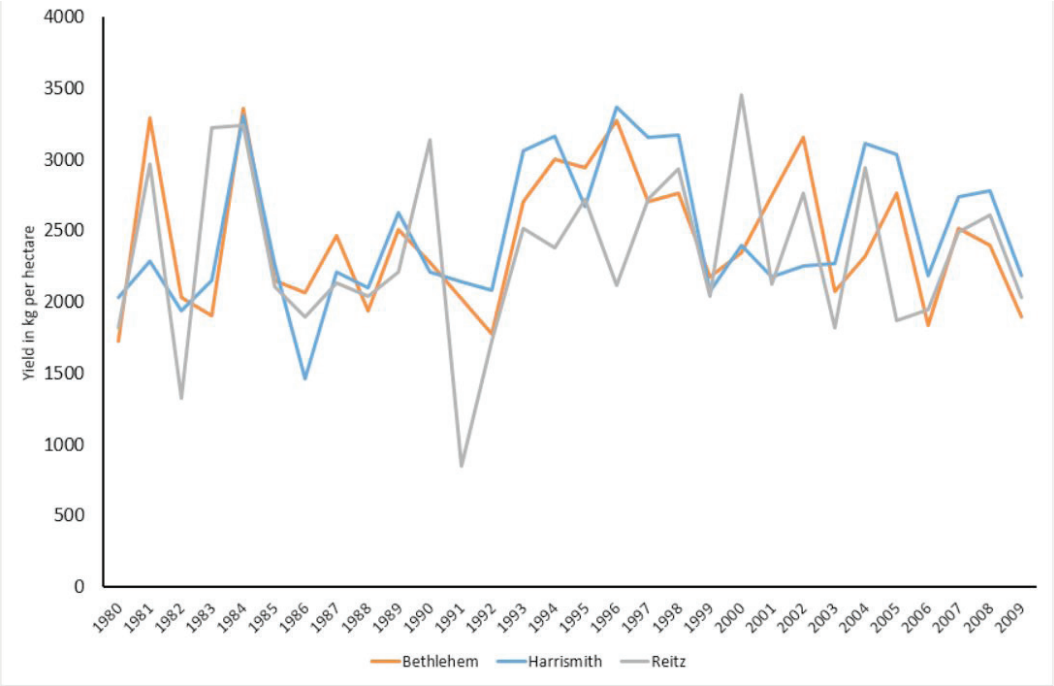

Figure 1. Yield estimate for eastern Free State from 1980 to 2009/10 agricultural season for October 1st planting.

Keywords: Climate data, climate variability, crop simulations, crop yields.

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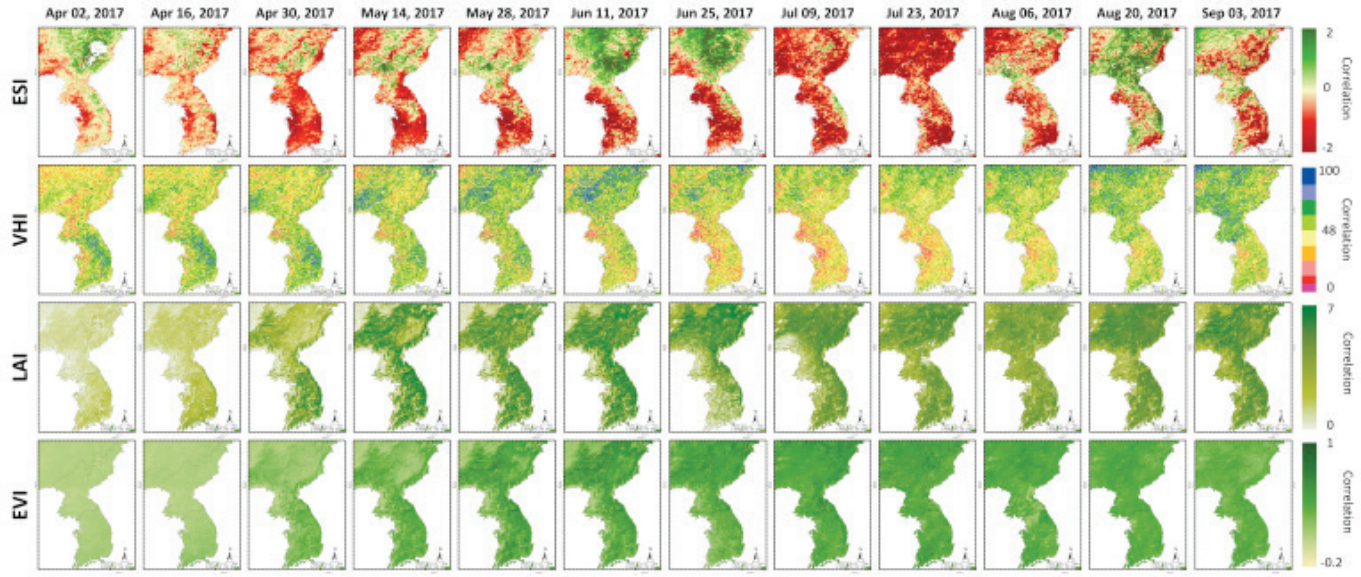
S5-P.23

Application in Agricultural Drought Management using Remote Sensing-Based Evaporative Stress Index of Crop Yield

Nam Won-Ho (wonho.nam@hknu.ac.kr)

Hankyong National University, Anseong, South Korea

Drought, as an extreme weather phenomenon, is one of the major climatic constraints to crop yield. Crop models can play a role in this agricultural management decision making process to cope with drought disaster. In many crop models, crop evapotranspiration is formulated in terms of both crop water use through transpiration and water lost through direct soil evaporation, making it a good indicator of soil moisture availability and vegetation health. Remote sensing offers an opportunity to obtain spatially distributed estimates of actual evapotranspiration time evolution over the growing season. An Evaporative Stress Index (ESI) as a new remote sensing drought indicator, has been developed to provide drought-specific vegetation condition which is based on temporal anomalies in reference evapotranspiration retrieved using satellites imagery. The objective of this study was to develop a satellite-based ESI of crop yield that could improve the spatial resolution of agricultural drought monitoring on a national scale. We extend the application of ESI-based stress detection and crop yield estimation to detect relatively short periods of warm surface temperature and anomalously low and rapid decreasing soil moisture. In this study, we examine the characteristic evolution of vegetation conditions and ESI drought indicator response associated with several flash drought events in recent years that have impacted agricultural areas over the South Korea.



Keywords: crop yield, remote sensing, drought monitoring, evaporative stress index (ESI), evapotranspiration.

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S5-P.24

Assessing the suitability of soybean crop in France under present and future climates by a simple phenological model

Schoving Céline[1] (celine.schoving@inra.fr), Ben Soltane Myriam[2], Constantin Julie[1], Champolivier Luc[2], Maury Pierre[3], Philippe Debaeke[1]

[1] *UMR AGIR, INRA, Castanet-Tolosan, France*; [2] *Terres Inovia, Castanet-Tolosan, France*; [3] *UMR AGIR, INP-ENSAT, Castanet-Tolosan, France*

Introduction

Increasing the protein self-sufficiency of France (and Europe) goes through higher yields and protein contents of rich-protein crops (as soybean) in traditional production areas and/or their extension towards new areas with climate change. In France, soybean is grown as a main crop in South-West (Maturity Groups I/II, irrigated) and Center-East (MG 00/I, rainfed) and as a double crop (MG 000) in southern irrigated systems. A simple phenology algorithm (SPA), easy to calibrate and adapted to MG < III, was developed to assess soybean crop suitability at France level (Schoving *et al*., 2019).

Materials and Methods

The algorithm simulates the duration of phenophases between VC and R7 stages as a function of temperature and photoperiod. It was calibrated for 10 cultivars (from MG 000 to II) in a pot experiment with 6 planting dates and with a germination experiment to determine the response of growth process to a wide range of temperatures. Multi-location field trials including 5 sites, 4 years, and 2 sowing dates were used for evaluation (75 units of simulation). Series of daily temperature were retrieved from the SAFRAN historical reanalysis which covers France at 8 × 8 km resolution (Vidal *et al.*, 2010). The SPA model was applied on each of the 8602 grid cells on the 1990-2017 period (baseline), excluding cells with elevation > 600 m. The crop duration was simulated for the 10 varieties sown (i) as soon as possible from 15th March (early sowing); (ii) on 5th May (conventional) and (iii) on 1st July (double crop). Early sowing was decided when air temperature was greater than 10 °C during 5 successive days. Soybean crop should be harvested before 10th Oct at least 8 years out of 10 to be suitable. Climatic projections from 2020 to 2100 under the different RCP scenarios were applied to 12 representative climatic stations.

Results

The performance of SPA was reasonable enough to attempt simulations at France level (RMSE for crop duration < 6 days). Maps were generated for each of the 10 varieties and the 3 sowing dates (early, conventional, double crop) as illustrated for ES Pallador. Considering that only harvest dates less than 283 (JD) are acceptable, we conclude that soybean cropping of a cultivar from MG I is feasible in most of the country (70 % of the cells) except the NE and NW fringes (Fig.1). Double cropping is possible from 5 % to 55 % of the climatic situations depending on the varieties. Considering 3 climatic stations, from North to South (Mons, Dijon and Toulouse), we can follow the potential northward extension of early sowing and double cropping with climate change for cv. Mentor from MG 00 (Fig.2).

Discussion and Conclusion

Whether choosing adapted varieties, soybean cropping is possible in a large proportion of the French territory when considering only climatic requirements and realistic conditions for sowing (temperature) and harvesting (date). Climate change will expand the possibilities of growing soybean in France as a main or double crop as simulated in the US (Seifert and Lobell, 2015).

This preliminary study ignored the nature of the soils. Calcareous and stony soils should be excluded in a first approach. Our decision rules should include soil moisture at sowing (emergence) and harvest (risks of compaction). This will probably set aside several climatically-suitable situations. A crop simulation model could then be applied to determine the potential and accessible yields both in irrigated and rainfed systems.

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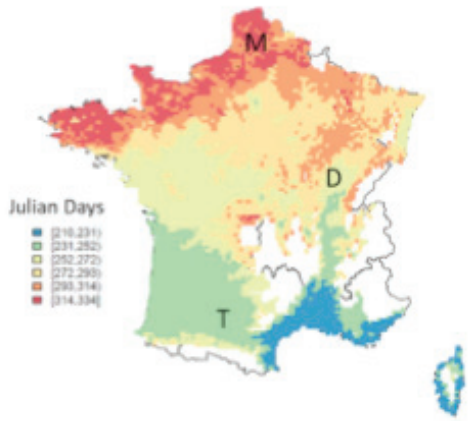

Fig.1 – Soybean harvest dates (Julian days) feasible 8 years out of 10 for early sowing (cv Pallador, MG I) - 1990-2017

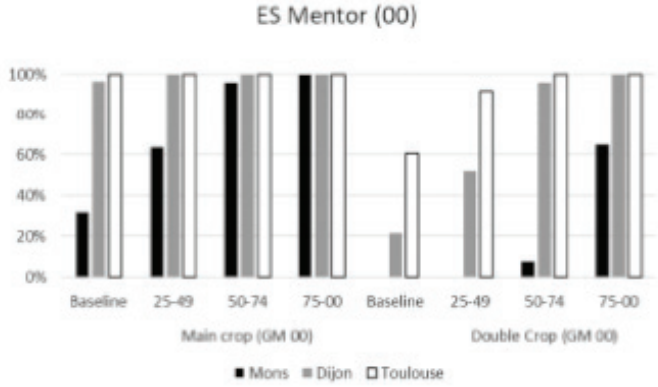

Fig.2 – % of years where soybean (cv. ES Mentor – MG 00) is feasible as main or double crop on periods 1990-2017 (baseline), 2025-49, 2050-74, 2075-00 - RCP 8.5 – M: Mons ; D : Dijon ; T : Toulouse

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S5-P.25

ASCROM: A crop model designed to simulate agricultural water constraints in semi arid areas from plot to territory

Baccar Mariem[1] (mariem.baccar@inra.fr), Raynal Hélène[2], Casellas Eric[2], Ruiz Laurent[3], Sekhar Muddu[4], Bergez Jaques Eric[1]

[1] *UMR AGIR, INRA, Castanet Tolosan, France*; [2] *UR 875 MIAT, MIA, INRA, Castanet Tolosan, France*; [3] *Indo-French Cell for Water Sciences, IIISC, INRA, IRD, Bangalore, India*; [4] *Indo-French Cell for Water Sciences, IIISC, Bangalore, India*

Introduction

Farming systems are challenged by climate change and must adapt in particular to the depletion of water resources. Integrated Assessment Modeling (IAM) is broadly used to design and evaluate adaptation options. Such approaches are complex: i) they need to encompass all the components of farming systems ii) they should be able to integrate multiple spatial scales of decision making (plot, farm, territory…), and iii) involvement of stakeholders in the modeling process is essential (Challinor et al., 2018). IAM tools developed to represent this complexity should be simple to make it possible for stakeholders to understand and to handle them. Here, we introduce the newly developed crop model ASCROM, developed during an IAM exercise in South India. The model is based on a parsimonious representation of the system but still accounts for its functional complexity and is able to meet the expectations of local stakeholders.

Materials and Methods

In semi-arid regions of South India, agriculture is facing a major crisis, due to groundwater overexploitation. In this context, we implemented an IAM approach using the Berambadi watershed (84 km2, tropical sub-humid climate, Sekhar et al. 2016) as a case study. Surveys available in this site (ORE BVET, http://bvet.obsmip.fr/en) and workshops with stakeholders allowed us to identify the main agricultural issues and possible adaptations: the development of irrigation since the 1990s led to a fast decline in groundwater levels and a decrease of pump yields (Sekhar et al. 2011). Farmers are adapting quickly either by increasing the number the number of borewells or by changing their irrigation practices and cropping pattern according to groundwater availability. Main solutions proposed by stakeholder include water conservation (i.e. harvesting runoff in farm ponds for irrigation and/or groundwater recharge) and increased water use efficiency (i.e. drip irrigation, smart sensors for improved irrigation scheduling …).

Results and Discussion

The ASCROM crop model was designed to represent parsimoniously the South Indian specific features. It comprises 3 modules: i) the atmospheric demand of cropping systems is computed using the dual crop coefficient equation of FAO (Allen et al., 1998) as to simulate accurately transpiration and evaporation fluxes (critical for assessing water use efficiency), ii) the irrigation module represents different irrigation techniques (drip, sprinkler, furrow) and practices (in particular the fact that farmer are adapting in real time irrigation schedules according to water availability) and iii) the water balance module simulates the daily water flows between the atmosphere, soil (represented by 2 layers) and the crop. The three modules are coupled, enabling the exchange of variables values at a daily time step. In order to represent the interactions and feedbacks governing the evolution of farming systems, ASCROM was embedded within an integrated model, comprising the groundwater model AMBHAS (Tomer, 2012) and an bio-economic model.

The most relevant feature of this framework its capacity to be implemented at different spatial scales, such as the plot, the farm, or the watershed scale (Figure 1).

Conclusions

ASCROM, while parsimoniously representing the system, allowed to simulate complex interactions and feedbacks. Embedded within an integrated model allowing to consider a variety of spatial scales, it is a useful tool for engaging with a large variety of stakeholders.

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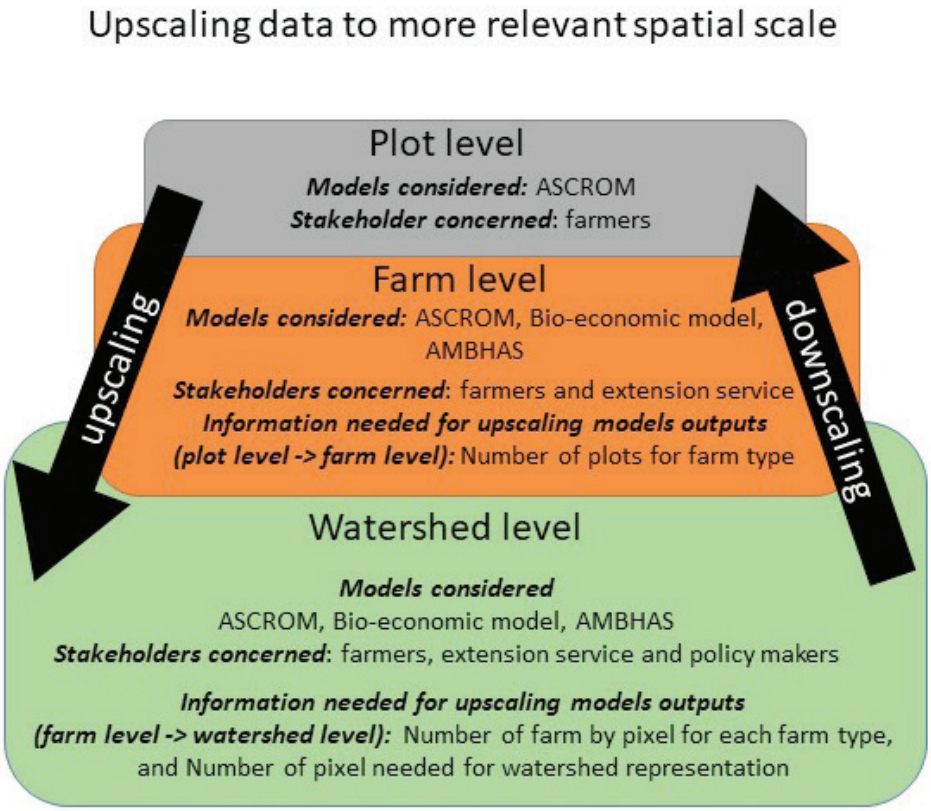

Architecture of spatial scale change and data aggregation in the integrated model.

Keywords: IAM, climate change adaptation, irrigation, semi-arid tropics.

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S5-P.26

Control of ascochyta blight in Pea/Wheat intercrops based on qualitative modelling

Corrales David Camilo[1] (davidcamilo.corralesmunoz@inra.fr), Baranger Alain[2], Jumel Stephane[2], Leclerc Melen[2], Le May Christophe[2], Langrume Christophe[2], Moussart Anne[3], Robin Marie-Helene[4], Aubertot Jean-Noel[1]

[1] *AGIR, INRA, Toulouse, France*; [2] *INRA, Rennes, France*; [3] *Terres Inovia, Thiverval-Grignon, France*; [4] *INRA / INPT-EI Purpan, Toulouse, France*

Introduction

Crops are affected largely by diseases causing significant economic losses. On average, they lead to between 20% and 40% of yield losses global agricultural productivity. For instance, Ascochyta blight, mainly caused by Didymella pinodes is one of the most damaging aerial diseases on pea crops. Today, chemical pesticides are the main methods used to control the disease, and can lead to environmental pollution, biodiversity loss (including landrace loss) in the agricultural systems, and eutrophication of ground and surface waters (Gliessman, 2000). Alternative strategies such as intercropping (using species mixtures involving the growth of two or more crops in the same field at the same time, or relayed ; Willey, 1979) could enhance the control of Ascochyta blight due to the presence of non-host species that act as physical barriers to inoculum dispersal, or to the modification of the canopy microclimate or plant receptivity (Fernández-Aparicio, et al, 2010 ; Schoeny et al, 2009).
Modelling is powerful tools that can improve the management of disease control allowing the building and understanding of relationships between variables such as cropping practices, soil, weather, crop phenology and field environment. In this sense, we proposed a qualitative model to predict Ascochyta blight severity in pea/wheat intercrops based on a modelling platform named Injury Profile SIMulator (IPSIM) (Aubertot & Robin, 2013).

Materials and Methods

The development of IPSIM-Pea/Wheat-Acyrthosyphon pisum followed three steps (Aubertot & Robin, 2013): (I) Identification and organisation of attributes in hierarchical structure, (II) Definition of ordinal or nominal scales for basic and aggregated attributes, (III) Creation of aggregating tables for each aggregated attribute. A set of “if-then” rules define the value of the considered attribute as a function of the values of its immediate descendants.

Results

IPSIM’s consists in designing models with an aggregative hierarchical tree of attributes. IPSIM-Ascochyta-Blight-severity is composed of 37 attributes, 25 input attributes, and 12 aggregated included the output attribute Ascochyta blight severity (Figure 1). Afterwards, we defined qualitative scales for all attributes. The qualitative scale corresponds to discrete values (Figure 1. Attribute “Tillage” scale values correspond to Ploughing, Superficial tillage or No tillage) rather than numbers. Attribute values in red, black and green are respectively favorable, neutral and unfavorable to Ascochyta blight development.
Finally, we built aggregative tables for each aggregated attribute, a set of IF-THEN rules defines the value of the considered attribute as a function of the values of its immediate descendants attributes in the model. Currently, we are evaluating the model prediction quality. This evaluation consists in comparing observed and simulated classes of disease severity using an independent dataset covering a wide range of production situations. In addition, in order to run the qualitative model, it is necessary to design a converter that will transform nominal input variables (such as chemical control in Figure 1), or quantitative input variables (such as a pea sowing doses in Figure 1) into ordinal variables such as required by the IPSIM approach.

Conclusions

Currently, we are building a dataset from French experimental crops in order to evaluate the predictive quality of IPSIM-Pea/Wheat-Ascochyta blight.

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Attribute	Scale
D.pinodes severity on pea/wheat intercrops	Extreme; High; Moderate; Low; *Very low*
Cropping practices	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Preventive measures	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Chemical control	*Yes*; No
Sowing date	Early; Normal; *Late*
Risk for seed transmision	*Absence*; Presence
Impact of intercropping	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Competition	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Cultivar choice for wheat	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Cereal canopy height	*Short*; Average; High
Tillering ability	High; Moderate; *Low*
Cultivar choice for pea	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Pea canopy height	*High*; Average; Short
Resistance to lodging	High; Moderate; *Low*
Foliage type	conventional; *Semi-leafless*
Available N by the end of winter	High; Moderate; *Low*
Pea density in the mixture	Pea sole crop; Intercrop-pea density equal to the recommended sowing dose; *Intercrop-pea density lower thant recommended sowing dose*; *Intercrop-pea density much lower than recommended sowing dose*
Curative chemicals	*Yes*; No
Weather conditions	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Weather from emergence to the end of winter	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Temperature	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Relative Humidity	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Rainfall	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Weather from end the winter to flowering	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Temperature	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Relative Humidity	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Rainfall	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Weather from flowering to seed filling	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Temperature	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Relative Humidity	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Rainfall	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Dew	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Irrigation	Favorable to D.pinodes; Moderately favorable to D.pinodes; *Unfavorable to D.pinodes*
Interactions with landscape: Stubble management	*Efficient*; Quite efficient; Unefficient
Shredding	*Yes*; No
Exportation	*Yes*; No
Tillage	*Ploughing*; Superficial tillage; No tillage

Figure 1. Aggregative hierarchical tree of attributes and qualitative scales of IPSIM-Pea/Wheat-Ascochyta blight (DEXi screenshot).

Keywords: Didymella pinodes, IPSIM, Aggregative hierarchical tree, crop mixtures.

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S5-P.27

Soybean Yield Gap over the Brazilian Cerrado

Cuadra Santiago[1] (santiago.cuadra@embrapa.br), Boote Kenneth[2], Macena Fernando[3], Evangelista Balbino[4], Andrade Junior Aderson[5], Boucas Farias Jose Renato[6], De Castro Victoria Daniel[7], B de Almeida Monteiro Jose Eduardo[7], Fortes de Oliveira Aryeverton[7]

[1] *Brazilian Agricultural Research Corporat, Campinas, SÃO PAULO, Brazil*; [2] *Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, United States*; [3] *Brazilian Agricultural Research Corpor, Brasília, DF, Brazil*; [4] *Brazilian Agricultural Research Corpor, Palmas, TO, Brazil*; [5] *Brazilian Agricultural Research Corpor, Terezina, PI, Brazil*; [6] *Brazilian Agricultural Research Corpor, Londrina, PR, Brazil*; [7] *Brazilian Agricultural Research Corpor, Campinas, SP, Brazil*

Introduction

With population growth and increased demand for food, fiber and biofuels, the agricultural sector will face enormous challenges to ensure sustainable rural production. Specifically, in Brazil, the demand for exports has placed the country as one of the main agricultural producers in the world. Therefore, the Brazil's agro-ecosystems should adopt technological innovations that guarantee food security, for its current and future population, as well as preserve its natural resources.

Despite the significant increase in average soybean yield in recent decades, only part of the potential from new technologies and management practices have been translated into grain production. In order to quantify and identify the reasons why the majority of producers have obtained yields below the technological potential, we estimated the attainable soybean yield using the CROPGRO-Soybean model, previously calibrated for the region, and discuss the present yield gap throughout the Brazilian Cerrado biome.

Materials and Methods

We used the CROPGRO model in the DSSAT platform (Decision Support System for Agrotechnology Transfer, Hoogenboom et al., 2017). CROPGRO can simulate the growth of many legumes, some non-legumes such as cotton, as well as forage crops (Boote et al., 1998; Pequeno et al., 2014). The model was calibrated through field experiments carried out by Embrapa and partners (measuring phenology, growth and soil water). The yield data of Embrapa's breeding program and its partners were used for validate the model results.

The model was applied to simulate the yields obtainable without irrigation for the entire Cerrado considering a 25 x 25 km spatial grid. To estimate the yield at municipal level we weighted the average pixel results by agricultural area of the pixels belonging to each municipality, considering only the areas with soybean cultivation, 2016/17 crop (Agrosatélite, https://agrosatelite.com.br/en/), and the pasture areas (LAPIG, https://www.lapig.iesa.ufg.br/lapig/). Results are available in the Agroideal system (https://agroideal.org/en/).

Results and Discussion

Results shows that there is a significant yield gap in most of the Biome today, Figure 1. The gap was estimated by the relationship between the current attainable soybean yield (AY) and the average present yield (PY) – PY derived from IBGE (Brazilian Institute of Geography and Statistics) data normalized to the present yield levels, detrended. The yield gaps can be interpreted as a potential for intensification/optimization of soybean crop production. Considering that the current average soybean yield in the Cerrado biome is ~ 3000 kg ha-1 and that producers could obtain on average 80% of the attainable yield, estimated as ~ 4000 kg ha^{-1} on average, if this fraction of the gap were reduced there would be an average increase of ~ 18 M t of soybean production in the biome, which is equivalent to the production from ~ 6 M ha assuming the current average yield.

Conclusions

There is a significant soybean yield gap in most of the Biome today. Reducing this gap to 80% of the attainable yield would result in an average increase of ~ 18 M t of soybean production in the biome, which equals the production from ~ 6 M ha with current average yield.

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Acknowledgements
We gratefully acknowledge the DSSAT Foundation for the DSSAT software. We gratefully acknowledge the funding support of The Nature Conservancy do Brasil (TNC) and the Gordon and Betty Moore Foundation.

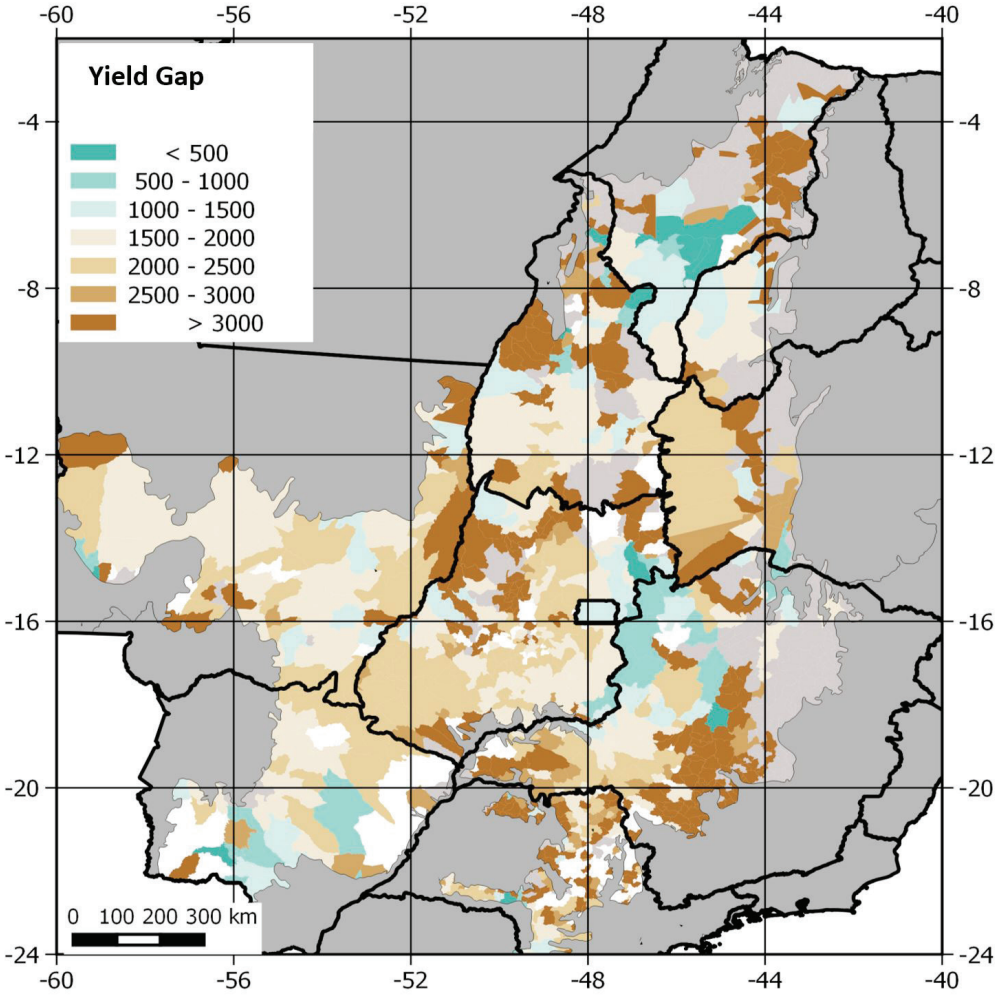

Figure 1. Soybean yield gap (kg ha-1) over the Cerrado biome at municipal level.

Keywords: Soybean, yield gap, Cerrado biome.

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S5-P.28

Model-based yield gap analysis and constraints of rainfed sorghum production in southwest Ethiopia

Desta Abera*[1] (aberatsion2008@gmail.com), Worku Walelign[1], Gayler Sebastian[2], Ayalew Dereje[3], Mamo Girma[4]

[1] *Hawassa University, Hawassa, Ethiopia*; [2] *Hohenheim University, Stuttgart, Germany*; [3] *Bahir Dar University, Bahir Dar, Ethiopia*; [4] *EIAR, Melkassa, Ethiopia*

Introduction

For ensuring food demand of the fast growing population in developing countries, quantification of existing crop yield gaps and exploring ways to increase productivity are very crucial(Van Ittersum, et al., 2013; FAO. 2017*)*. Model-based analyses can help to identify limiting factors and production constraints. Even though sorghum is one of the most important climate change resilient crops, especially in rainfed farming systems in Ethiopia(Belay and Meresa, 2017), information about existing yield gaps under current crop management and environmental conditions, and potential production constraints is lacking. This study aimed at analyzing existing yield gaps and exploring major production constraints of rainfed sorghum production in Southwest Ethiopia.

Materials and methods

A crop simulation model approach, using AquaCrop, was used to analyze the gaps between different yield levels (actual, attainable and water limited potential yield) of rainfed sorghum production in Southwest Ethiopia. The model was calibrated and evaluated using data sets from field experiment conducted in 2018 and 2019. Simulations of water limited potential yield of two varieties (Melkam and Teshale) that differ in days to maturity and yield potential were performed after model evaluation using historical weather data for the period 2003 to 2017. Finally, sorghum production constraints were assessed using data from a survey study that was conducted in sorghum production belts of the region through interview of 245 household head using structured questioners.

Results and discussion

The statistical parameters (R2, RMSE and D statistic) and well fitted one to one regression plots for canopy cover, soil moisture content, and above ground biomass showed good accuracy of the model for simulating water limited potential yield of sorghum. The water limited potential yields of sorghum varieties were 5.15 to 5.64and 5.44 to 6.24tons ha-1forMelkam and Teshale, respectively for the period 2003 to 2017. The actual yield of sorghum for the same period was 0.58 to 2.52tons ha-1indicating existence of 2.63 to 5.66 tons ha-1ofyield gaps. As the majority of farmers responded different factors; seasonal variability of rainfall (90%), poor soil fertility (85%), lack of improved varieties (76%), weed management (35%), disease and insect pest problems (20%); accounted for existing yield gaps.

Conclusions

The simulated gaps between potential, attainable and actual yields showed the level of existing opportunity for actual productivity improvement. The gaps could be narrowed if proper interventions such as adoption of improved varieties, planting date adjustment, fertilizers application and conservation tillage are made.

Acknowledgements

The work is an output of a PhD scholarship at the Hawassa University, in the framework of the German-Ethiopian SDG Graduate School “Climate Change Effects on Food Security (CLIFOOD)” between the Food Security Center, University of Hohenheim (Germany) and the Hawassa University (Ethiopia), supported by the DAAD with funds from the Federal Ministry for Economic Cooperation and Development (BMZ).

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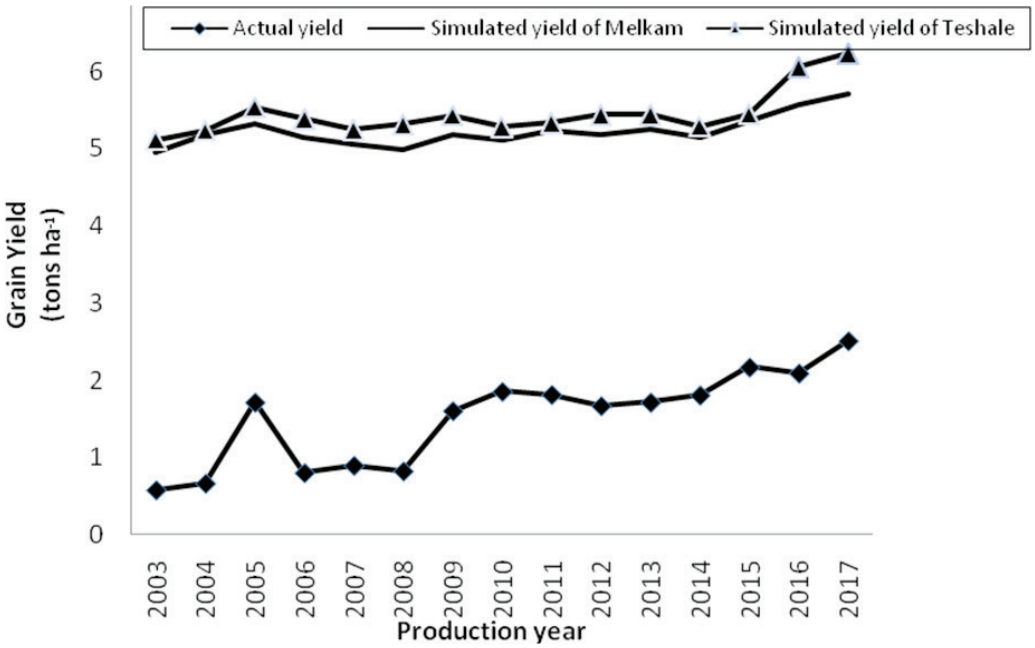

Figure 1. Time series yield gaps (actual vs. water limited potential yield) of sorghum varieties in southwest Ethiopia.

Keywords: AquaCrop, Simulation, Survey study, Actual yield, Potential yield.

References:

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S5-P.29

Sugarcane yield future scenarios in Southern Brazil as predicted by the APSIM-Sugar model with a new feature for transpiration efficiency

Dias Henrique[1] (henrique.bdias@yahoo.com.br), Sentelhas Paulo[1], Inman-Bamber Geoff[2], Everingham Yvette[2]

[1] *«Luiz de Queiroz» College of Agriculture, University of São Paulo, Piracicaba, SP, Brazil*; [2] *James Cook University, Townsville, QLD, Australia*

Introduction

The APSIM-Sugar model has recently been upgraded for simulation of sugarcane production in Brazil and to cater for climate change impacts under water-limited conditions (Inman-Bamber et al., 2016; Dias et al., 2019). Here we report the success of the upgrade using a new set of field measurements and then we use the same model settings to assess the impact of climate change on yields at a traditional site in Brazil.

Materials and Methods

Stalk dry mass (SDM) measurements for plant and ratoon crops from four rainfed field experiments previously published (21 observations) were used to validate model parameters of Dias et al. (2019). These were compared with the original trait parameters for the Australian variety Q117 (Keating et al., 1999) to test the advantages of Dias' parameters when using the model for Brazilian varieties and conditions. The new transpiration efficiency (TE) response to water stress and CO_2 feature in APSIM-Sugar (Inman-Bamber et al., 2016) was also assessed. Standard statistical indices were used in the model evaluation.

The TE feature and Dias' parameters were then used in long-term simulations (1980-2010) for Piracicaba, Southern Brazil, at CO_2 concentrations of 350 (ambient), 550 and 720 ppm, for current and future climate scenarios. Simulated crops started in April, July and October and comprised 12-months old plant and four ratoons, with residues left in the soil after harvesting. Nitrogen was applied to avoid any stress and simulations were continuous (no resetting).

Future climate projections considered a business-as-usual scenario (RCP8.5) based on a subset of five Global Climate Models (GCM) from Coupled Model Intercomparison Project project (CMIP5). The subset followed Ruane and McDermid (2017) to capture the full ensemble of temperature and precipitation changes considering basic classes of climate changes. MIROC5, GFDL-ESM2, CESM1-BGC, HadGEM2-AO and GFDL-CM3 models were selected to represent relatively cool/wet, cool/dry, middle, hot/wet, and hot/dry classes, respectively. A crop starting in April was used at this stage with the same management settings previously described.

Results and Discussion

Dias' parameters without the new TE feature improved the simulation of observed SDM considerably (1:1 box in Figure 1). R^2 increased from 0.80 to 0.93, d from 0.91 to 0.98, E from 0.65 to 0.93 and RMSE dropped from 9.7 to 4.7 t ha^{-1}. RMSE dropped further to 4.4 t ha^{-1} when the TE feature was turned on thus supporting its use in accounting for CO_2 effects on TE. Aboveground biomass increased 13.7% and 26.0% with the additional 200 and 370 ppm CO_2 (box in Figure 1) in line with measured responses in other C_4 crops of 18.0% at 550 ppm (Kimball, 2016).

Future (ensemble) projections indicated that SDM at harvest will decline at a rate of 0.031 t ha^{-1} $year^{-1}$ (about 0.12 t ha^{-1} of cane yield) at Piracicaba. Expected changes are variable between climate models though, with the end-of-century period presenting large uncertainty (Figure 1).

Conclusions

Recent trait parameters and features improved the capability of the APSIM-Sugar model to simulate sugarcane performance. Cane yields in projected future climates is likely to decline slightly at Piracicaba, Brazil.

Acknowledgements

This study was supported by FAPESP (grant#2016/11170-2). Assistance of Dr. Fabiani Bender (INPE) on generating future climate scenarios is gratefully acknowledged.

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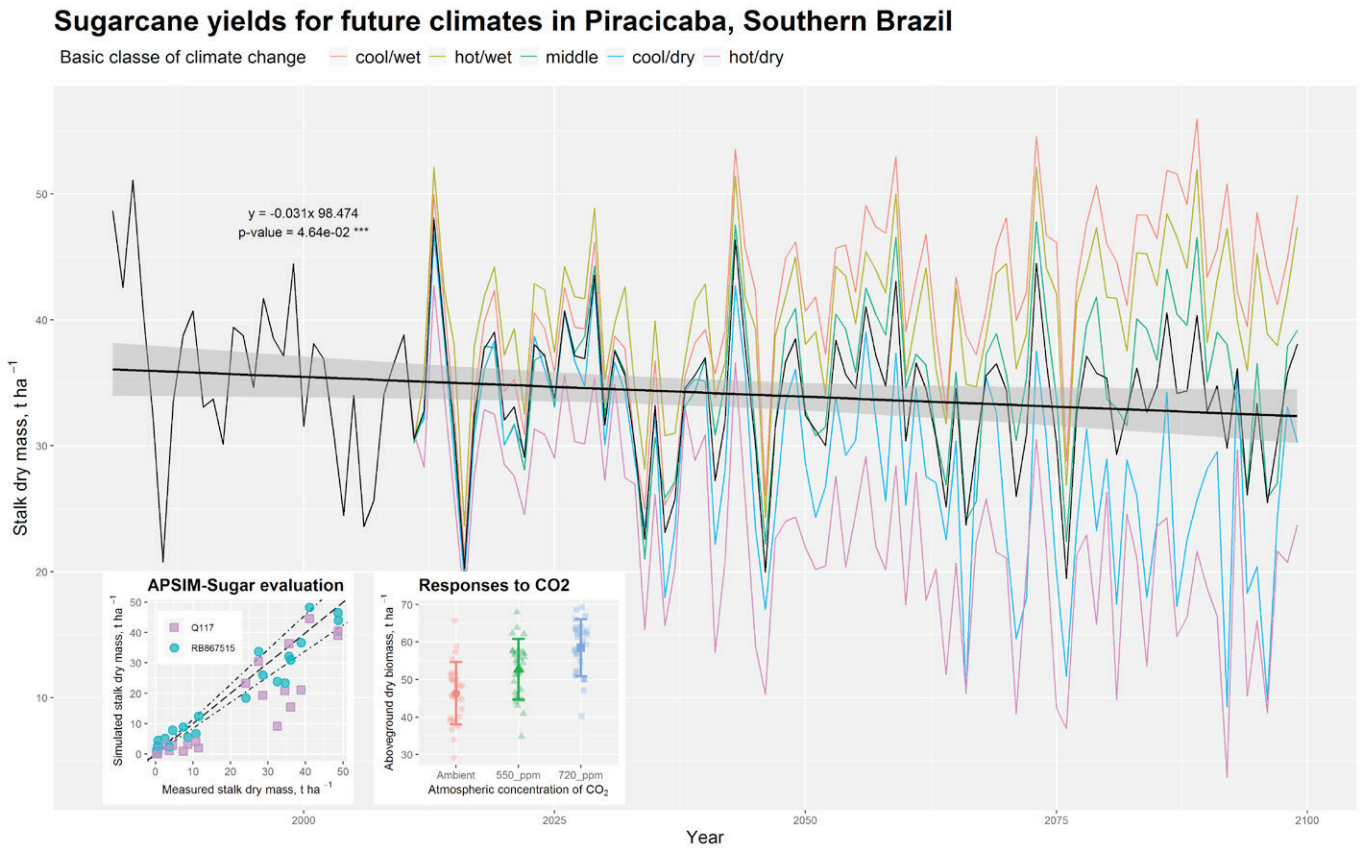

Figure 1. Future cane yield projections by APSIM-Sugar for Piracicaba, Southern Brazil, according to different climate models representing basic classes of climate change. Model evaluation for predicting stalk dry mass and aboveground biomass responses to CO_2 with a new feature are presented in the boxes.

Keywords: Saccharum spp., Modelling, Climate change, CO_2, Impacts.

References:

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S5-P.30

Evaluating soil organic N balance under different crop rotations with grass-clover leys using Daisy simulation

Duan Yun-Feng[1] (duan@plen.ku.dk), Borgen Signe[2], Bruun Sander[1], Jensen Lars Stoumann[1]

[1] *Dept. of Plant and Environmental Science, University of Copenhagen, Frederiksberg, Denmark*; [2] *The Danish Agricultural Agency, Copenhagen, Denmark*

Introduction

Daisy is a mechanistic model for simulation of water, matter, and gas fluxes across the soil-plant-atmosphere interfaces (Abrahamsen and Hansen, 2000). It also contains a sophisticated crop module that can simulate the plant growth, nutrient uptake, partitioning of photosynthate into yield components, etc. The ability to combine the modelling of crops with environmental processes makes Daisy a versatile tool for simulation of farming practices, and evaluation of the environmental consequences.

In the Danish project "StyrN", we utilized the Daisy model to investigate soil organic N (SON) balances in Danish agricultural systems, as affected by crop rotations, fertilizer type and amount, cultivation history, soil types, initial soil organic matter (SOM) levels, and climate zones. In this comprehensive study, over 1400 scenarios with combinations of different factors were analysed. Here we present a facet of this study, where SON balance under typical Danish dairy farm crop rotations was evaluated with selected factors.

Methods

The Daisy crop submodels were calibrated so that the dry matter (DM) and N yields match the national averages for these crops. The photosynthetic rate was changed to achieve a reasonable DM yields. To further match the N-yields, N partitioning into different plant organs at different development stages were adjusted; and additionally, parameters determining the maximum uptake of nitrate/ammonium were modified.

Dynamics of SON under different dairy farm crop rotations were simulated with Daisy for a period of 24 years, covering a minimum of 4 complete rotations of the crops. The scenarios used for the simulation were the combination of 3 soil textures (sandy, sandy-loam, and loamy), 3 initial SOM levels (low, medium, and high), and 6 crop rotations consisting of 1–5 consecutive years of grass-clover leys, and cereal crops for the remaining years (Fig. 1).

Results and Discussion

On the average of all scenarios, simulated DM and N yields after calibration fitted reasonably well with the actual yields. In most cases, the yield differences compared to the national averages were within ±20%.

The simulation results for SON showed a clear trend that having higher proportion of cereal crops in the rotation had a negative impact on SON, whereas increasing proportion of grass-clover leys led to improvement of SON levels, which corresponds with field trial experience. The sandy soil had the lowest SON content, but the most positive annual SON changes, particularly with 4–5 grass-clover leys in the rotations. This indicates that grass-clover leys contribute to SON build-up and thus have a positive effect on soil quality, especially for coarse-textured soils. Higher initial SOM levels have a strong negative effect on SON, particularly in fine-textured soils. This is likely due to higher mineralization rate stimulated by higher SOM and richer microbial biomass in loam and clay soils (Liu et al., 2017).

The R3a and R3b rotations, both with 3-yr grass-clover leys, showed visible differences where R3b had more positive changes in annual SON balance. R3a had winter barley whereas R3b had maize in the rotation, and this indicates that there may be an effect of the different cereal crops, which deserves further exploration.

Conclusion

Our study demonstrated Daisy's capability of combining crop and environmental modelling to produce sensible results, which can be used to support decision and policy making in agricultural management.

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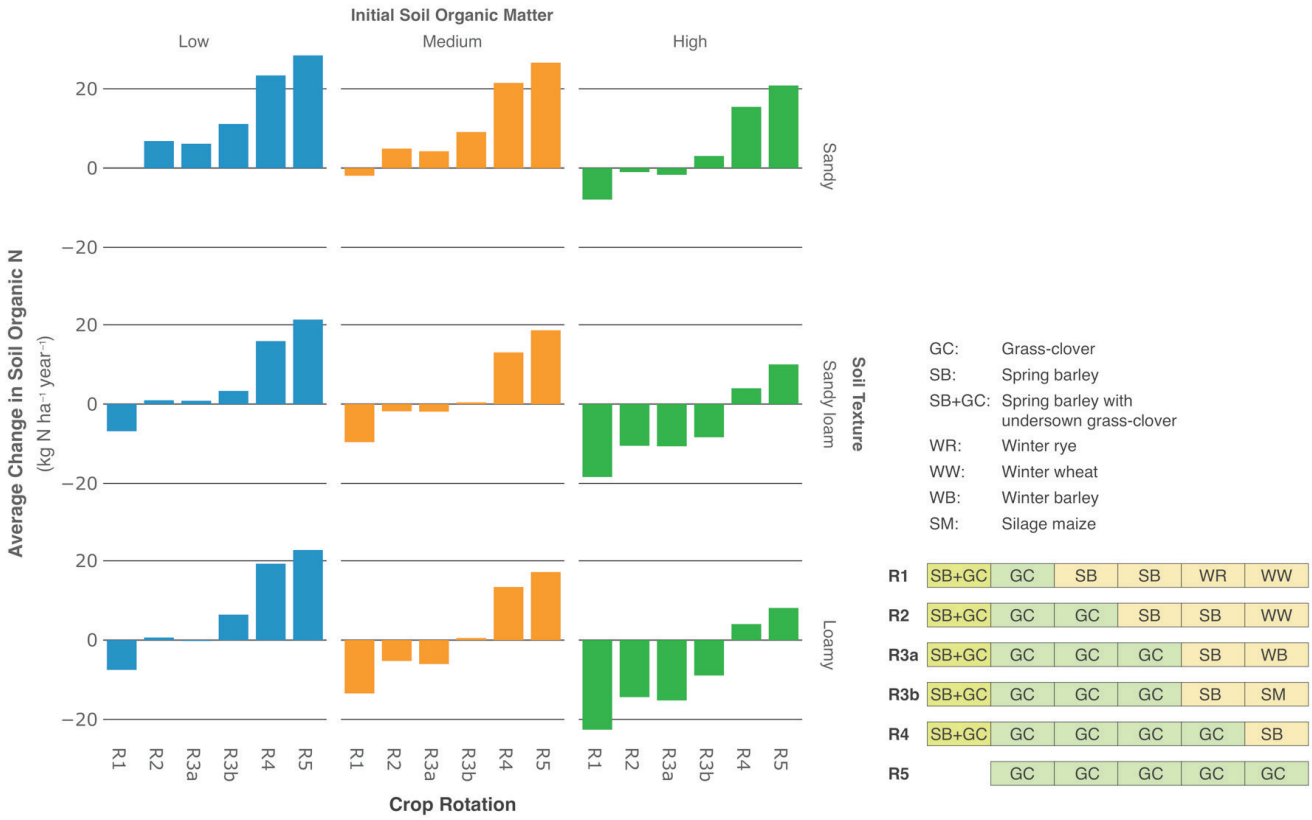

Figure 1: Simulated average annual changes in soil organic N (kg N ha–1 yr–1) for different dairy farm crop rotations, in sandy, sandy-loam, or loamy soils, and with low, medium, or high initial soil organic matter content (corresponding to the 20th, 50th and 80th percentile for the respective soil types from the Danish soil database).

Keywords: Daisy, Soil organic nitrogen, Crop rotation, Grass-clover leys.

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S5-P.31

AZODYN-rapeseed: a dynamic crop model to simulate the performance of rapeseed crop in constrasting environnements

Gervois Sébastien[1] (s.gervois@terresinovia.fr), Pinochet Xavier[1], Langlois Marc[1], Clement Charlène[1], Valantin-Morison Muriel[2]

[1] *Terres Inovia, Thiverval-Grignon, France*; [2] *UMR AGRONOMIE, INRA, Thiverval-Grignon, France*

The dynamic crop model AZODYN-rapeseed computes the above-ground biomass production from climate data (radiation, rainfall and temperature), soil characteristics and management practices. It works on a daily time step and describes plant phenology, leaf expansion and biomass production and its allocation to the grain. Rather classically, actual growth depends on potential growth modulated by nitrogen, temperature and radiation. Soil water and nitrogen at sowing were initialized from water balance and nitrogen balance computed by the model from the 1st of July.

The model outputs were compared with measurements for biomass, plant nitrogen content and soil nitrogen content in different regions of France from 2004 to 2018. Then, we tested the model in various situations of soil (deep, median or superficial), and of climate (Western or Eastern region). There are 40 sites. Based on these results we improved the autumn and winter phases of the cultivation cycle. The final evaluation assessed model robustness: no variables had a large prediction error, indicating that the final output error results more from poor prediction for all variables than from error compensation. We compared observed and simulated yields. The model overestimated a little bit the yields for deep soils, at the opposite, the model underestimated yields for superficial soils.
The model can be useful as a support tool. The model computes the variability of crop performance in response to the main abiotic stresses occurring in the field (light, temperature, water, nitrogen). In order to quantify the abiotic stress level in the studied experiments, we provided statistical methods (Partial Least Square regression) based on model outputs and climate data. Several cases will be presented in this communication.
Irregular climate events occurred last years (severe droughts in September/October or in Spring, strong rainfalls in Spring). In the next years, these events would be more and more common. We tested the model performance over the years with irregular climate events. The model performance is quite similar for the simulations with irregular climate than others situations. It is possible to study the impact of climate change on abiotic stress with this model.

This work is in progress and supported by the RAPSODYN (RAPeSeed Oil content anD Yield under low Nitrogen input) project.

Keywords: rapeseed, Abiotic stress, Climate change.

S5-P.32

A global meta-analysis on weed suppression in annual intercropping

Gu Chunfeng[1] (chunfeng.gu@wur.nl), Bastiaans Lammert[1], Anten Niels[1], Makowski David[2], van der Werf Wopke[1]

[1] *Centre for Crop Systems Analysis, Wageningen University, Wageningen, Netherlands*; [2] *INRA, Thiverval Grignon, France*

Introduction

Weeds are a severe constraint for crop yield and quality (Bastiaans et al., 2008). Intercropping is considered as a potential method for ecologically-based weed control because different species can be complementary in resource capture and thus reduce the resource space available for weeds (Liebman and Dyck, 1993). A meta-analysis has assessed the cash crop-legume cover cropping on weed control (Verret et al., 2017), while no quantitative synthesis has been made on the weed suppressive ability of mixtures of two cash crops. The aim of this study is thus to quantify the effects of two cash crop systems on weeds compared to the sole crops, and assess which factors affect weed suppressive ability.

Materials and Methods

Forty two studies were found in *Web of Science,* reporting 364 data records from 79 experiments. Three ratios were defined as effect sizes. *Relative weed biomass (RWB)* was used to compare weed biomass in intercrops to the expected weed biomass based on sole crops. *RWB* was calculated as the weighted average of the weed biomass in the sole crops, where the proportion of the component species in the mixture was used as a weight. Two other indices, R_{strong} and R_{weak} , were used to compare weed biomass in intercrops with that in pure stands of the most and least suppressive crop species in the mixture, respectively. Five explanatory variables were defined for analysis: intercrop composition, relative biomass total of crops (RBT), intercrop design (i.e. replacement and additive), spatial pattern (i.e. mixed, row, strip), and N input. We used linear mixed effect models to estimate the mean effect sizes, and explore relationships between response and explanatory variables. We identified the best random effect structure using Akaike's information criterion. The assumptions of models were graphically checked. The effect sizes were log-transformed (as $lnRWB = ln(RWB+1)$) for further analysis. Calculated effect sizes were back-transformed to the original scale to report.

Results and Discussion

Weed biomass in intercrops was 38% lower than expected on the basis of the weighted average weed biomass in the sole crops. Weed biomass in intercrops was 51% lower and 18% higher than weed biomass in the least and most weed suppressive sole crop, respectively. Intercrops consistently provided better weed control than the least competitive sole crop. However, there was variation in intercrop performance in comparison to the most competitive sole crop. A first analysis suggests that mixed intercropping systems laid out following an additive design and including small grain cereals provide the strongest improvement in weed suppression relative to that of its component crops.

Conclusion

Intercropping contributes to improved weed suppression of poorly competitive arable crops. A more detailed analysis of the effect of explanatory variables on weed suppression of intercrops is currently in progress. Results of this analysis can help guide the design of more weed suppressive intercrops. More details will be presented during the presentation.

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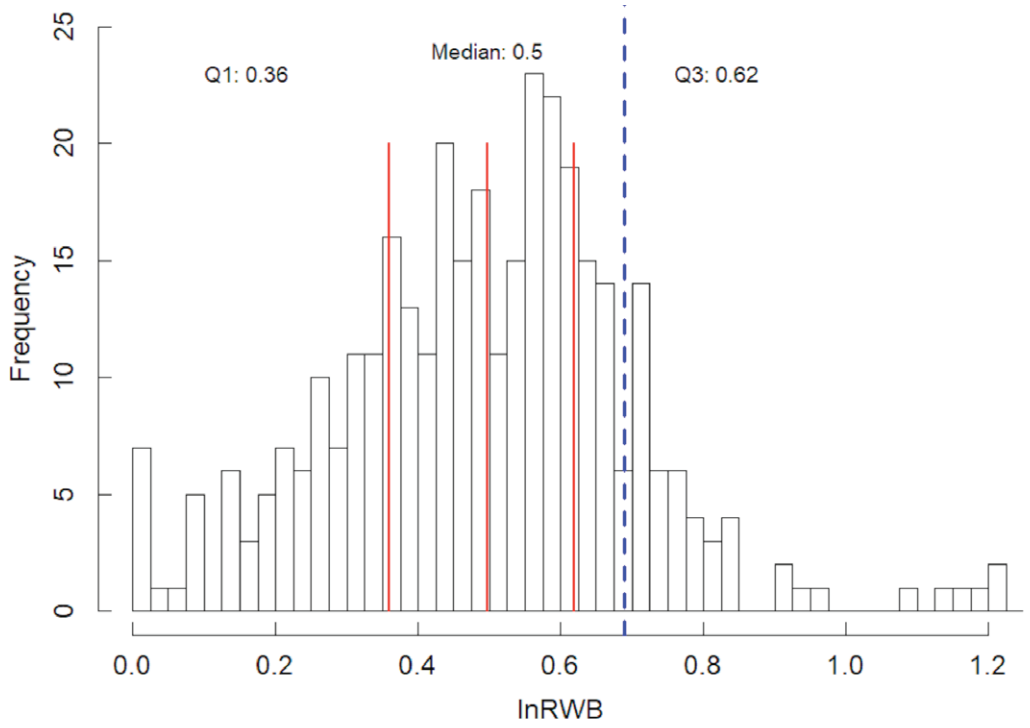

Figure. 1. Frequency distribution of lnRWB across all studies (n=364). Vertical red lines in panels of frequency distribution indicate the first quartile (Q1), median and the third (Q3) quartile of lnRWB. A value of 0.69 corresponds to an RWB equal to one (vertical blue dashed line).

Keywords: weeds, cash crop, intercropping, meta-analysis.

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S5-P.33

Towards the evaluation of crop disease response models to climate change adaptation: the OPERATE project

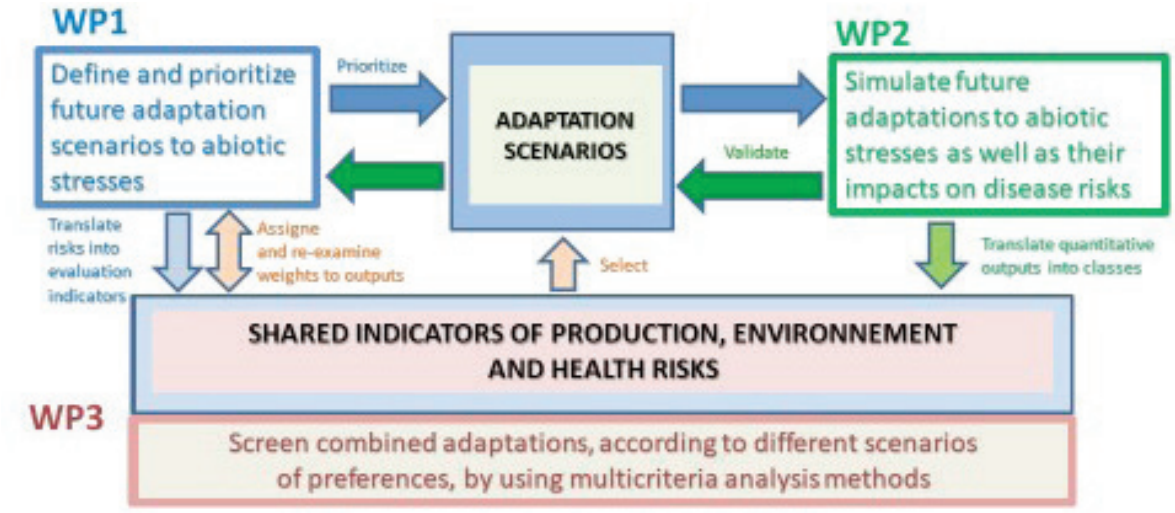
Huber Laurent[1] (laurent.huber@inra.fr), Bancal Marie-Odile[2], Violaine Deytieux[3], Gravoueille Jean-Michel[4], Gourdain Emmanuelle[4], Gaucher Denis[4], Preudhomme Hélène[5], Mestries Emmanuelle[6], Robin Marie-Hélène[7], Aubertot Jean-Noël[8], Debaeke Philippe[8], Launay Marie[9]

[1] *UMR 1402 EcoSys, INRA, Thiverval-Grignon, France*; [2] *UMR 1402 EcoSys, AgroParisTech et Université Paris-Saclay, Thiverval-Grignon, France*; [3] *UE 115 Domaine d'Epoisses, INRA, Bretenière, France*; [4] *Station expérimentale, ARVALIS-Institut du Végétal, Boigneville, France*; [5] *Agro-Transfert Ressources et Territoires, Estrées-Mons, France*; [6] *Terres Inovia, Castant-Tolosan, France*; [7] *INP Ecole d'Ingénieurs de Purpan, Purpan, France*; [8] *UMR 1248 AGIR, INRA, Castanet-Tolosan, France*; [9] *US 1116 Agroclim, INRA, Avignon, France*

Proven yield declines owing to climate change are challenging global food security now. Cropping systems are therefore forced to adapt for sustained productivity, the major constrains being the necessary adaptations to water stress and heat stress to come. Consequently, crop sectors in France tend to already anticipate the adaptations to these major abiotic stresses.

Annual crops provide a well-suited agronomical framework to address important questions within the OPERATE project (see project organization on the diagram below) which belongs to the INRA programme on "Adaptation of Agriculture and Forest to Climate Change": which major crop adaptations to climate change should be recommended in the case of wheat, sunflower and potato to sustain the productivity at an acceptable level? Which consequences will have these adaptations on crop health? To what extent does a given adaptation preventing a single crop disease prove to be robust when considering a multiple pathosystem? How to evaluate adaptation strategies to face abiotic and biotic stresses according to crop performances, environment and health?

Thanks to our interdisciplinary R&D network, we (i) identify adaptation scenarii with the support of crop experts, (ii) evaluate adaptations on production, environment and crop health using various models and decision support tools, and finally (iii) screen combined adaptations by using multicriteria analysis methods. Several databases such as Vigicultures® and Pest Observer are also available to the project to be used as external validation data. Expected results include the prioritization of adaptation scenarii, the accounting for uncertainty sources, and the development of a methodology to combine different modelling frameworks. Based on a participative design of scenarii, outputs are delivered to stakeholders and end-users and thus will allow to put forward new research questions and contribute to agroclimatic services for agriculture.



Organization of the OPERATE project as part of the INRA-ACCAF programme on climate change adaptation.

Keywords: crop disease, pathosystem, models, climate change, adaptation.

S5-P.34

Coupling the land surface model Noah-MP with the crop growth model Gecros: Model description, calibration and validation

Ingwersen Joachim[1] (joachim.ingwersen@uni-hohenheim.de), Högy Petra[2], Wizemann Hans-Dieter[3], Warrach-Sagi Kirsten[3], Streck Thilo[4]

[1] *Biogeophysics, University of Hohenheim, Stuttgart, Baden-Württemberg, Germany*; [2] *Institute of Landscape and Plant Ecology, Stuttgart, Baden-Württemberg, Germany*; [3] *Institute of Physics and Meteorology, Stuttgart, Baden-Württemberg, Germany*; [4] *Institute of Soil Science, Stuttgart, Baden-Württemberg, Germany*

Introduction

Interactions between vegetation and atmosphere have a large impact on weather and climate. During the last decade, enormous efforts have been made to improve the representation of vegetation dynamics in land surface models (LSM). The present study extends the LSM Noah-MP by the dynamic crop growth model Gecros that enables simulating the development of crop stands in a weather-driven manner. This extension is a pre-requisite to simulate two-way climate-crop interactions in climate projections.

Material and Methods

Based on a comprehensive five-year dataset on energy- and water fluxes, and soil water and crop data from two different climate regions of southwest Germany (Kraichgau and Swabian Alb), we adapted the crop growth model Gecros, integrated it with Noah-MP, calibrated the coupled model for winter wheat and maize and tested its robustness in multiple-year validation runs against independent measurements.

Results and Discussion

This sound data set yielded a robust parameterization that performed well both in calibration and in validation runs over in total 16 seasons. Due to pronounced differences in phenology among maize cultivars, wheat simulations were better than maize simulations. The simulated dynamics in leaf area index of wheat and maize differed largely from the one used in standard Noah-MP simulations. The new model yielded pronounced differences in the partitioning of evapotranspiration into transpiration and soil evaporation.

Conclusions

The new Noah-MP-Gecros enables simulating the development of early and late covering crops in a weather-driven way. It is intended for investigating two-way interactions in high-resolution, coupled crop-climate simulations. The added value of this improved description of the vegetation dynamics needs to be evaluated in future.

Acknowledgements

We gratefully acknowledge the financial support by the German Research Foundation (DFG) in the frame of the Research Unit 1695 “Agricultural Landscapes under Global Climate Change – Processes and Feedbacks on a Regional Scale”. We thank the farmers Mr. Bosch senior†, Mr. Bosch junior, Mr. Fink, Mr. Herrmann, and Mr. Reichart for their cooperation.

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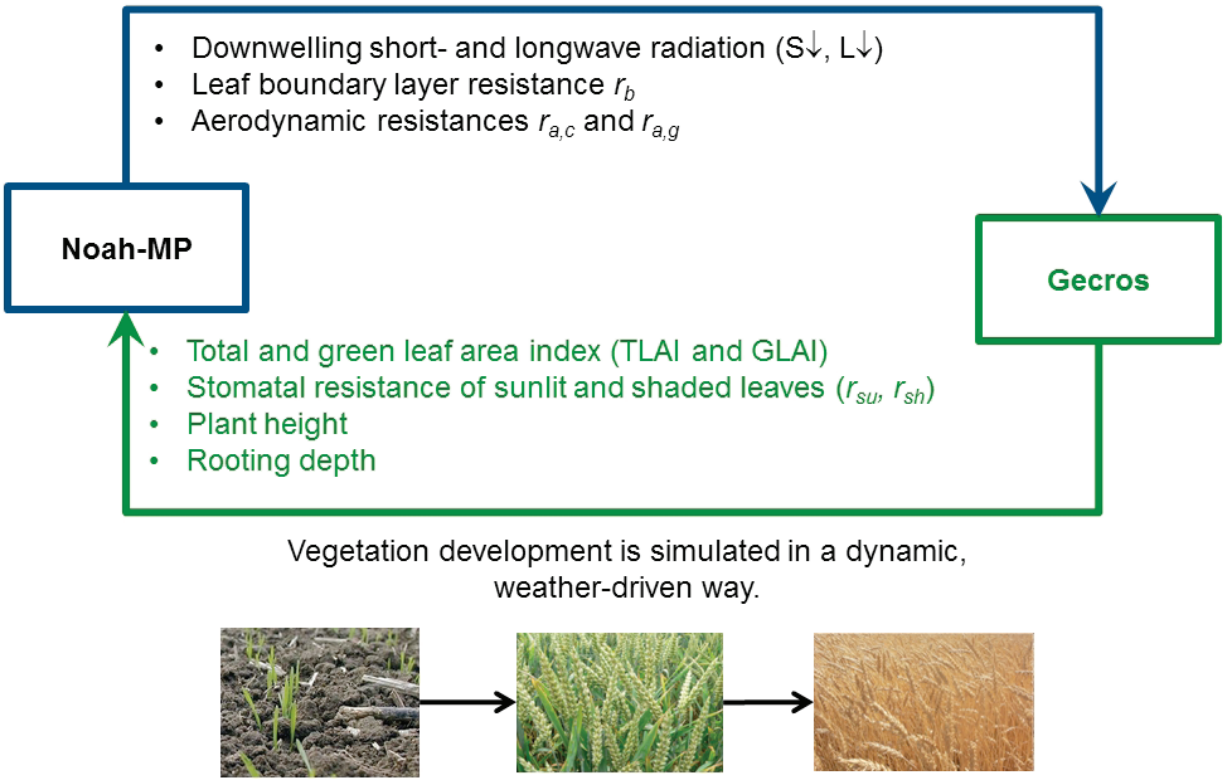

Figure 1: Coupling scheme of Noah-MP-Gecros.

Keywords: soil-plant-atmosphere feedback, land surface modeling, crop model.

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S5-P.35

Improving the simulation of crops in South Asia

Mathison Camilla[1] (camilla.mathison@metoffice.gov.uk), Challinor Andrew[2], Deva Chetan[2], Falloon Pete[1], Garrigues Sebastien[3], Moulin Sophie[3], Williams Karina[1], Wiltshire Andrew[1]

[1] *Climate science, UK Met Office, Exeter, Devon, United Kingdom*; [2] *ICAS, Leeds University, Leeds, Yorkshire, United Kingdom*; [3] *EMMAH, INRA, Avignon, France*

Introduction

South Asia (SA) is a region with complex orography and a highly variable climate. The region relies on industries with a high demand for water such as agriculture and hydroelectric power. These features make SA vulnerable to climate change and important for crop simulations to assess climate impacts. The Joint UK Land Environment Simulator (JULES) represents rivers but irrigation and crops require development to represent key features of the SA crop calendar; these include: the correct growing season inputs for crops, the capability to simulate several crops in rotation during a single growing period (sequential cropping) and crop specific irrigation. These are the main development needs for representing crops across the SA region. We address these development needs.

Materials and Methods

A precipitation climatology (shown in mm day^{-1}) highlights that the main monsoon period for SA correlates with the main rice season (green rectangle), while wheat (orange rectangle) is mainly grown during the dry season. Crop yields are shown in kg m^{-2} and irrigation demand is shown in mm $year^{-1}$.

Results and Discussion

Improved growing season inputs for climate simulations including crops are generated by estimating sowing and harvest dates for SA based on the dominating climatological phenomena, the Asian Summer Monsoon (ASM). This method provides a more accurate alternative to the global datasets of cropping calendars than is currently available and generates more representative inputs for climate impact assessments (Mathison et al., 2018). Most crop models are only able to simulate a single crop per year. We present a method for sequential cropping implemented in a branch of JULES at version 5.2 to improve the crop modelling capability for SA (Mathison et al., 2019). The sowing and harvest dates based on the ASM reproduce the present day sowing and harvest dates for most parts of India. The method is also able to ensure that the growing season remains consistent with the internal model climate by modifying the estimated sowing and harvest dates for two future periods. JULES can simulate two crops in rotation within a growing season both for a point and region. At a site in Avignon, France, with observations of latent heat, sensible heat and gross primary productivity, the fluxes correlate well with observations.

Conclusions

The use of the sequential cropping method at Avignon means that the actual vegetation coverage can be simulated, which improves the representation of surface fluxes. The regional simulation of Uttar Pradesh and Bihar uses the method for estimating sowing and harvest dates based on the ASM and the new sequential cropping method in JULES vn5.2. These simulate the two crops of rice and wheat in rotation for several years, with plausible leaf area index (LAI), canopy height and yields for each year.

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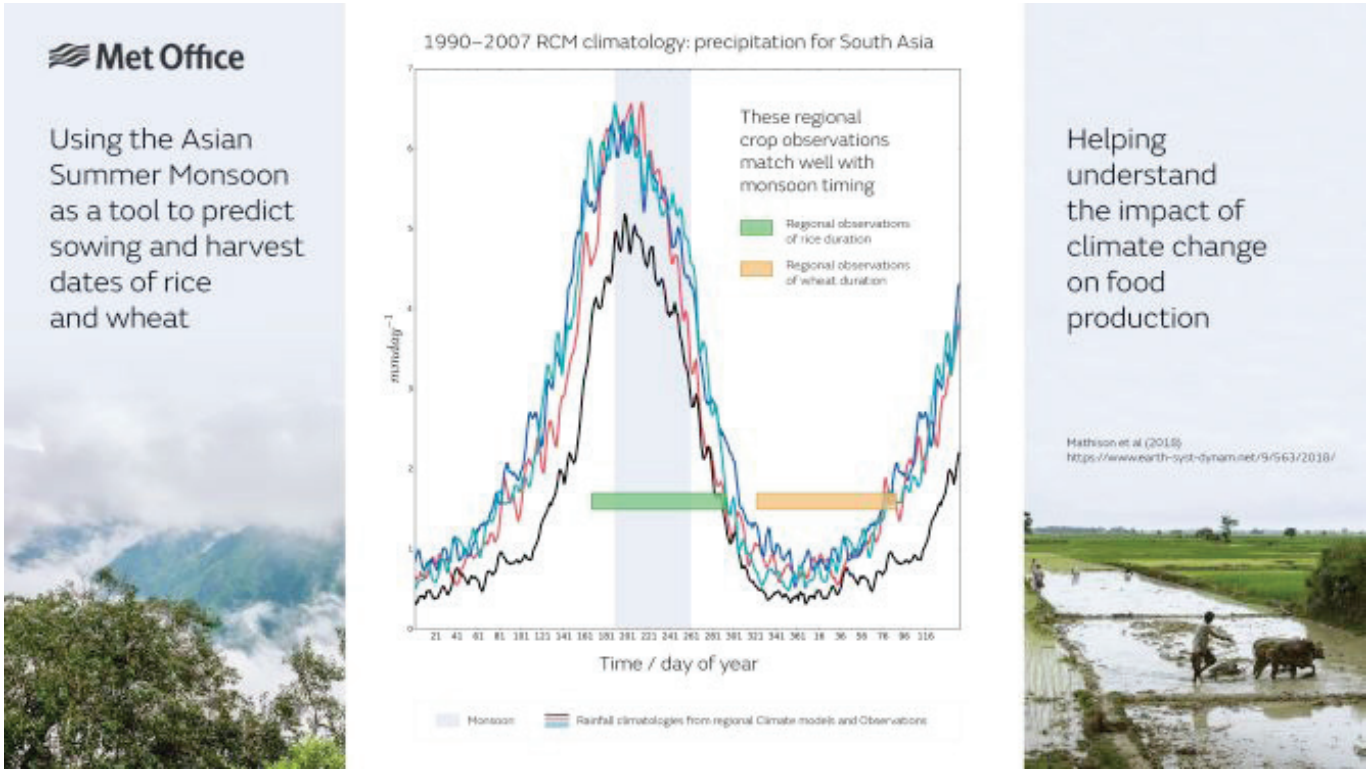

Improving the simulation of crops in South Asia.

Keywords: Rice, Wheat, monsoon.

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S5-P.36

Implementation of multiple cropping into a global gridded crop model

Waha Katharina[1] (katharina.waha@csiro.au), Müller Christoph[2]

[1] *Global Food and Nutrition Security, CSIRO, St Lucia, QLD, Australia*; [2] *Climate Resilience, Institute for Climate Impact Research, Potsdam, Germany*

Introduction

Multiple cropping systems, with two or more crops grown in a sequence, are common and a widespread management strategy in low-land tropical and subtropical agriculture where rainy seasons are long enough or irrigation is viable. It allows for risk-spreading and diversification to different growing seasons and different crops for own use or markets if farmers have access to seeds, fertilizer, water and labour. Multiple cropping systems are often intensively managed systems in which the same crop is harvested several times, but can also exist as a highly diverse cropping system with several crops grown in a sequence and intercropped. In the past, increases in harvest intensity accounted for 9% of the global crop production growth and 31% of the crop production growth in sub-Sahara Africa between 1961 and 2007 (Ray and Foley 2013; Alexandratos and Bruinsma 2012). The current generation of global land use and agricultural models tend to neglect some important feedbacks in agricultural production systems such as interactions between different crops in multiple cropping systems and instead mostly simulate monocultures and specialized crop systems. It is expected that overcoming this shortcoming will increase the accuracy of simulated crop production, climate change impacts on crop production and water fluxes in agricultural systems and the representation of agricultural management strategies in global crop models.

Materials and Methods

The implementation of multiple cropping requires (i) a representation of multiple cropping systems in the input file describing current land use and area shares of different crops and cropping systems and (ii) model development towards simulating cropping sequences in addition to single crops. The multiple cropping area and systems are estimated from a global data set reporting the monthly growing area of 26 crops based on national and sub-national crop calendars (Portmann, Siebert, and Döll 2010). Model development in the global gridded crop model LPJmL requires a division of crop 'stands' into single and double cropping stands. Stands are subunits of grid cells and represent different types of land use (Schaphoff et al. 2018). Crop parameters for shorter and longer growing varieties in single and double cropping systems differ to represent observed differences in the length of growing periods. Phenological heat units (PHU) of crop varieties grown in double cropping system are about 80% of the PHU of crop varieties grown in single cropping systems (67% for cassava to 99% for groundnut) (Waha et al. 2013).

Results and Discussion

We estimate that multiple cropping is prevalent on 135 million hectares (Mha) or 12% of global cropland (**Fig. 1**). Our results suggest that double cropping extents to 130.4 Mha (11.3%) with 81.5 Mha irrigated and triple cropping extents to 4.1 Mha globally (0.35%) with 2.9 Mha irrigated. Single cropping extents to 1020.6 Mha land (88.4%) with 132.1 Mha irrigated cropland. This amounts to 1.16 billion hectares and represents the global physical cropland extent without fallow land. 44% (49.63 Mha), 13% (24.12 Mha) and 10% (13.49 Mha) of the rice, wheat and maize area, respectively are under multiple cropping, making it an important cropping system for cultivating these crops. Crop calorific yields in single cropping systems are only 38–54% of crop calorific yields in sequential cropping systems due to shorter growing periods.

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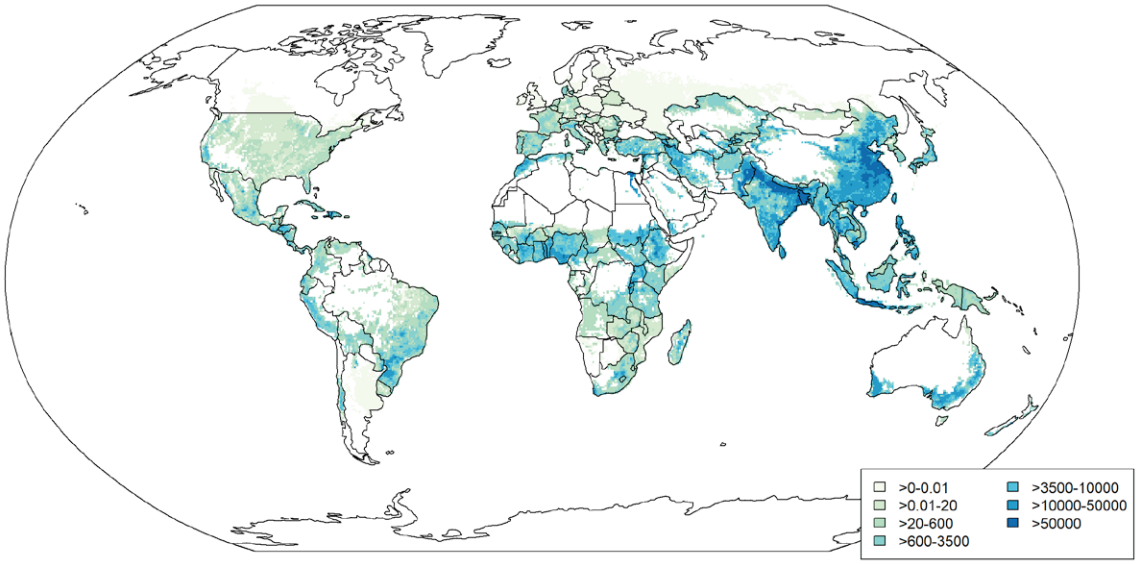

Figure 1 Physical area (ha) of all multiple cropping systems in each 30 arc-min grid cell, 1998-2002. White areas indicate locations with total crop area less than or equal to 1% of the grid cell area.

Keywords: sequential cropping, double cropping, crop management, crop parameter.

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S5-P.38

Modelling crop growth and soil organic carbon, nitrogen and phosphorus at the long-term fertilizer experiment Dikopshof

Seidel Sabine J.[1] (sabine.seidel@uni-bonn.de), Gaiser Thomas[1], Krauss Gunther[1], Hüging Hubert[1], Bauke Sara L.[2], Gocke Martina I.[2], Welp Gerd[2], Pätzold Stefan[2], Amelung Wulf[2], Ewert Frank[1]

[1] *INRES, University of Bonn, Crop Science Group, Bonn, Germany*; [2] *INRES, University of Bonn, Soil Science and Soil Ecology, Bonn, Germany*

Introduction

An appropriate soil organic carbon (SOC), phosphorus (P) and nitrogen (N) management in agriculture is a key for soil fertility and for mitigation of and adaptation to climate change. Long-term experiments are essential for our understanding of how changes in climate and in agricultural management influence soil nutrient dynamics, carbon sequestration and yields.

Materials and Method

The long-term fertilizer experiment (LTFE) Dikopshof, Germany, was established in 1904 with a 5-year crop rotation sugar beet, wheat, rye, clover and oat/potato on a fertile Haplic Luvisol formed from loess. We used this unique source of historic and recent soil and crop data spanning over more than a century to analyze the impact of farmyard manure (FYM) and mineral fertilizer application (NPKCa), P fertilizer omission and no fertilization on the shoot biomass production of five crops and on SOC, P and N dynamics with a soil-crop model.

The experimental data were used to simulate daily crop growth including crop water, and N and P uptake of selected treatments. For that, the modeling platform SIMPLACE was extended by two model components: The SimComponent SoilCNP calculates turnover processes of soil organic C, N and P in multiple pools in multi-layered soil profiles based on Corbeels et al. (2005). The SimComponent NPKDemandSlimNP calculates crop N and P demand and uptake and the turnover and leaching of soil mineral N (Addiscott and Whitmore, 1991). Moreover, the crop P demand and uptake and the soil mineral P dynamics are simulated in NPKDemandSlimNP (Jones et al.,1984). Crop growth is simulated based on Lintul5 (Wolf, 2012). In this study we focused on the four treatments NPKCa+FYM (receives highest mineral fertilizer amounts and about 12 t $ha^{-1}y^{-1}$ of FYM), NPKCa (same as NPKCa+FYM but without FYM), N_KCa (same as NPKCa+FYM but without manure and P) and the unfertilized treatment (control). The model was set up for four treatments using field data (i.e. sowing dates, fertilizer management, soil texture) from 1906 to 2018.

Results and Discussion

After calibrating the phenology parameters, the model was calibrated using the biomass data of each crop from treatment NPKCa+FYM. Simulations were compared to time series of observed biomass data of the other three treatments and to observed soil SOC, total N and P data. After transient simulations over more than 110 years, our model was able to describe the harvesting dates, shoot biomass (Fig. 1) and the SOC, total N and P observations. Increased fertilizer additions resulted in increased simulated biomass and higher stocks of C, due to FYM application in treatment NPKCa+FYM but also because of an increased formation of soil organic matter in the soil (NPKCa, N_KCa > control), since the crop residues in all treatments were removed. SOC contents in the Ap horizon varied considerably between the treatments, but trends were obvious: as expected, the addition of farmyard manure resulted in higher final stocks of C in the soil compared to the control treatment and we observed and modelled a post-millennial increasing loss of topsoil C.

Conclusions

We conclude that simulation studies on LTFEs improve our understanding of long-term effects of nutrient application on crops and soils.

Acknowledgements

The study was funded by the Federal Ministry of Education and Research (BMBF), Germany (BOMA03037514) and the Deutsche Forschungsgemeinschaft (DFG) under Germany's Excellence Strategy - EXC 2070 – 390732324.

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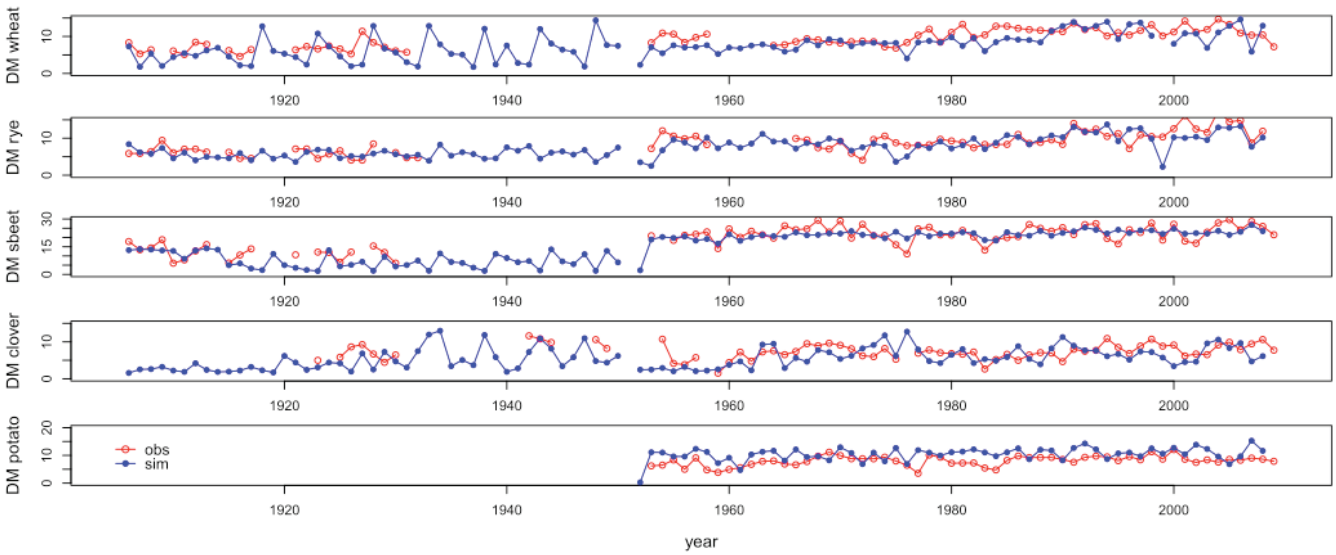

Fig.1: Observed (red) and simulated (blue) total dry matter (DM) above-ground biomass in t ha-1 of (from top to bottom) winter wheat, winter rye, sugar beet, persian clover (third cut) and potato (treatment NPKCa+FYM) at Dikopshof.

Keywords: long-term field experiment, soil organic carbon, phosphorus, nitrogen, crop modelling.

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S5-P.39

Modelling maize response to N application in the Nigeria savannas with and without P fertilization

Tofa A. I.[1] (A.Tofa@cgiar.org), Kamara A. Y.[2], Chiezey U. F.[3], Babaji B. A.[3], Beah A.[4]

[1] *Agronomy, IITA, Tarauni, Kano, Nigeria*; [2] *Agronomy Unit, IITA, Tarauni, Kano, Nigeria*; [3] *Department of Agronomy, Ahmadu Bello University, Zaria, Kaduna, Nigeria*; [4] *Department of Geography, Bayero University, Kano, State, Nigeria*

Introduction

The Decision Support System for Agricultural Technology Transfer (DSSAT) presents an important opportunity for extrapolating short-duration field experimental results to other years and other locations making use of long-term weather and soil information. The use of crop growth simulation models to estimate more general recommendations has been suggested as most appropriate because it takes into consideration genetic, environment, and crop management interaction and its effects on grain yield (Fosu-Mensah and Mensah, 2016). . The objective of the study was to assess the performance of DSSAT in simulating the effect varying N and P on grain yield of medium maturing maize varieties in three agro-ecologies of northern Nigeria.

Materials and Methods

The CERES-maize model was calibrated and validated with field data sets collected during the 2015 and 2016 rainy seasons from Samaru and Iburu research farms by comparing simulated and measured values of days to anthesis, days to physiological maturity, harvest index, grain yield, and shoot weight at maturity. Model statistics used to evaluate model performance included: root mean square error (RMSE), normalized RMSE, and *d* statistic (Willmott at al., 1985). Two improved and medium maturing maize varieties (SAMMAZ-15 and SAMMAZ-16), seven N rates (0, 30, 60, 90, 120, 150 and 180 kg N ha-1), and three P rates (0, 30 and 60 kg P2O5 ha-1) were compared in Kano Sudan savanna (SS), Samaru, northern Guinea savanna (NGS), and Abuja, southern Guinea savanna (SGS) using the seasonal analysis tool of DSSAT v4.7.

Results and Discussion

The DSSAT v4.7 CERES-maize model was successfully calibrated and evaluated under Guinea savanna agroecological conditions. Predictions were generally very good and closely conformed to the observed field data. Results of seasonal analysis from a 30-year period for the different N and P showed that when no P fertilizer was applied, applying N fertilizer beyond 60 and 30 kg N ha-1 in Kano and Samaru, respectively, resulted in marginal grain yield for both varieties at 25% probability. In Abuja, grain yield increased with increasing N application up to 90 and 60 kg N ha-1 for SAMMAZ 15 and 16, respectively when P was not applied. However, with application of 30 kg P2O5 ha-1 the results shows that at 75% probability, grain yield increased with increase in N fertilizer up to 150 kg N ha-1 in Kano and Samaru and up to 120 in Abuja, for both varieties. Meanwhile, in Kano and Samaru, applying N fertilizer beyond 120 kg N ha-1 did not show much difference in grain yield. Applying 120 kg N ha-1 and 30 kg P ha-1 farmers are guaranteed grain yields of at least 2654 and 2353 kg ha-1 in Kano, 4900 and 4200 kg ha-1 in Samaru and 3500 and 3300 kg ha-1 in Abuja, each for SAMMAZ-15 and SAMMAZ-16, respectively. This result was in conformity with the findinds by Onasanya et al. (2009) whose reports confirms the role of nitrogen and phosphorus fertilizers in increasing growth and yield of maize production in Nigeria. According to the economic analysis of this study application of 150 kg N ha-1 + 30 kg P2O5 ha-1 in Kano and Samaru, and 120 kg N ha-1 + 30 kg P2O5 ha-1 in Abuja were found to give the optimum monetary returns with marginal increases in mean returns at higher N application rates.

Conclusions

Maize response to N was dependent on application of phosphorus. Irrespective of P application maize grain yield increased with increase in N application. Increasing P from 0 to 30 kg P2O5 ha-1 significantly improved maize performance; further increase to 60 kg P2O5 ha-1 did not show much difference on grain yield in all the study areas for both varieties. SAMMAZ 15 was found to be more responsive to added N and P rates in the three agro-ecologies. Therefore, DSSAT model can be used to drive best management options in proportion to environmental conditions.

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Keywords: DSSAT, Nitrogen, Phosphorus, Intermediate maize.

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S5-P.41

In-season yield forecast analysis for peanut in Georgia, USA using CRAFT-DSSAT

Castillo Oscar (ocastilloromero@ufl.edu), Hoogenboom Gerrit, Shelia Vakhtang, Boote Kenneth

Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States

Introduction

In-season crop yield forecasting is a valued analysis that provides decision support information for food security, resource use efficiency, and crop management alternatives based on future weather uncertainty and climate variability that affect crop production. CCAFS Regional Agricultural Forecasting Toolbox (CRAFT) is a gridded crop simulation support tool that performs seasonal yield forecasts by using the Decision Support System for Agrotechnology Transfer (DSSAT) as a crop engine and the Climate Predictability Tool (CPT) (Hoogenboom et al., 2019; Jones et al., 2003; Mason and Tippett, 2019; Shelia et al., 2019). The goal of this study was to evaluate in-season peanut yield prediction in a spatio-temporal context.

Materials and Methods

Daily weather data from 1984 to 2018 was obtained from the NASA POWER (https://power.larc.nasa.gov/) and the Climate Hazards Group InfraRed Precipitation (https://www.chc.ucsb.edu/data/chirps) portals. The soil data was downloaded from the Global High-Resolution Soil Profile Database for Crop Modeling Applications (https://harvestchoice.org/publications/global-high-resolution-soil-profile-database-crop-modeling-applications). The peanut crop mask for 2018 was obtained from the United States Department of Agriculture (https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php). Crop management and initial conditions were assumed good with respect to soil water, nitrogen, and organic matter content under rainfed conditions. CRAFT workflow begins with the yield simulation per grid cell, it also includes observed yield-detrending and simulated yield calibration. Simulated calibrated yield for 35 years is used as predictand, and sea-surface temperature observations as the predictor employing for this purpose multivariate statistical and a canonical correlation analysis (CCA). Yield forecast for 2018 is conducted based on the CCA training (Hansen et al., 2004).

Results and Discussion

Peanut growth and development were simulated from 1984 to 2017 and then yield data was calibrated against reported values. Planting date was May 1st with a crop growing cycle from five to six months. Forecast for 2018 uses multiple dates during the current growing season with different lead times such as the first day of May, June, July, August, and September to study at what point during the growing season we likely could get better results of yield prediction. The results show that yield forecasts through the season follow a slow increasing behavior as the harvest date is approached. This may be due to the lack of available information provided to the crop model, and the assumption that there was good management, including irrigation. The figure below shows a map representing the quartiles of the distribution of yield forecast. At State level, the best results were obtained when forecast date is in mid-June according to the observed yield (4,988 kg ha^{-1}). Spatial variability of forecast showed a 45 percent of correlation and a 80 percent for linear error in probability space (LEPS). The aggregation process represented a trade-off of values where the predicted observed difference is within 19 percent.

Conclusions

Peanut yield was predicted for each grid cell in the southern region of the Georgia State for 2018 using several forecast dates during the growing season. The regional yield forecast evaluation showed that forecasting during June resulted about 3% difference compared to the observed yield.

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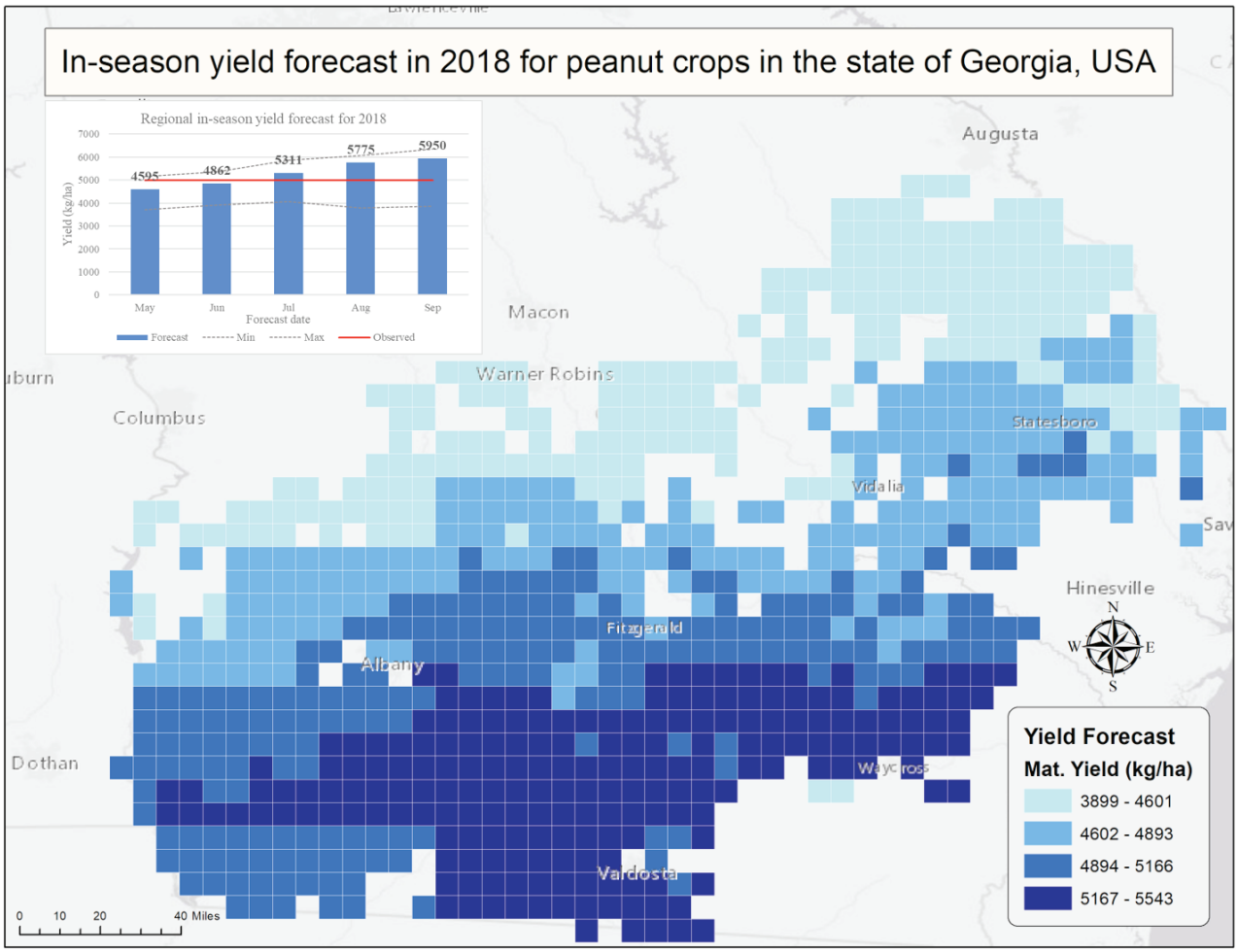

Spatial variability of in-season yield forecast for peanut crop in 2018.

Keywords: Gridded crop model, Decision Support, Sea-Surface Temperature, Economic Impacts.

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S5-P.42

A global review of local yield forecasting approaches and the required data resources

Schauberger Bernhard[1] (schauber@pik-potsdam.de), Jaegermeyr Jonas[1], Gornott Christoph[2]

[1] *PIK Potsdam, Potsdam, Germany*; [2] *PIK, Pot, Germany*

Introduction

Forecasting crop yields is an art. Knowing already several weeks in advance how much there will be on the field at harvest time requires an idea of future events and how these will influence yield formation. Yet farmers, agricultural markets, insurances, seed traders or logistics companies and regional authorities necessitate an outlook on expected harvests to adapt their management of fields, firms or food balances to foster food security. There is a multitude of techniques to forecast crop yields, both in the scientific literature and in practical application.

Materials and Methods

Here we present a systematic review of more than 300 existing and (mostly) successful approaches to forecast yields weeks or months before harvest time. These cover almost the whole globe and a large range of food and cash crops. Complementing this systematic review of methods we also describe a compendium of weather data, satellite products and crop masks that are necessary for forecasting yields and production.

Results

The compilation of results allows for an upscaling of small-scale approaches from field or regional level. A comprehensive data base of the reviewed articles is provided to enable a rapid lookup. Moreover, we delineate improvement options specific to crop, region and method. A strong bias in geographic coverage and crop selection of the current literature is apparent. Apart from methods, we provide a compendium of weather products, crop masks and satellite products necessary to successfully apply and upscale forecasts.

Conclusions

We conclude that forecasting crop yields during the season is reliably possible in certain areas and for certain crops, but we also encourage to study forecasting possibilities in neglected areas and crops in particular in the tropics.

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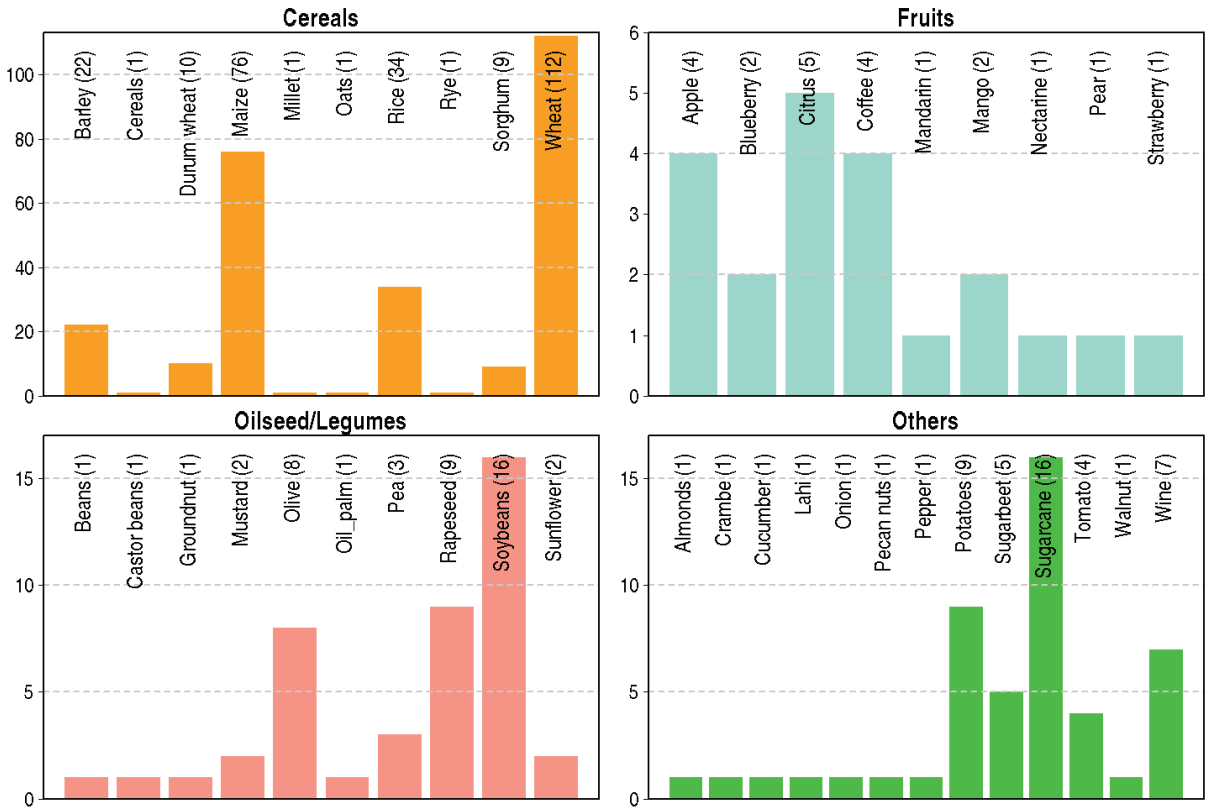

Crops with their number of studies on yield forecasts (out of 307, multiple mention possible).
Note the different scales across categories.

Keywords: yield forecast, global, remote sensing, crop model, weather.

S5-P.43

Institutionalizing crop modelling in Nepal using CRAFT (CCAFS Regional Agricultural Forecasting Toolbox)

Suman Saurav[1] (saurav.suman@wfp.org), Gyawali Dhiraj[2], Aboubacar Moctar[3], Shirsath Paresh[4], K C Arun[4], Aggarwal Pramod[4]

[1] *Evidence Policy and Innovation Unit, United Nations World Food Programme, Lalitpur, Nepal*; [2] *Hydrological modelling, University of Stuttgart, Stuttgart, Germany*; [3] *United Nations World Food Programme, Lalitpur, Nepal*; [4] *CCAFS / BISA / CIMMYT-India, Delhi, India*

Introduction

The unpredictability of crop yields in climate-vulnerable regions is damaging in many ways, negatively impacting food security as well as imports, exports, food prices, and livelihoods. The CCAFS Regional Agricultural Forecasting Toolbox (CRAFT) is an open source, flexible crop-forecasting platform that helps estimate the yields of major crops well in advance before harvest providing stakeholders and policy makers lead time in mapping out the response and proper planning.

Materials and Methods

CRAFT includes a crop-simulation module, a weather and seasonal forecast module, and a geographic information system module. The tool uses historical databases of weather and crop yields as well as the current weather to estimate the yield of various crops. The detailed process flow diagram of CRAFT has been laid out in figure 1. CRAFT uses DSSAT as the crop simulation module and divides a geographical area into grids for which separate inputs are given into the model and then the outputs are evaluated.

Results and Discussion

CRAFT has performed with good results at the national as well as sub-national level. The hindcast analysis using CERES-Wheat model gave a R squared value of 0.8849 that validates the model across historical time series. The model has showed a strong correlation between observed and the simulated yield of wheat in Nepal.

Conclusions

As CRAFT generated estimates and official MoALD estimates have aligned closely as illustrated in figure 2, the outputs of the tool can be used to provide information to ensure better management of agricultural risks associated with increased climate variability and extreme events. This could enable the stakeholders as policy makers, line agencies, cooperatives, extension workers and farmers to better prepare mitigation strategies to cope with the risks. CRAFT has been in use in Nepal since November 2014, forecasting wheat and paddy yields; forecast levels aligned closely with Ministry estimates. Currently, CRAFT is being used for yield forecasting at the sub-national level in Nepal.

Acknowledgements

This work has been made possible with the assistance of the European Union, Canadian International Development Agency, World Bank, New Zealand Ministry of Foreign Affairs and Trade and Danida and with the technical support of IFAD.

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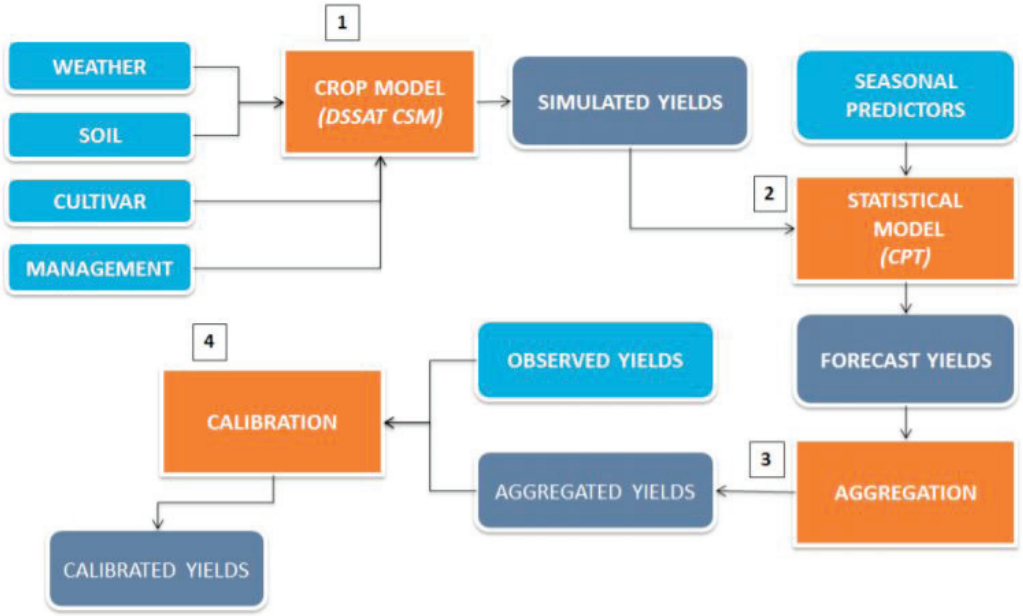

Figure 1. CRAFT process flow diagram (Hansen, 2013).

Keywords: Crop modelling, Climate change, Food Security, Agriculture, CCAFS.

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S5-P.44

Identifying eligible crop adaptations to climate change: application to sectors of wheat, potatoes and sunflower.

Bancal Marie-Odile[1] (marie-odile.bancal@inra.fr), Amato Delavoipierre Roxane[2], Drosne Léa[2], Delaunay Stella[3], Brustel Jean[3], Fontaine Mathilde[3], Laugnier Coralie[3], Massias Julien[3], Gate Philippe[4], Gravoueille Jean-Michel[5], Gaucher Denis[5], Preudhomme Hélène[6], Mestries Emmanuelle[7], Aubertot Jean-Noël[8], Debaeke Philippe[8], Robin Marie-Hélène[8], Deytieux Violaine[9], Launay Marie[10], Huber Laurent[1]

[1] *ECOSYS / EA, UMR INRA AgroParisTech Paris Saclay, Thiverval-Grignon, France*; [2] *AgroParisTech, Paris, France*; [3] *INP Ecole d'ingénieurs de Purpan, Toulouse, France*; [4] *Arvalis Institut du Végétal, Paris, France*; [5] *Arvalis Institut du Végétal, Boigneville, France*; [6] *Agro-Transfert Ressources et Territoires, Mons, France*; [7] *TerresInovia, Toulouse, France*; [8] *AGIR / EA, INRA INP Toulouse Ecole d'Ingénieur, Toulouse, France*; [9] *UE 115 Domaine d'Epoisses /EA, INRA, Epoisses, France*; [10] *US1116 AGROCLIM / EA, INRA, Avignon, France*

Introduction

For crop ecosystems facing climate change, plant health impacts of adaptations to major future abiotic stresses remain largely unknown. The INRA research project OPERATE aims at quantifying "crOP disEase Response to climATE change adaptation" for three crops: wheat, potato and sunflower. To do so, the first requirement is to identify potential consistent crop adaptation scenarios.

Materials and Methods

The initial step of the project was to define the main adaptation paths considered by each of the three crop sectors in France to counterbalance negative impacts and also benefit from opportunities provided by climate change. The increase of both average annual temperature and radiation is expected as well as the decrease of rainfall and rise of inter annual climate variability. Several scenarios of adaptation to climate change were built for each crop according to existing data and an interview with a number of crop experts from research or extension services. Then, their feasibility was discussed with main sector actors covering genetics firms, cooperatives, advisory organizations, and processing industries. Finally, three scenarios with different objectives were completed for each crop with the most feasible identified adaptations.

Results and Discussion

The main selected adaptations were (i) compensation strategies such as irrigation - with possible constrains in terms of investment and local water availability- and genetic improvement of the plant tolerance to water and heat stress, (ii) avoidance strategies such as changing the sowing dates and the range of precocity of varieties, and (iii) redesign strategies by proposing the introduction of related robust species like rye in the case of wheat, or agroforestry management practices. Other adaptations were abandoned, for instance the use of variety mixtures, difficult to sort, store or process, or agroforestry in the case of sunflower or potato, inducing too much competition for resources or investments, as well as early sowing for wheat, risky in terms of germination rates.

A lot of uncertainty remains on the extent of climate change, so that these propositions must still be considered as prospective paths that need to be further evaluated and discussed. So far, in the project, the consequences of the chosen adaptations on production, environment and sanitary risks will be quantified using different modeling frames to compare their adequacy to the objectives of the three crop sectors. Adequacy of selected adaptations and crop models is discussed at each step of the project – i.e. verifying expected climate change impacts on abiotic stresses and yield, then simulating how eligible adaptations limit negative impacts on production and environment outputs.

Conclusion

Eligible crop adaptations in terms of production and environmental risks will finally be evaluated and classed regarding the potential sanitary risks they imply in future climate conditions in France.

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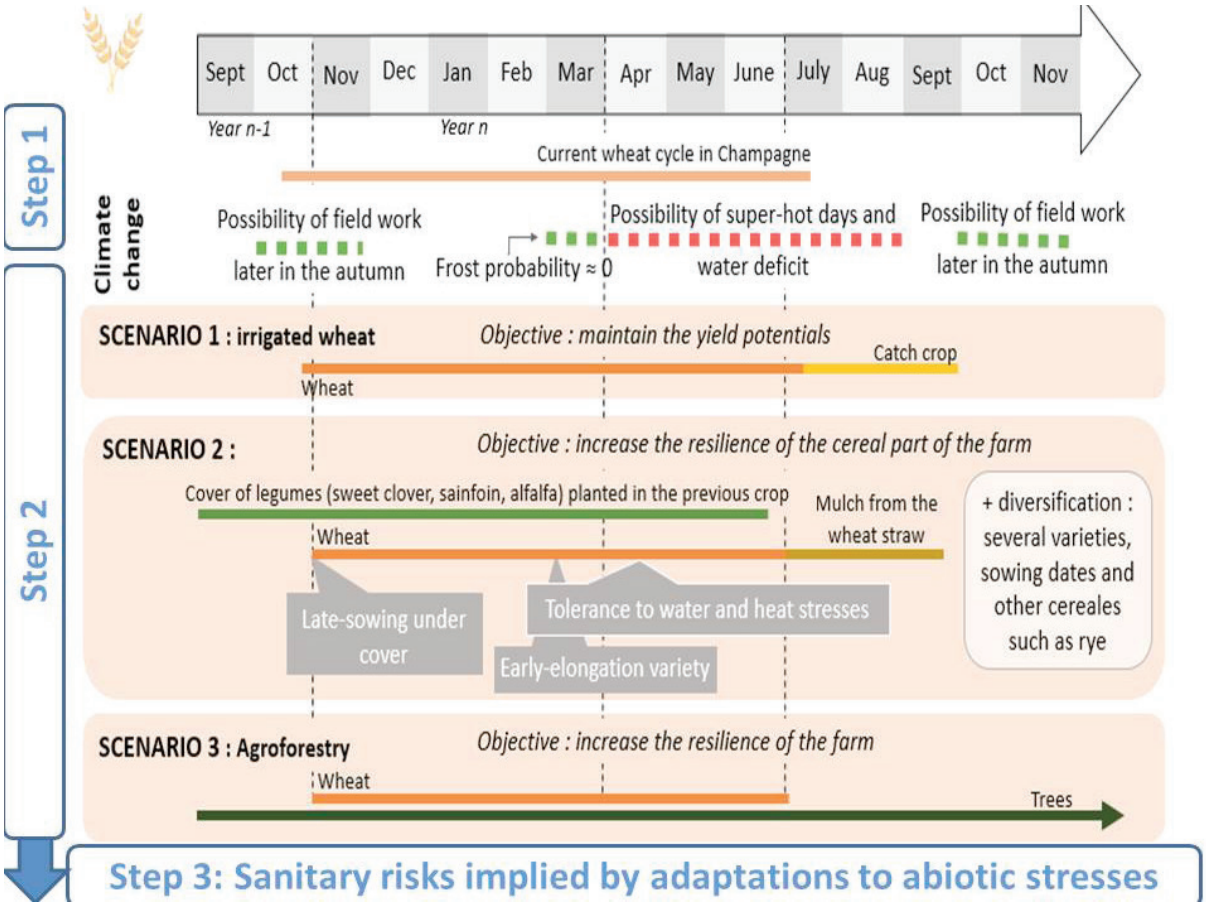

Figure 1: Steps in project mobilizing crop models. Step 1: Using a reference cropping system to identify main abiotic stresses with climate change using crop model (STICS without irrigation);
Step 2: Designing and simulating impacts of adaptation scenarii on yield and abiotic stresses:
Step3: Using different modeling frames (Stics MILA, IPSIM, disease infection functions to quantify sanitary risks.

Keywords: abiotic stresses, multi actor survey, production risks, environmental risks.

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S5-P.45

Towards optimal G×E×M to improve maize productivity and water use efficiency under hot areas and global warming

Deihimfard Reza (deihim@sbu.ac.ir), Rahimi-Moghaddam Sajjad

Environmental Sciences Research Institut, Shahid Beheshti University, Tehran, Iran

Introduction: Water limitation has become a major concern for agriculture sector in the present and future. This issue is more noticeable in fragile and drought-prone environments such as hot and semi-arid regions particularly under global warming conditions (Ye et al., 2015). In such agro-ecosystems, a sustainable maize production system could be achieved by considering the interaction of genotype, environment and management (G×E×M), particularly as effected by climate change (Rahimi-Moghaddam et al., 2019). The current research focused on finding the best G×E×M to increase maize yield and water use efficiency (WUE) under hot regions and global warming.

Materials and methods: The Agricultural Production Systems sIMulator (APSIM) (Holzworth et al., 2014) was applied to investigate the impact of future global warming on grain maize productivity and WUE in 15 locations of Khuzestan province in southwestern Iran for two cultivars (as genotype factor), two sowing seasons (as environment factor) and nine irrigation regimes (as management factor). The future climate of the study locations was projected using the baseline period of 1980–2010 and Miroc5 GCM (general circulation model) for 2040–2070 under two emission scenarios (RCP4.5 and RCP8.5) using AgMIP (The Agricultural Model Intercomparison and Improvement Project) methodology (AgMIP, 2013).

Results and Discussion: The results indicated that grain yield and WUE were reduced 6.04% and 5.4%, respectively across all locations and scenarios compared with the baseline. However, the reduction can be mitigated by applying an optimal G×E×M interaction. For winter sowing season, an early-maturity cultivar × 10-time irrigation per crop season was the optimal G×M while a late-maturity cultivar × 10-time irrigation over growing season had the best performance for summer sowing season in the future (Fig. 1). The results also indicated that shifting from winter maize cultivation to summer one in the upcoming period would have some advantages including a reduction in mean temperature (-2.6˚C), an increase in rainfall (81.3 mm) as well as an increment in the length of maize growing season (7.9 days). Under these circumstances, maize water consumption would be also reduced by 185.3 mm and WUE and grain yield increased by 4.3 kg ha-1 mm-1 and 88.3 kg ha-1 (Fig. 1), respectively.

Conclusion: Overall, the results illustrated that global warming will reduce maize grain yield and increase maize water consumption in the middle of the 21st century in hot and semi-arid regions. However, a sustainable maize production in hot and semi-arid areas can be achieved by choosing an optimal G×E×M in the upcoming global warming conditions.

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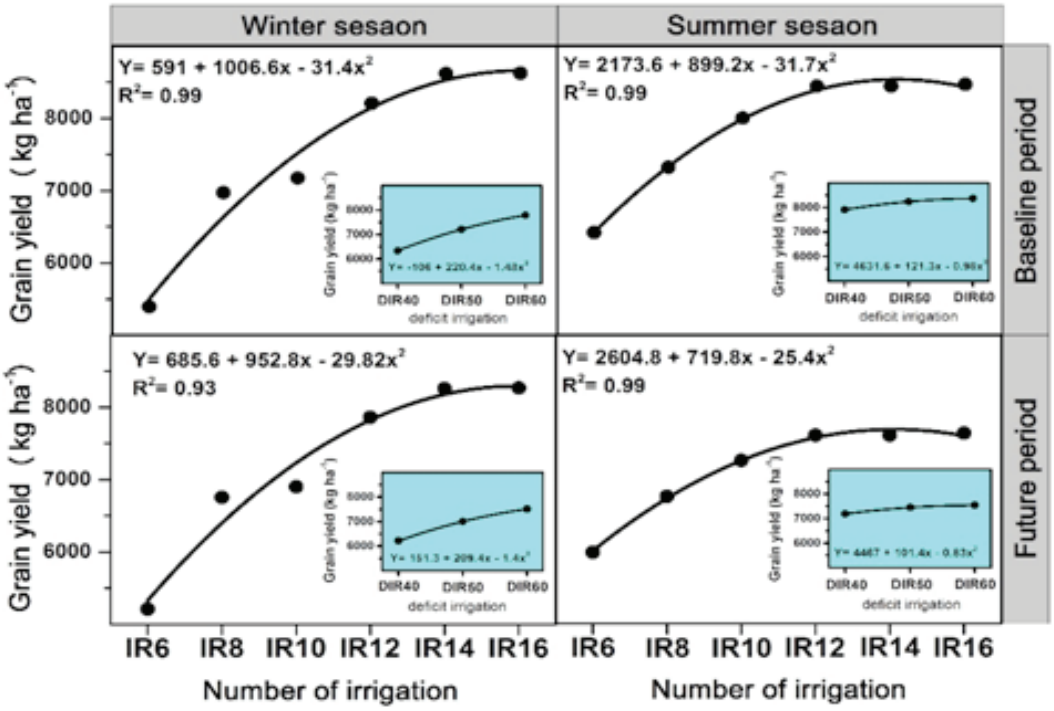

Figure 1. Relationship between grain yield and irrigation treatments at baseline and future scenarios in winter and summer seasons, averaged across all study locations. IR6, IR8, IR10, IR12, IR14 and IR16 are 6-, 8-, 10-, 12-, 14-, and 16-times irrigation per crop season. DIR40, DIR50 and DIR60 are deficit irrigations of 40%, 50% and 60% of 16- times irrigation per crop season.

Keywords: Climate change, APSIM, Sustainable production, AgMIP, Irrigation regime.

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S5-P.46

Adaptation to climate change in the agriculture in Lower-Saxony, Germany: soybean production potential in the future

Fajardo Andrea Catalina (andrea.fajardo@posteo.de)

GERICS (Climate Service Center Germany), Hamburg, Hamburg, Germany

Introduction

Agriculture is extremely sensitive to climate variability, which in line with climate projections can have several type of impacts. Solely, last year in Germany drought episodes affected heavily crop yields negatively. Specifically, in Lower-Saxony in Germany crop yields per hectare are 26% below the three-year average of previous years and according to IPCC report climate change will increase the probability of experiencing droughts and other extreme weather conditions.

Based on this, the motivation for this study was fourfold:

May new climatic conditions in the region lead to cultivate successfully new crops?

How to maintain fertile soils for agricultural purposes?

Soybean production in Brazil and Argentina is under increasing pressure. May legume production in Germany alleviate the problem?

There is an interest in producing more soybeans and other legumes locally with projects such as «Domestic protein from Lower-Saxony". However, soybean production needs to be increased by around 63% in order to compete with wheat.

Methods

The EPIC (Environmental Policy Integrated Climate) model was developed by the USDA (United States Department of Agriculture) to assess how agricultural activities affect the status of US soil and water resources. It has been continuously expanded to allow simulation of other processes relevant for agriculture.

Its major components are crop growth, yield and competition, weather simulation, hydrological, nutrient and carbon cycling, soil temperature and moisture, soil erosion, tillage, and plant environmental control. As EPIC calculates on a daily basis can be used for long-term soil assessments like humus build-up processes. It is analyzed the effects on yields, fertilizer and pesticide input, water use, potential humus build-up capacity and emissions for a future climate (2020-2100) for 3 RCPs (2.6, 4.5, 8.6), which is compared with a reference period (1979-2000). As the historical German weather data does not include all the parameters that EPIC requires, the rest are estimated by the model. Reanalysis data is also used in order to see how sensitive the model is to different climate data sources for the same location.

EPIC validation is conducted by comparing yields and inputs consumption with soybean field studies in Germany and real operation data for wheat, potatoes, sugar beet and maize from a real farm and reported yields. Its calibration is based on Wang et al. by including automatic fertilization, and decreasing the years of cultivation at the start of the simulation.

The scenarios to be tested are based on both management strategies and crop rotation. This means that for each crop rotation is simulated for every management option stated in table 1.

Expected results

From this analysis, it is expected to find two main results that will help to answer the questions in the introduction part:

The system is quite sensitive to climate change scenario in comparison with RCP 2.6. The presence of more frequent droughts due to higher temperatures will lead to extended vegetation periods, but will increase the water requirements from irrigation. The heat and water stresses could be reduced by optimizing the crop rotation and soil recovery operation.

Soybean production may be competitive in Lower-Saxony only with irrigation. The reduction of fertilizer by having soybeans within the crop rotation may represent an advantage. Humus build-up may be only significant in 50 years.

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Management Scenarios	
Irrigation options	Irrigation/No Irrigation
Operation Type	Conventional Operation (Chemical treatment)
	Ecological Operation (Mechanical Operation)
Crop Rotation (4 years period) 1. **BAU (Business as usual)** 2. **Soybean instead of maize** 3. **Soybean instead of wheat**	1. **BAU:** **Sugar beet** **Maize -> 2. Soybean** **Wheat -> 3. Soybean** **Potatoes**

Keywords: climate change, EPIC model, soybeans, emissions, humus build-up.

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S5-P.47

A UK climate-crop modelling capability for impact assessments on food security: plans and progress

Falloon Pete[1] (pete.falloon@metoffice.gov.uk), Challinor Andrew[2], Galdos Marcelo[2], Rivington Mike[3], Semenov Mikhail[4], Matthews Robin[3], Freeman Brendan[5], Pope Edward[6]

[1] *Met Office Hadley Centre, Exeter, Devon, United Kingdom*; [2] *School of Earth and Environment, University of Leeds, Leeds, United Kingdom*; [3] *Information and Computational Sciences, James Hutton Institute, Aberdeen, United Kingdom*; [4] *Plant Science, Rothamsted Research, Harpenden, United Kingdom*; [5] *Committee on Climate Change, London, United Kingdom*; [6] *Met Office Hadley Centre, Exeter, United Kingdom*

Climate change could affect UK food security through both national impacts such as direct effects on crop yields and agricultural practices, and international dimensions such as changing productivity and trade overseas. Given that the UK produces 60% of its food (Defra, 2017), risks to both domestic and international food production and trade were noted as a key priority in the recent Climate Change Risk Assessment (CCRA) (CCC, 2017). Climate impact assessments of food security often rely on crop models and are increasingly being delivered through coordinated model inter-comparison projects (MIPs) such as AgMIP and ISIMIP, which can help produce robust assessments, understand uncertainties and provide roadmaps for future model development.

However, results from MIPs can be difficult to communicate given they often produce wide spreads in impacts probabilities that may be difficult to interpret due to differences in model formulations and experimental design. In addition, such MIPs are largely conducted at the global scale, which is relevant to international dimensions of food security, but lacks the detail required for local to national adaptation planning such as informing future crop breeding programmes. Conversely, detailed local to national scale crop modelling studies may not be robust when scaled up to larger regions.

We therefore propose the development of a UK climate-crop modelling and impact assessment capability that would:

a) bring together key expertise and capability in crop-climate modelling (including a range of approaches such as models, crop indices and climate metrics) and required data across space and time scales in the UK;
b) facilitate coordinated participation in relevant MIP projects, and
c) deliver robust assessments of climate impacts on UK food security.

Activities under this plan will help to deliver improved assessments of climate-related risks, opportunities and adaptation needs for crops, both in the present-day and in the future. Outcomes from the new capability will deliver key, coordinated contributions to the Climate Change Risk Assessment, IPCC Assessment Reports and related assessments. Additional benefits will be realised through an improved understanding of crop-climate interactions, identification and focus on key science questions and research gaps, targeted model development, and ultimately pull-through from these findings to benefit the representation of agriculture in earth system models in the longer-term.

We present plans and progress towards these aims.

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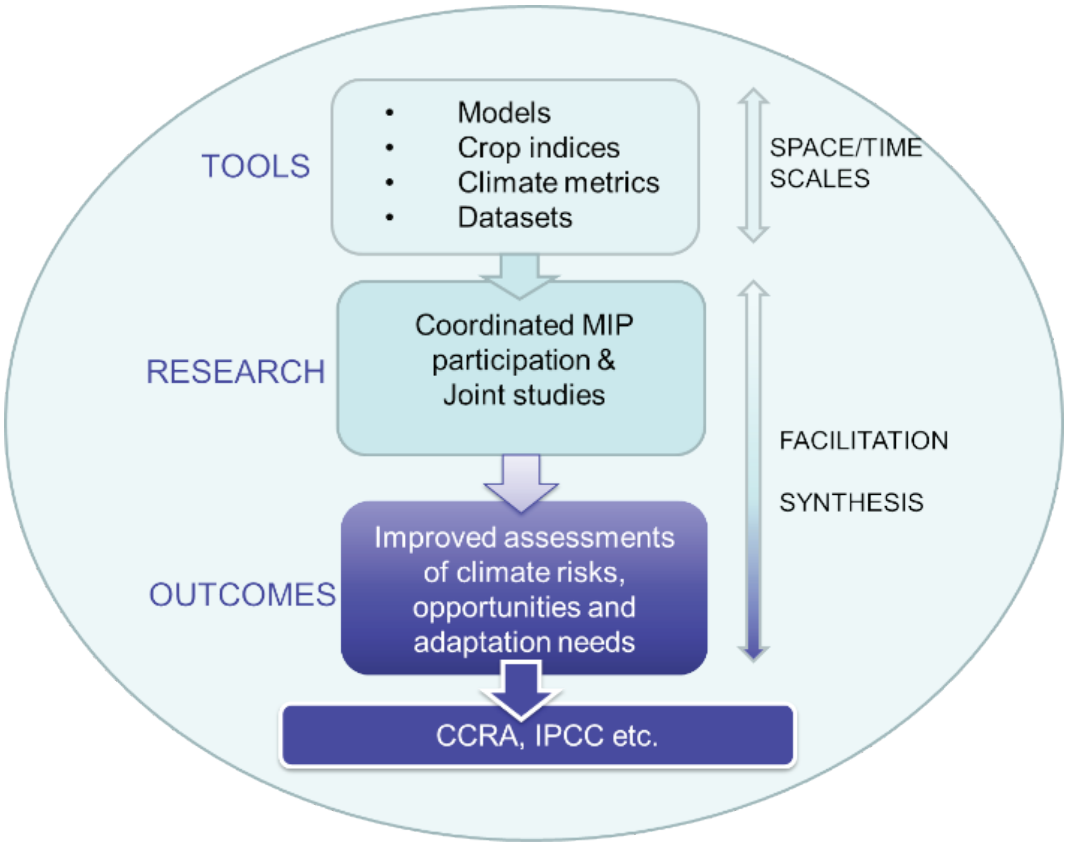

Figure 1. Outline framework for UK climate-crop modelling capability for climate impact assessments on food security.

Keywords: climate service, synthesis, coordination, intercomparison, frameworks.

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S5-P.48

Could crop irrigation requirements be reduced under future climate scenarios?

Garcia-Vila Margarita[1] (g82gavim@uco.es), R. Tenreiro Tomas[2], Fereres Elias[1]

[1] *University of Cordoba, Cordoba, Spain*; [2] *IAS-CSIC, Cordoba, Spain*

Introduction

Water resources are under increased pressure in the Mediterranean region. Predicted future climate scenarios in the region indicate an increase in crop water requirements thus affecting the limited irrigation supply. Maize is an important summer crop in the Guadalquivir basin (GB; Southern Spain), having the highest net irrigation water allocation (500 mm) after rice and some fruit trees. Although some studies address the impact of the CC on irrigated crops in the region (Gabaldón-Leal et al., 2015), the crop models used did not consider all the impacts of water stress on crop yield, unlike the AquaCrop model. In this study, the impacts of CC projections on maize irrigation water requirements (IWR), yield (Y) and irrigation water productivity (IWP) in the GB have been assessed using AquaCrop.

Materials and Methods

Four locations were selected across the GB, specifically, Jeréz de la Frontera, Sevilla, Córdoba and Jaén. AquaCrop was parametrized for local maize varieties using experimental data from the RAEA dataset that included about 30 varieties, 4 locations and 3 growing seasons. The simulated sowing date (15 March) was the average sowing date in the RAEA dataset, as well as the soil parameters for each location. To assess the CC impacts on the IWR of maize, we used as climate scenarios a reference scenario (current climate) and the RCP 8.5 scenario (IPCC) for the period 2070-2099, using the outputs of the GCMs with more pessimistic and more optimistic results of the 9 models analyzed, MIROC and CGCM3 models, respectively. According to these scenarios, we generated a synthetic 30-year series of climate data for each location using CLIMAGEN. Under these climate scenarios, AquaCrop was run to simulate the net IWR, the potential dry Y and the IWP (the ratio of the dry Y to net IWR). Once the impacts of these CC scenarios were analyzed in comparison with the reference scenario, the impact of an adaptation strategy (earlier sowing date, 1st February) was also assessed.

Results and Discussion

We found a 3-4% decrease in maize Y and a 15-22% decrease in net IWR under the RCP 8.5 scenario using the CGCM3 model. In the case of the MIROC model, the reductions range between 7-11% and 18-23% for the Y and net IWR, respectively. By contrast, the IWP increased 15-22% and 9-22% with CGCM3 and MIROC, respectively. The most negative impacts occur in Córdoba, while the most positive impacts were found in Jaén. The apparent causes of the lower IWR as compared to the reference scenario were primarily a shorter growing cycle, with additional contributions from a reduced transpiration and increased normalized WP. The lower Y suggested the need for adaptation measures which we assessed as earlier sowing (Fig. 1). Using CGCM3, earlier sowing increased Y by 2-4% with a 25-30% IWR reduction, leading to a 38-50% higher IWP. The reduction in IWR and the increase in IWP were even more enhanced with MIROC. Our results suggest that future maize production in the region will not be affected, even if the basin water resources decline, as estimated to be 32% less by CEDEX (2017) under the RCP 8.5 scenario.

Conclusions

A positive impact of CC on maize IWR in the GB is predicted, causing a reduction in future water demand and an increase in IWP. This positive response is enhanced by the implementation of adaptation strategies, such as earlier sowing, which also increases simulated Y.

Acknowledgements

The H2020 SHui project (Project nº: 773903) funded this research.

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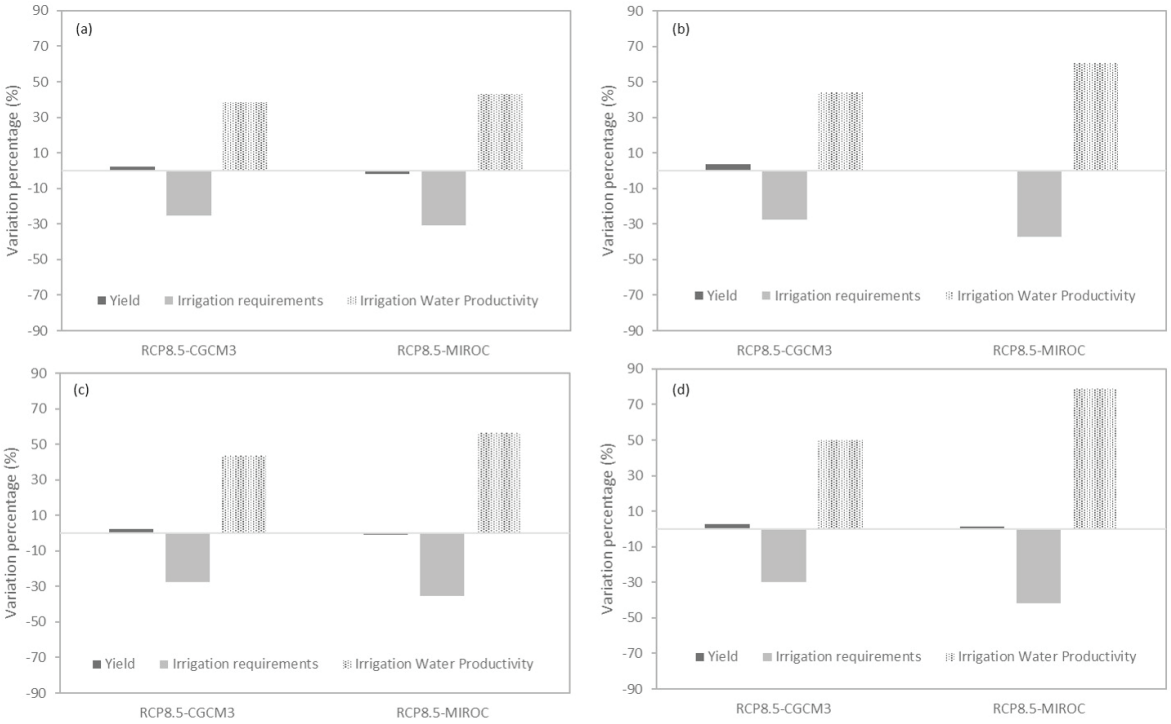

Figure 1. Variation percentage in dry yield, net irrigation requirements and irrigation water productivity for maize with earlier sowing date (adaptation strategy) under the RCP 8.5 scenario simulated with MIROC and CGCM3 models with respect to the reference scenario in four locations of the Guadalquivir river basin: (a) Jeréz de la Frontera; (b) Sevilla; (c) Córdoba; and (d) Jaén.

Keywords: Climate Change, AquaCrop, Water Productivity, Maize.

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S5-P.49

Application of DSSAT for climate change impact assessments and possible adaptation measures in rice farming, Sri Lanka

Nissanka Sarath[1] (spn@pdn.ac.lk), Karunaratne Asha[2], Weerakoon WIjayasiri[3], Punyawardena Ranjith[4], Wallach Daniel[5]

[1] *Department of Crop Science, University of Peradeniya, Peradeniya, Sri Lanka*; [2] *Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka*; [3] *Field Crops Research and Development Ins, Department of Agriculture, Mahailuppallama, Sri Lanka*; [4] *Natural Resources Managements Centre, Department of Agriculture, Peradeniya, Sri Lanka*; [5] *INRA, Toulouse, France*

Introduction

Rice production in Sri Lanka is greatly affected due to climate variability. This study aimed to assess the productivity of rice for 20 General Circulation Models (GCMs) for mid-century (2040 to 2069) and climate sensitivity of selected rice varieties using C3MP, and to identify possible adaptation measures to combat climate change impacts using DSSAT.

Methodology

Yield predictions for rice varieties (Bg300, At308, Bg357, Bg358, Bg379-2) grown in two seasons of major [October-February] and minor [April-September] at three locations (Rajanganaya, Nikawaratiya and Bathalagoda) in Kurunegala district were conducted for mid-century also with possible adaptation strategies, and compared the outcome with the baseline period of 1980-2010. Mid-century climate was generated using downscaled daily climate data for GCMs of the Fifth Phaseof Coupled Model Inter-comparison Project (CMIP5) archive.

Results and Discussion

The study demonstrated reasonably good agreement between field observations and predictions for selected locations. The RMSE ranged from 807 kg ha–1 (Rajanganaya) to 1111 kg ha–1 (Nikawaratiya) in minor season and 950 kg ha–1 (Bathalagoda) to 1046 kg ha–1 (Nikawaratiya) for major season. Compared to the baseline temperature (average of 1980-2010), the average acrossGCMs for mid-century, the minimum temperature increased by 1.9 ºC and 1.8 ºC for minor and major seasons, while the maximum temperature increasedby 1.8 ºC and 1.6 ºC, respectively. Average across GCMs, rainfall decreased by 2.2% in the minor season, while it is increased by 18.5% in the major season. The predicted rice yield decreased in all GCMs for both seasons. The mean reduction across GCMs for minor season is 30% (range from 15% - 40%) when compared to the major season of 16% (range from 7% to 24%). Reduction of the duration of grain filling and nitrogen use efficiency, and increased water stress were the main attributors for yield reduction. The overall mean annual yield reduction (across both seasons) of 22.5% in the mid-centurycould result a yield reduction of 1.04 mt/ha, causing a severe threat to country's food security. Climate sensitivity analysis (C3MP) conducted for Bg300 and Bg357 varieties reported that the Bg357 was more sensitive to carbon dioxide and temperature changes than Bg300 indicating a significant varietal variations in yield responses. Among the adaptation strategies assessed using the DSSAT for 5 GCMs (CCSM4, GFDL-ESM2M, HadGEM2-ES, MIROC5, MPI-ESM-MR)indicated that,significant genotypic variations exist in adapting to future climate. Three months old varieties of Bg300 and At308, and three and half monthsold varieties of Bg357 and Bg358 reported yield reductions of 9.6%, 31.6%, 34.7% and 12.8% for the minor season and 10.4%, 21.2%, 16.7% and 12.5% for the major season, respectively, across GCMs. Delaying of planting date by two weeks compared to the recommended planting time period was not having significant impact. However, split application of nitrogen (Urea) fertilizers reduces the yield losses and improves the N use efficiency which could also be considered as a viable adaptation strategy.

Conclusions

Overall results revealed a significant yield reduction for all tested rice varieties under all GCMs for mid-century when the same agronomic practices are adopted. Identification of tolerant varieties and split application of N fertilizers could be considered as suitable adaptation strategies to combat future climate change impacts.

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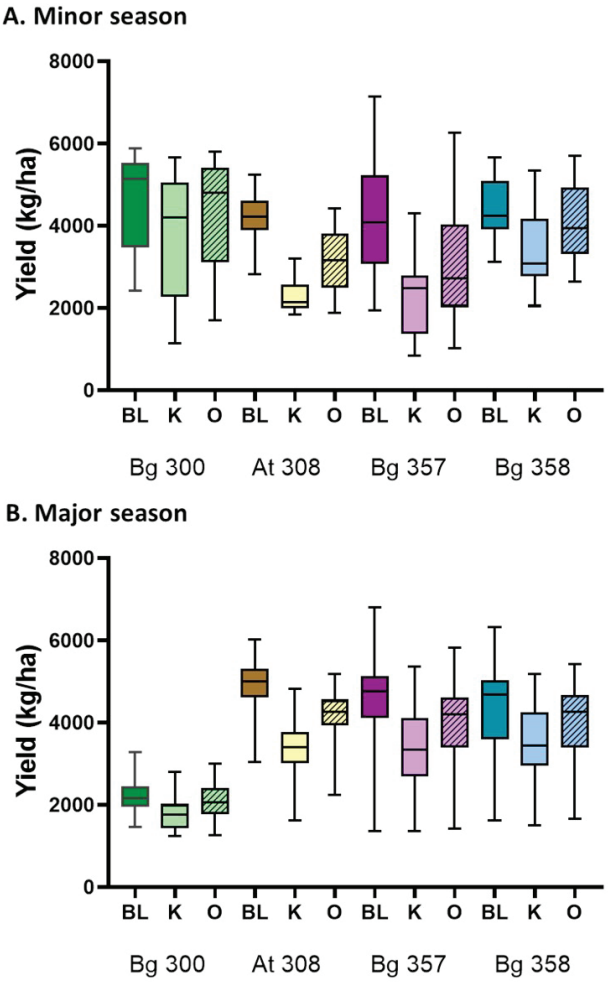

Comparison of rice yields forthe highest (K=HadGEM2-ES) andthe lowest (O=MIROC5) impacted GCMs out of 05 selected GCMs compared to the baseline (BL)for selected rice varieties.

Keywords: rice production, climate vulnerability, climate adaptation.

S5-P.50

Modelling of wheat production with the use of 3 crop models to assess impact of climate change and adaptation strategies

Krzyszczak Jaromir[1] (jkrzyszczak@ipan.lublin.pl), Baranowski Piotr[1], Zubik Monika[2]

[1] *Institute of Agrophysics PAS, Lublin, Poland*; [2] *Institute of Physics, Maria Curie-Sklodowska University, Lublin, Poland*

Introduction

Climate change uncertainty largely complicates adaptation and risk management evaluation at the regional level, therefore new approaches for managing this uncertainty are still being developed. For this purpose impact response surfaces (IRS) (Fronzek et al., 2018; Pirttioja et al., 2015) and adaptation response surfaces (ARS) (Rodríguez et al., 2019; Ruiz-Ramos et al., 2018) methodologies can be used. This approach is found to be effective for the visualization and rapid evaluation of model sensitivities across a wide range of combinations of climate changes that are not specific to individual projections from climate models.

Materials and Methods

Winter wheat (WW) yield responses were investigated under various adaptation measures and climatic changes at sites lying in varying climatic zones across a European transect: Lleida (Spain), Dikopshof (Germany) and Jokioinen (Finland). In this study 3 crop models were used (DNDC, WOFOST and DSSAT) to explore the utility of IRS and ARS methodologies.

IRSs depict the response of an impact variable to changes in 2 explanatory variables as a plotted surface. They are constructed by plotting the results of the sensitivity analysis of model outputs as contour lines along the axes of changes of the explanatory variables. To build IRS, the sensitivity of modelled yield to systematic increments of changes in temperature (-1 to +6°C) and precipitation (-30 to +50%) was tested by modifying values of baseline (1981 to 2010) daily weather. Four levels of CO_2 (360, 447, 522 and 601 ppm) representing future conditions until 2070 were considered.

Adaptation of crops to climate change has to be addressed locally due to the variability of soil, climate and the specific socio-economic settings influencing farm management decisions, which implies a high regional uncertainty for future conditions. In order to analyze the effect of an adaptation option under combinations of change of explanatory variables, IRSs are constructed both with and without the given adaptation option and for the same parameters and then the difference between the two is calculated. New plot is as an Adaptation Response Surface. To build ARS, adaptation options were: shortening or extending the crop cycle of the standard cultivar, sowing earlier or later than the standard date and additional irrigation.

Results and Discussion

Preliminary data indicate that yields are declining with higher temperatures and decreased precipitation. Yield is more sensitive to changes in baseline temperature values and much less sensitive to changes in baseline precipitation values for arable fields in Finland, while for arable fields in Germany, ARS indicates yield sensitivity at a similar level for both variables. Also, our data suggests that some adaptation options provides increase of the yield up to 1500 kg/ha, which suggest that ARSs may be valuable tool for planning an effective adaptation treatments.

Conclusions

This research shows how to analyze and assess the impact of adaptation strategies in the context of the high level of regional uncertainty in relation to future climate conditions. Developed methodology can be applied to other climatic zones to help in planning adaptation and mitigation strategies.

Acknowledgements

This study has been partly financed from the funds of the Polish National Centre for Research and Development ramework of the project BIO-FERTIL, contract number: BIOSTRATEG3/347464/5/NCBR/2017

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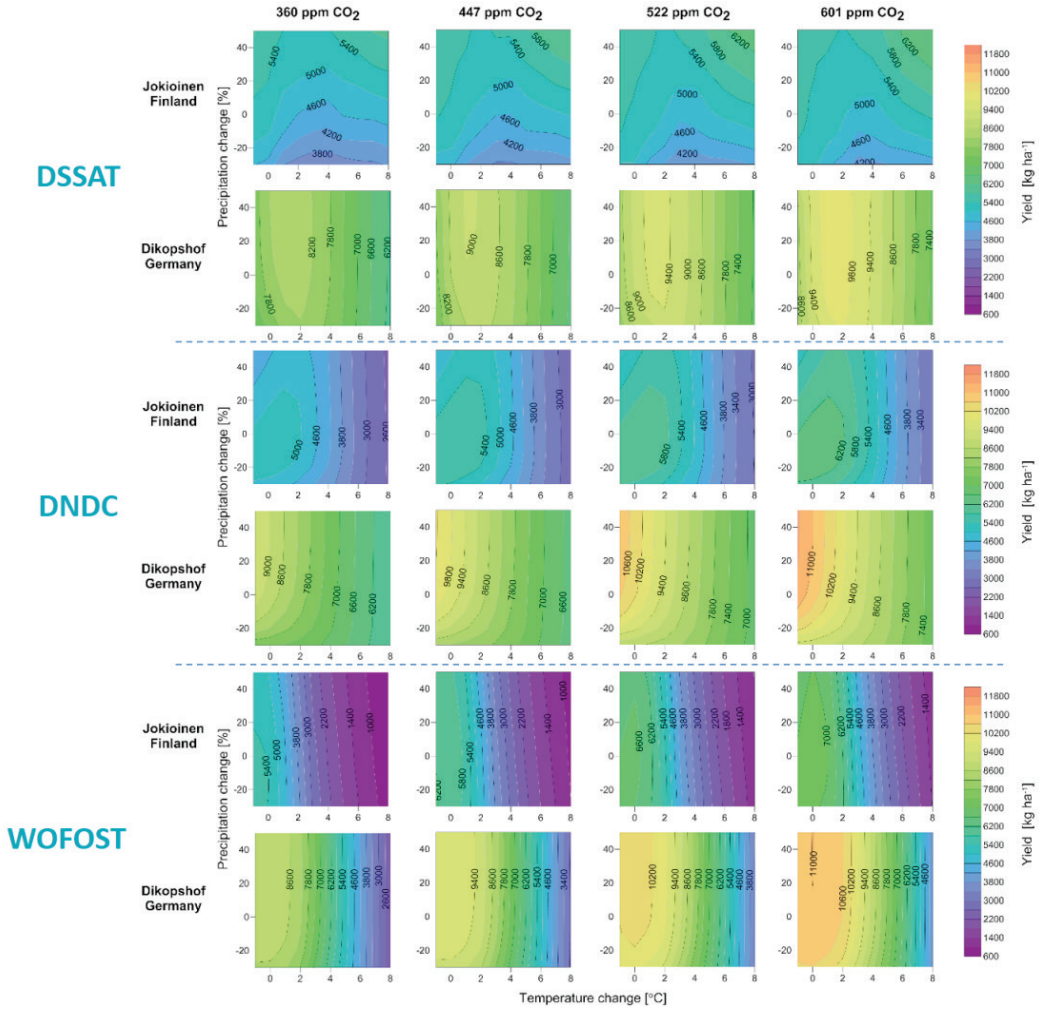

Exemplary impact response surfaces for winter wheat (WW) for different levels of CO_2 concentration and two locations (Jokioinen in Finland and Dikopshof in Germany) obtained using 3 models - DSSAT, DNDC and WOFOST.

Keywords: IMPACT RESPONSE SURFACES (IRS), ADAPTATION RESPONSE SURFACES (ARS), DNDC, WOFOST, DSSAT.

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S5-P.52

How much can irrigation reduce climate-induced risk to sustainably intensifying maize production in southern Africa?

Nelson William[1] (wnelson@gwdg.de), Koch Marian[1], Merante Paolo[1], Bracho-Mujica Gennady[1], Hoffmann Munir[2], Roetter Reimund[1]

[1] *TROPAGS, University of Goettingen, Goettingen, Niedersachsen, Germany*; [2] *ZALF, Muencheberg, Germany*

Introduction

Maize is the staple crop in Southern African drylands, but smallholder farmers are far from achieving potential yields. Climate change projections warn that low and variable yields will be exacerbated, making farming riskier without adaptation. Drought-tolerant cultivars (Cairns & Prasanna, 2018), balanced site-specific fertilisation (Rötter & van Keulen, 1997) and adjusted sowing (Rapholo et al., 2019) could reduce yield gaps and improve crop system resilience.

We examine the extent to which irrigation can reduce risk and support Sustainable Intensification (SI) of maize production in Southern African drylands. Various SI and adaptation options are studied in Limpopo Province, Republic of South Africa (RSA), where ca. 55% of households are far from food secure (de Cock et al., 2013) hypothesising that SI of maize production cannot be achieved without irrigation.

Materials and Methods

Two sites were chosen within the Limpopo Province that exemplify two ends of the soil-water holding capacity and rainfall spectrum: (i) Syferkuil, University of Limpopo, Mankweng, and (ii) University of Venda, Thohoyandou. Syferkuil has low-rainfall and limited soil conditions, with averaged total annual rainfall of 491 mm (1980-2010). The soil is a sandy clay loam, and has a plant available water capacity (PAWC) of 55 mm. Venda receives higher annual rainfall (847 mm) and is a well-drained sandy loam (PAWC of 143 mm).

Maize growth was simulated with the APSIM model (Holzworth et al., 2014) from 1981 to 2010. The response of several maize cultivars, including high-yielding (Hybrid614), and drought-tolerant (Katumani) cultivars was tested. Three irrigation levels (no irrigation: rainfall; deficit: 82 mm; and full: 149 mm) (averaged over 1981-2010), and three fertilisation treatments were applied (0, 90, and 180 kg/ha mineral N as urea; two intervals: sowing and 60 days after sowing).

Results and Discussion

Maize yields increased from 0 to 90 N kg/ha, with only a slight increase from 90 to 180 N kg/ha. Deficit irrigation led to strong yield gains compared to no irrigation, with only slight additional increases under full irrigation. Our simulation experiments address and quantify the point at which yield gains cease. They also highlight the most promising options for farmers from an economic point of view with current and expected maize prices as well as input costs under climate change projections and anticipated socio-economic trends.

Several scenarios were considered for input costs, such as energy and fertiliser vs. maize prices, as well as possible fluctuations to calculate gross margins and variable risk, for both the baseline and future periods. Energy price turned out to be most influential on economic viability for both periods.

Conclusions

Crop simulation results from two contrasting sites in the Limpopo Province prove deficit irrigation to be crucial to reduce maize production risks and gain benefits from yield-increasing inputs, such as N fertiliser. Risk-oriented management strategies that include adequate and economically viable combinations of irrigation, fertiliser and suitable cultivars are needed. It is vital to identify when irrigation, in particular, is a 'pre-condition', which can be evaluated *ex ante* using appropriate crop model simulation experiments.

Acknowledgement

South African Limpopo Landscapes Network (SALLnet) (grant no.: 01LL1802A); funded by the German Federal Ministry of Education and Research (BMBF), SPACE2 programme.

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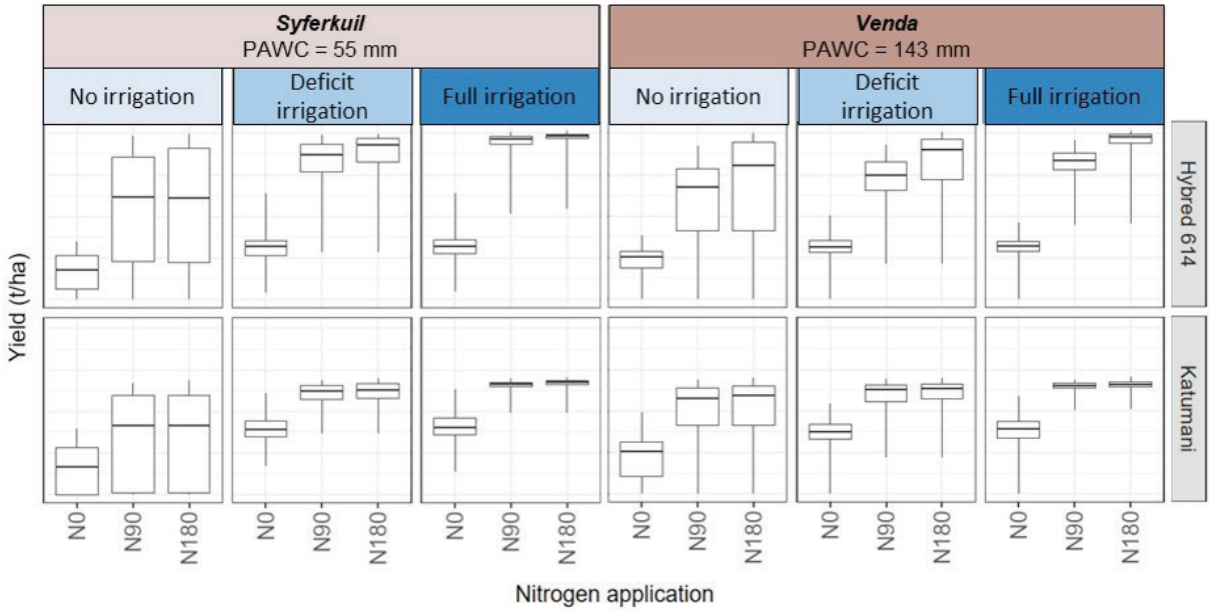

Figure 1. Maize yield of two cultivars (Hybrid 614: 136 and 159 days; and Katumani: 81 and 94 days in Venda and Syferkuil, respectively) from Venda (good soil) and Syferkuil (poor soil), with the respective Plant Available Water Capacity (PAWC) (water storage capacity of the soil) for each site. Three levels of irrigation (no: rainfall; deficit: 82 mm; and full: 149 mm), and three levels of N application (0, 90, and 180 kg/ha mineral N as urea in two intervals: sowing and 60 days after sowing) were applied for the weather data used (1981-2010). Each box represents a sample number of 30. The three horizontal lines indicate the 75% percentile (up), median (solid line across boxes) and 25% percentile yield (bottom); the upper and bottom bars outside the boxes show the maximum and minimum values respectively.

Keywords: Crop modelling, food security, risk management, sustainable intensification, water use.

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S5-P.53

Climate impact and adaptation for global wheat production

Pequeno Diego[1] (d.pequeno@cgiar.org), Hernandez-Ochoa Ixchel[2], Reynolds Matthew[3], Sonder Kai[1], Molero-Milan Anabel[3], Robertson Ricky[4], Silva Sabino Lopez Marta[5], Xiong Wei[6], Gerber Stefan[7], Babar Ali Md[8], Rowland Diane[8], Asseng Senthold[2]

[1] *SEP, CIMMYT, Texcoco, EDOMX, Mexico*; [2] *Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States*; [3] *GWP, CIMMYT, Texcoco, EDOMX, Mexico*; [4] *IFPRI, Washington, DC, United States*; [5] *IRTA, Barcelona, Spain*; [6] *SIP, CIMMYT, Beijing, China*; [7] *Soil and Water Sciences, University of Florida, Gainesville, FL, United States*; [8] *Agronomy, University of Florida, Gainesville, FL, United States*

Climate change impacts and adaptation strategies for wheat across the world were simulated for new crop genetic traits, including heat tolerance, early vigour and late flowering, and additional nitrogen (N) fertilizer applications with three wheat crop simulation models and five Global Climate Models (GCM) for RCP 8.5 at mid-century. The wheat simulation models including CROPSIM-CERES, CROPSIM, and NWheat within The Decision Support System for Agrotechnology Transfer (DSSAT) were selected for this study. The three wheat models share the same soil and water balance routines, which helps to standardize model inputs and assess model differences and uncertainty. The three models simulate on a daily time step using the radiation use efficiency (RUE) approach for crop biomass accumulation, also considering water and nitrogen dynamics including stress routines (Jones et al., 2003; Keating et al., 2001). Crop simulation models are embedded within the MINK system, which is a global-scale gridded simulation platform for the use of economic models for agriculture at global scale (Robertson, 2017). For the future scenarios, Representative Concentration Pathways (RCP) 8.5, which is the highest greenhouse gas emission scenario, was selected for mid-century (2050s) impact assessment. The RCPs are greenhouse gas concentration trajectories for future climate adopted by the Intergovernmental Panel on Climate Change (IPCC, 2013). Five downscaled and bias-corrected GCM scenarios from the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP, revised version from November 2015) were collected from the Potsdam Climate Institute (Mueller and Robertson, 2014). Daily temperature and rainfall values were extracted and averaged into monthly averages for the baseline period (1980 to 2010) and the 2050s future period (2041-2070). Calculated monthly changes were applied to the daily climate of the historical weather data (baseline) to create future scenarios. The resulting daily value of temperature is the old daily value plus the calculated change between the future monthly value from the GCMs and the historical monthly value; daily rainfall values were handled using the same procedure. Solar radiation remained unchanged for the future scenarios. Raster result files corresponding to each mega-environment cultivar, nitrogen level, sowing dates, GCMs, and crop models were combined in one single raster, keeping separated irrigated and rainfed simulations. Then, the baseline and future national wheat production was obtained by summing up all the wheat production by grid cell. Country yields were calculated running irrigated and rainfed production simulations separately and then dividing it to the total combined irrigated and rainfed areas to report the aggregated yield per country, which was later used to compare with the observed wheat yield and production data. Global wheat production changes due to climate change and adaptation strategies were then calculated by percentage difference between future scenario (without and with the adaptation strategies) and baseline global production. Preliminary results show that climate change is projected to reduce global wheat production, but adaptation strategies including heat tolerance, early vigor and late flowering could increase wheat yields and production, even with the ameliorative effect of warmer temperatures and changes in rainfall. As growing conditions and impact from climate change vary across the globe, more region-specific adaptation strategies are needed to be explored to increase the possible benefits of adaptations to climate change in the future.

Keywords: Wheat, Climate change, Adaptation strategies, Global, Yield.

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S5-P.54

Identifying Optimum Irrigation Strategy for Winter Canola in the Southern High Plains of the USA

Singh Paramveer[1] (param@nmsu.edu), Boote Kenneth J.[2], Schutte Brian[3], VanLeeuwen Dawn[3], Begna Sultan[1], Stamm Mike[4], Angadi Sangu[1]

[1] *New Mexico State University, Clovis, NM, United States*; [2] *University of Florida, Gainesville, FL, United States*; [3] *New Mexico State University, Las Cruces, NM, United States*; [4] *Kansas State University, Manhattan, KS, United States*

Introduction

Crop simulation models are important tools to increase the resource use efficiencies and have been used for several crops to determine optimum management strategies. In this study, CSM-CROPGRO-Canola model was used to simulate growth and yield of winter canola subjected to dormant period and in-season irrigation regimes. Deciding on a management strategy from a few years of field experiments at a single site is not ideal and has a high-risk factor. Crop simulation models offer a platform for exploration of results from a single site across several agroecosystems and seasonal variations; provided soils and weather data are available. So, the experiment was simulated for 10 years (2006-16) to quantify the effect of weather conditions on the performance of winter canola under different irrigation strategies.

Materials and Methods

The two-year field experiment was conducted at Agricultural Science Center (ASC), Clovis, NM (34° 36' N, 103° 12'W and 1331 m elevation) from 2016 to 2018. Eight combinations of two dormant period treatments (Applied-DI and not applied-NDI) and four in-season treatments (full irrigation-Irr, no irrigation during vegetative growth-VStss, no irrigation during reproductive stage-RStss, and no irrigation at all-RD) were used in this study. An area of 0.25 m2 was hand harvested at different intervals during the growing season for recording aboveground biomass. Five plants were harvested at maturity to determine pods per plant, seeds per pod, and seed weight. For seed yield, 9.2 m^2 plot area was harvested using a plot combine (Model Elite Plot 2001, Wintersteiger, Reid, Austria). Data from 2016-17 was used to calibrate the model and data collected in 2017-18 was used for model evaluation.

Results

The model predicted flowering and maturity date of winter canola satisfactorily. Aboveground biomass was underestimated in both years, but the gap was higher in 2017-18. Overall, seed yield was well simulated with RMSE=414, nRMSE=32%, d=0.92, EF=40, for 2016-17 and RMSE=341, nRMSE=19%, d=0.94, EF=60 for 2017-18, respectively. The model was unable to fully capture the water stress level during reproductive stage and thus, over-predicted seed yield for D+RStss, ND+RStss, and D+RD in 2016-17. With current calibration, model depicted lower risk involves with winter canola if dormant irrigation was applied (treatments- 1, 3, 5, and 7) irrespective of in-season irrigation treatments (Fig. 1).

Conclusion

With diminishing ground water, DI+RStss and DI+VStss appears to be optimum irrigation strategies for the region. These strategies require less water than DI+Irr (treatment-1) and are more reliable than NDI+Irr (treatment- 2) under varied precipitation amounts and distribution. In future, third year data (2018-19) will be evaluated. Soil parameters will be calibrated using Neutron Gauge data which will further improve model calibration. Later, experiment will be simulated for 30 years using weather data (Max and min. temperature, and precipitation) of Clovis Weather Station and satellite solar radiation data for the experimental site.

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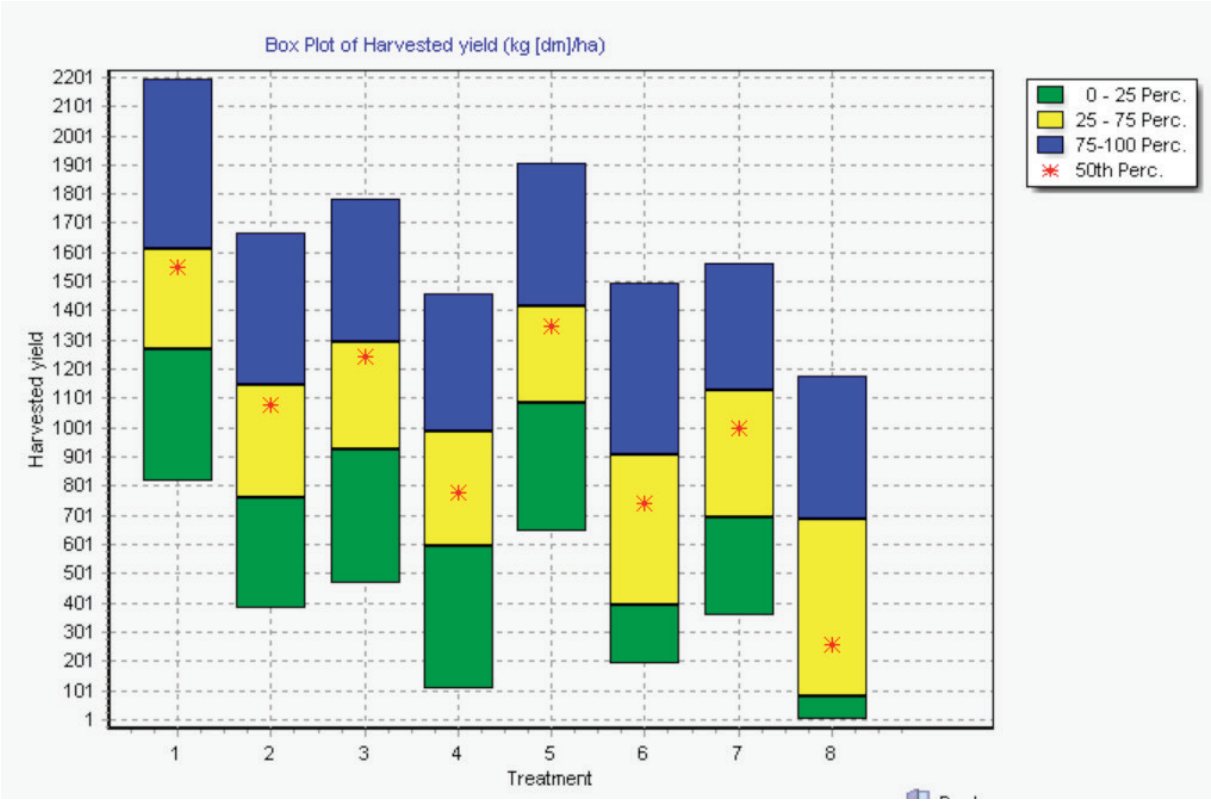

Figure 1. Variation in simulated winter canola yield under different irrigation treatments during 2006-2016. Treatments 1-8 refers to different irrigation strategies. 1. Dormant irrigation applied+full irrigation (DI+Irr) 2. Dormant irrigation not applied+full irrigation (NDI+Irr) 3. Dorman irrigation applied+no irrigation during vegetative stage (DI+VStss) 4. Dormant irrigation not applied+no irrigation during vegetative stage (NDI+VStss) 5. Dorman irrigation applied+no irrigation during reproductive stage (DI+RStss) 6. Dormant irrigation not applied+no irrigation during reproductive stage (NDI+RStss) 7. Dormant irrigation applied+no irrigation at all (DI+RD) 8. Dormant irrigation not applied+no irrigation applied (NDI+RD).

Keywords: CROPGRO-Canola, Dormant Irrigation, In-season Irrigation, Winter Canola.

S5-P.55

Designing cotton and durum wheat cropping system ideotypes by simulation for the future in the Mediterranean basin

Traoré Abdou[1] (abdou.traore@cirad.fr), Tsaliki Eleni[2], Chamekh Zoubeir[3], Loison Romain[4]

[1] *UPR AÏDA / CRA-Tambacounda, Cirad / SODEFITEX / ISRA, Tambacounda, Senegal*; [2] *Institute of Plant Breeding and Genetic, HAO-DEMETER, Thessaloniki, Greece*; [3] *National Agronomic Institute of Tunisia, Tunis, Tunisia*; [4] *UPR AÏDA / CRA-Tambacounda, Cirad, Tambacounda, Senegal*

Introduction

Cotton and durum wheat are two major crops in the Mediterranean basin. The impact of the agriculture on the environment, the impact of the climate on the crop and the increasing cost of inputs such as fertilizers and irrigation water urge the need for more sustainable cropping systems. The use of resilient cultivars, appropriate crop rotations and optimized use irrigation water and fertilizers should support farmers into more resilient income to the changes. Selecting more salt tolerant genotypes and improving water and nitrogen use efficiency (respectively WUE and NUE) are among the main targets of crop research for Mediterranean environments (Ayadi et al., 2016 ; Chamekh et al., 2016). Crop model could assist agronomists in this prospect. The project TomorrowS aims at the optimization of cropping system that use two major Mediterranean crops: cotton (*Gossypium hirsutum L*) and durum wheat (*Triticum durum*) and a legume in the rotation. For those two crops, optimized crop management adapted to projected climate change negative impacts will reduce inter-annual variability on crop yield. In addition, it will be designed cropping systems that are resilient to a reduced use of inputs due to uncertainties on irrigation water availability and fertilization costs.

Materials and Methods

Three years of cotton and durum wheat Genotype x Environment x Crop Management (GEM) experiments were and will be conducted in Greece and in Tunisia. The factors studied are the cultivar, amount of fertilization, amount of irrigation and, in Tunisia, the salt content of irrigation water (Figure 1). All data collected from these experiments are stored in a relational database. The relational database will be used to feed two deterministic crop models embedded in the Decision Support System for Agrotechnology Transfer (DSSAT) software application (Hoogenboom et al., 2017). The data should be sufficient to calibrate, evaluate and improve, if necessary, the two models in order to simulate observed GEM interactions. Then the models will be used to design virtual ideotypes of cropping systems based on tradeoffs between production, resilience, use of resources and uncertainty on production. In addition, economic viability of crop management ideotypes will be evaluated.

Results and Discussion

The results should contribute to (i) increase yield while reducing yield inter-annual variability, (ii) increase economic viability of farms by increasing water and fertilizer use efficiencies.

TomorrowS is a trans-disciplinary project that requires insights from agronomy, physiology, crop modeling, data management and economics to design the optimized cropping systems. The project will build a cooperation network between three researchers from Greece, Tunisia and France in order to help them to exchange knowledge and strengthen their scientific capacities.

The first results of crop modeling will be presented at the conference iCROPM$_{2020}$.

Conclusions

The project TomorrowS include sciences from agronomy, crop breeding, crop modelling. It should help farmers to improve their sustainability.

Acknowledgements

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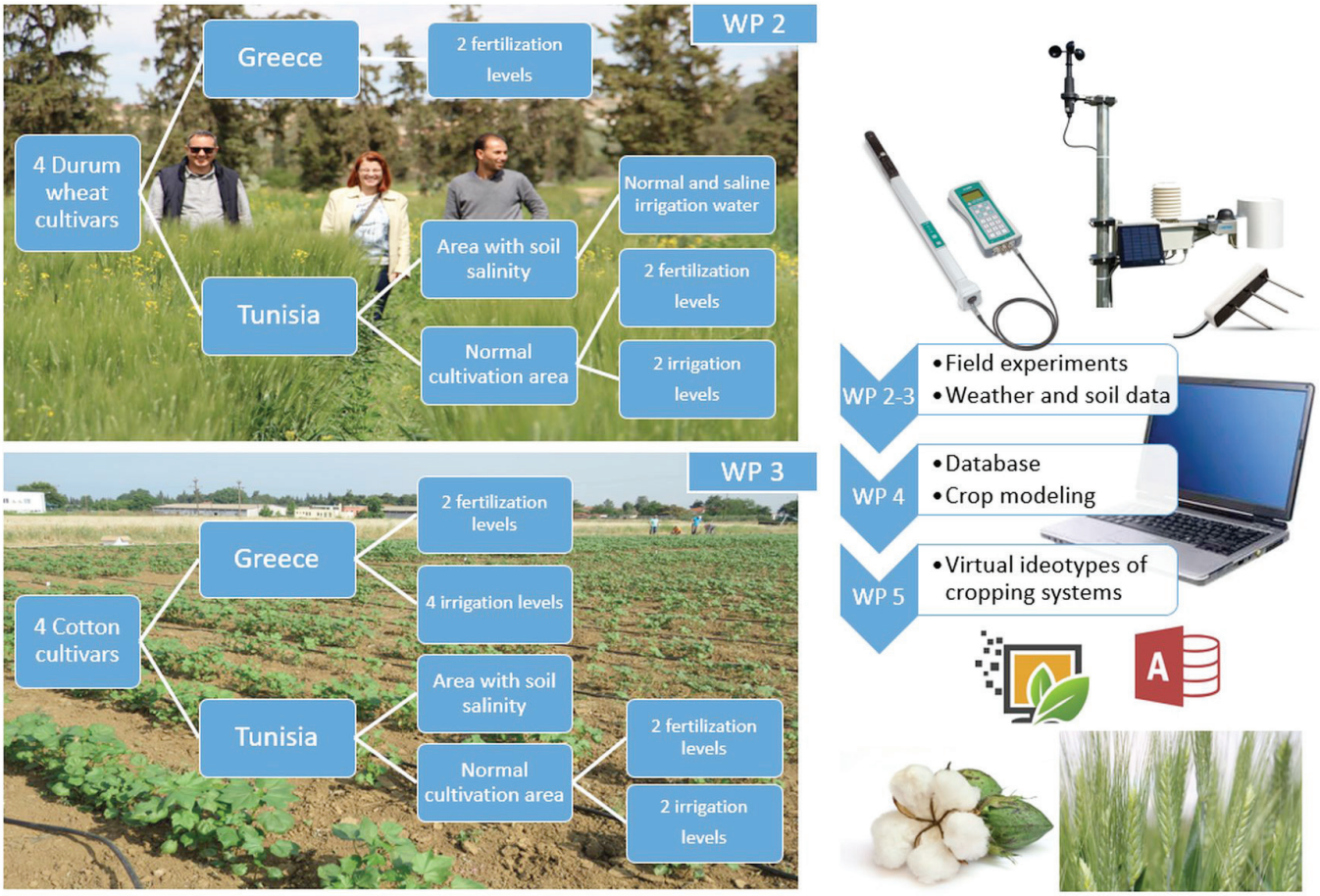

Figure 1. Work plan of the project.

Keywords: Cropping system ideotypes, Mediterranean basin, reduced use of chemical fertilizers, climate change, uncertainty.

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S5-P.56

Intensifying or expanding cereal cropping in Africa: impacts on greenhouse gas emissions

van Loon Marloes[1] (marloes.vanloon@wur.nl), Hijbeek Renske[1], ten Berge Hein[2], van Ittersum Martin[1]

[1] *Plant Production Systems Group, Wageningen University, wageningen, Netherlands*; [2] *Agrosystems Research, Wageningen Plant Research, wageningen, Netherlands*

Introduction

Cropping is responsible for substantial emissions of greenhouse gasses (GHGs) worldwide through the use of fertilizers and through expansion of agricultural land and associated carbon losses. Especially in sub-Saharan Africa (SSA) GHG emissions from cropping might increase steeply in coming decades, due to tripling demand for food until 2050 to match the steep population growth (Van Ittersum et al., 2016).

Materials and Methods

This study assesses GHG emissions of achieving cereal (maize, millet, rice, sorghum and wheat) self-sufficiency by the year 2050 for ten SSA countries (Burkina Faso, Ethiopia, Ghana, Kenya, Mali, Niger, Nigeria, Tanzania, Uganda and Zambia) on under four different scenarios of cereal production. 1) In 2050, cereal yields are the same as today (the year 2015); 2) Historical cereal yield trends are extrapolated to 2050; 3) Cereal yields are 50% of water-limited potential yield (Yw); or 4) 80% of Yw. Cereal area expansion was used to complement intensification to the extent needed to match cereal self-sufficiency. Spatially differentiated Yws were simulated using crop growth models (Van Ittersum et al., 2016; www.yieldgap.org). First, GHG emissions and required nutrient inputs were calculated, assuming high nitrogen use efficiency (N-AE; based on Ten Berge et al., 2019). Second, for maize only, current N-AE (mean N-AE obtained from large sets of on-farm experiments in SSA) was used. Finally, we analyzed GHG emissions across a wide range of N-AE and target yields.

Results and Discussion

Irrespective of intensification or extensification, GHG emissions of the ten countries jointly are at least 50% higher in 2050 than in 2015, assuming a high efficiency N-AE. With current yield trends and N-AE, GHG emissions for maize will be more than 400% higher than today. Thus, intensification will come, depending on the N-AE achieved, with large increases in nutrient inputs and associated GHG emissions. However, matching food demand through conversion of forest and grasslands to cereal area results in even higher GHG emissions. Moreover, many countries do not have enough suitable land for cereal expansion to match food demand (Chamberlin et al., 2014). The uncertainty in our GHG estimates was caused primarily by uncertainty in the IPCC Tier 1 coefficient for direct N_2O emissions, and by the N-AE value.

Conclusion

Intensification scenarios are clearly superior to expansion scenarios in terms of climate change mitigation, but only if current N-AE values are increased to levels commonly achieved in e.g. the United States, and which have been demonstrated to be feasible in some locations in SSA. As such, intensifying cereal production with good agronomy and nutrient management is essential to moderate inevitable increases in GHG emissions.

Acknowledgements

This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors.

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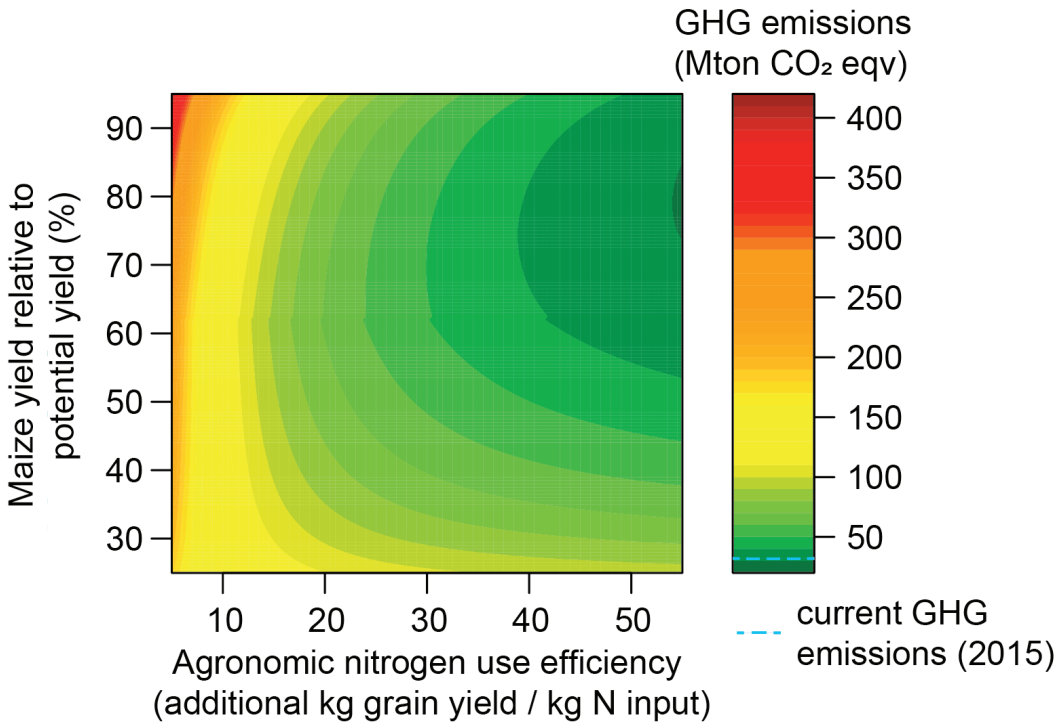

Figure 1. GHG emission (from fertilizer use, production and application, and land use change) from maize production to achieve self-sufficiency in ten sub-Saharan Africa countries by 2050 for different agronomic N use efficiencies and yield levels (Van Loon et al., 2019).

Keywords: food self-sufficiency, nutrient use efficiency, yield gaps, land use conversion, fertilizer.

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S5-P.57

Climate change impacts on crop growth and N leaching in contrasting regions - vulnerable areas at varying spatial scales

Villa Ana[1] (ana.villa@slu.se), Coucheney Elsa[1], Maharjan Ganga Ram[2], Gaiser Thomas[2], Trombi Giacomo[3], Bindi Marco[3], Moriondo Marco[4], Lewan Elisabet[1]

[1] *Soil and Environment, Swedish Univ of Agricultural Sciences, Uppsala, Sweden*; [2] *Crop Science Group, INRES, University of Bonn, Bonn, Germany*; [3] *DISPAA, University of Florence, Florence, Italy*; [4] *CNR-Ibimet, Florence, Italy*

Introduction

Impacts of climate change on agroecosystems can have an effect on the production of food and might contribute to degrading land, water quality and biodiversity. Food production for a growing population will amplify the need to reduce the impacts of the food system on the environment. In this study we explore the impacts of climate change on crop growth, Nitrogen (N) leaching and water drainage. We identify areas and soils most sensitive to climate change in two regions under two different climates (i.e. Mediterranean and temperate). Identification of vulnerable areas and soils with respect to different variables (i.e. agronomic and environmental) is important to be able to apply the appropriate mitigation measure at the right place and time. The spatial resolution might affect our assessments of possible climate change impacts. Therefore, we also investigate how the resolution of soil and climate input data affect the calculated impacts and vulnerable areas and soils in the two regions.

Materials and Methods

The one-dimensional process-based ecosystem model CoupModel was used to simulate winter wheat for the baseline period (P0: 1980-2010) and two future periods (P2: 2040-2070 and P3: 2070-2100) based on five climate models (GCM: GFDL-CM3, GISS-E2-R, HadGEM2-Es, MIROC5, and MPI-ESM-MR) under two forcing scenarios (RCP 4.5 and RCP 8.5). Soil and climate input data was applied at three spatial resolutions 25 km^2, 50 km^2 and 100 km^2 in two contrasting climatic regions: the temperate humid region of North Rhine Westphalia (NRW) in Germany and the Mediterranean region of Tuscany (Tus) in Italy. Simulations were conducted and evaluated for a nitrogen-water-limited production situation (crop growth limited by nitrogen, precipitation, temperature and radiation).

Results and Discussion

In NRW, the regional 30-year average biomass at the reference resolution (25 km^2) was 7.4 t DM ha^{-1}. Average values based on the other spatial resolutions were very similar to the reference and ranged from 7.5 to 7.7 t DM ha^{-1}. In Tus, average 30-year biomass values were also similar between resolutions and ranged from 8.8 to 8.9 t DM ha^{-1}. Minimum and maximum output values differed more between resolutions, especially in NRW.

Compared to the baseline scenario average annual biomass in NRW at 25 km^2 decreased by 24, 22, 35, 29, 51 and 83% under RCP2.6 P2, RCP2.6 P3, RCP4.5 P2, RCP4.5 P3, RCP8.5 P2 and RCP8.5 P3, respectively. In Tus, the corresponding changes were 22, 36, 24, 43, 29 and 55%. In NRW, average annual N leaching at 25 km^2 increased by 25, 25, 37, 33, 52 and 73%. In Tus, N leaching increased by 64, 104, 60, 119, 72 and 143%. In both NRW and Tus, the decrease in biomass was largest in RCP8.5 P3 and smallest in RCP2.6 P2.

Vulnerable areas at the regional level were analyzed under different periods, and spatial resolutions by identifying the fractional area with biomass below the grid-specific 10th percentile (at P0). In NRW, the vulnerable area was very similar whenever soil or climate input data was at 25 km^2 (in P2 and P3). The size of the vulnerable area decreased for combinations with both soil and climate input data at 50 and 100 km^2. In Tuscany, the differences between resolutions in P2 were small. In P3, the vulnerable area was larger whenever soil data was applied at 25 km^2, compared to that based on climate data at 25 km^2. The smallest fraction of vulnerable areas were derived from simulations in which both soil and climate data were applied at 50 and 100 km^2. The same analysis will be made with respect to N leaching and drainage.

The results so far refer to “30-year average patterns”. In addition, we will also explore the vulnerable areas with respect to individual years and extreme weather. The pattern of vulnerable soils within the two climatic regions will thus also be studied with respect to annual biomass, N leaching and drainage in the baseline and future scenarios.

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Conclusions

Results showed that total aboveground biomass decreased, while N leaching increased under all future RCP scenarios in both regions. Average N leaching will increase up to 73% and 143% under the worst-case scenario, in NRW and Tuscany, respectively. Identification of vulnerable areas and soils under climate change will depend on the spatial resolution and regional climate. Proper identification of soils associated with reduced crop growth and high N leaching will be important to be able to choose and apply the most efficient mitigation measures at the right place and time.

Acknowledgements

The study was supported by FACCE MACSUR knowledge hub (MACSUR – BB/N004922/1). It was also supported by the Swedish research council for Environment, Agricultural Sciences and Spatial Planning.

S5-P.59

Agricultural Adaptation Potentials to Climate Change

Zabel Florian[1] (f.zabel@lmu.de), Müller Christoph[2], Elliott Joshua[3], Minoli Sara[2], Dury Marie[4], Christian Folberth[5], Francois Louis[4], Lui Wenfeng[6], Sakurai Gen[7], Mauser Wolfram[1], Ruane Alex C.[8]

[1] *Ludwig-Maximilians-Universität München, Munich, Germany*; [2] *PIK, Potsdam, Germany*; [3] *University of Chicago, New York, United States*; [4] *Université de Liège, Liège, Belgium*; [5] *IIASA, Laxenburg, Austria*; [6] *EAWAG, Zürich, Switzerland*; [7] *NARO, Tsukuba, Japan*; [8] *NASA GISS, New York, United States*

Introduction

By how much agriculture can adapt to climate change is still an open question. A range of cultivars exists that are adapted to specific abiotic conditions. Utilizing this pool of genetic variability to adapt to abiotic changes however has not been considered in global crop model studies so far.

Materials and Methods

In a global multi-model sensitivity analysis within the Global Gridded Crop Model Initiative (GGCMI) of the Agricultural Model Intercomparison and Improvement Project (AgMIP), we systematically investigate the combined effects of environmental changes on yields for best temperature adapted cultivars. We show results of potential adaptation effects on global production for the major staple crops (maize, wheat, rice and soybean).

Results and Discussion

Globally aggregated, Fig. 1 shows the change in global calorie production under different abiotic conditions using temperature offsets and precipitation factors under different CO_2 concentrations applied on 1981-2009 historical climate data. Simulation results show the model median of 7 different global gridded crop models. While global calorie production decreases by approx. 5% per K warming without consideration of adaptation, it decreases by approx. 2% per K warming when considering best cultivar selection. However, the adapted varieties in general require more water due to extended growing periods and adaptation can only be effective if this water is available. The black line in Fig. 1 shows the compensation line without considering cultivar selection as a choice for adaptation, while the blue line shows the compensation line with adaptation. The space between the lines can be considered as an increased option space resulting from the selection of an adapted cultivar. While the option space from adaptation in tropical and arid regions is small, temperate and cold climate zones show large potential benefits.
Additionally, we show impacts on production under different RCPs with and without adaptation and investigate the potential for compensating potential yield losses due to climate change. Thereby, we identify regions with high efficiency of cultivar selection and in contrast find regions that cannot benefit by using adapted cultivars due to water stress. However, it's still unclear if the adapted varieties currently exist. We empirically estimate where required varieties may already exist. By excluding areas where we assume varieties not to be available today, global calorie production significantly decreases.

Conclusion

The use of temperature adapted varieties substantially improves future crop production by more than 20% in RCP 8.5 in comparison to non-adaptive varieties, which underpins the large potential of adaptation. This number significantly reduces if we consider only varieties that we assume are available today. The adapted varieties require more water, which potentially could increase conflicts with other sectors.
Using adapted cultivars, together with other adaptation options has not been considered so far in global studies on food security, but should be considered in future global studies. Future research is needed in order to consult and support breeders in terms of what crop properties are required for future climate conditions.

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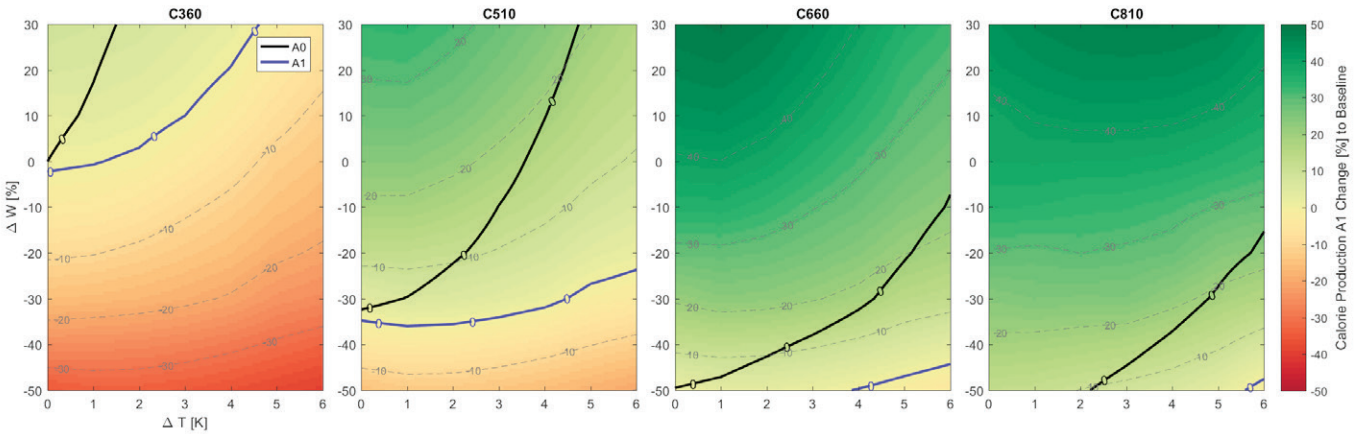

Impact response surface of global calorie production under different temperature offsets (y-axis), precipitation factors (x-axis), at four different CO_2 concentrations (360,510,660 and 810 ppm) as model median of 7 global gridded crop models (CARAIB, GEPIC, LPJ-GUESS, LPJmL, pDSSAT, PEPIC, PROMET). Global calorie production is calculated as the sum of maize, wheat, rice and soybean production on todays fractional cultivated rainfed and irrigated area according to the MIRCA dataset (Portmann et al. 2010). The change is shown in comparison with 1981-2009 baseline production without any temperature, precipitation and CO_2 changes (T0, W0, C360). The blue line shows the compensation line of the adapted cultivar (no change in comparison to baseline production), while the black line shows the compensation line without considering best cultivar selection as a choice for adaptation.

Keywords: Climate Change, Adaptation, Cultivar Selection, GGCMI, Ensemble.

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S5-P.60

How to transfer crop modelling effectiveness in decision making processes. The experience of the IBE-WMO RTC in Africa

Bacci Maurizio[1] (maurizio.bacci@cnr.it), Ferrise Roberto[2], Dibari Camilla[2]

[1] *Institute of BioEconomy (IBE) CNR, Florence, Italy*; [2] *DAGRI, University of Florence, Florence, Italy*

Introduction

Sub Saharan Africa agriculture production is strictly dependent on the weather conditions, and climate change is rapidly increasing the risk of food insecurity of millions of inhabitants that live in rural areas (FAO,2017). Food security is one of the priority for these countries and they need urgently to produce climate change impact assessments in order to define adaptation strategies as well as set up early warning tools to reduce the risk of losses in agricultural yields.

Since 2011, the World Meteorological Organization (WMO) promotes initiatives (e.g. establishment of weather and climate services through the establishment of the Global Framework for Climate Services) to support developing and emerging countries sensitive to meteorological threats. The implementation of climate services in developing countries is mainly pivoted on National Hydro-Meteorological Services (NMHS) and Ministry of Agriculture, as key actors in the implementation of new tools and instruments to cope with climate-related risks. Crop modelling represents a key tool in all this process but the skills of these actors is often very weak in dealing with these instruments. Accordingly, building capacities on crop modeling within national services becomes essential to promote an effective creation of services tailored to countries' needs.

Here, we present the experience of three different courses produced in the framework of the Regional Training Center context of WMO Region I (Africa) that aims to raise the use of crop modeling as one of the key tools to assess actual and future risks in agricultural production.

Materials and Methods

The courses have trained more than 60 officials and technicians from NMHS and Ministry of Agriculture of 19 Sub-Saharain Africa countries, institutions which are in charge of the collection of the main meteorological and agricultural data. The courses have been organized in different phases: distance learning, frontal lectures and post course activities and they were focused, among the others, on the use of crop models for assessing the response of local crop systems to the environment as well as testing alternative management strategies. The content consisted in an introduction to crop modeling, the presentation of a crop model (e.g. CropSyst; Stöckle et al., 2003), including how to set up simulations (and relevant data needs) and some practical examples concerning the main rainfed crops for each country in present and future scenarios.

Results and Discussion

Feedbacks from attendees, indicated a strong interest in the courses' contents. Particularly, the opportunity of using crop models for having a detailed picture of agricultural potentialities and limitations at different spatial and temporal scales was greatly appreciated. Nevertheless, some limitations arose. They mainly concern with the lack of crop modeling literature focused in developing countries and the absence of long time series of meteorological and crop data, thus making the calibration and validation of the models very difficult. We found that generally the raw data are not systematically collected in these countries with some particular cases such as Angola where there is a gap of more than 20 years in the time series due to the civil war. To overcome this issue, the course has focused the attention on alternative strategies to retrieve data from remote sensing dataset for rainfall estimation and soil information. Another barrier was the difficulty in teaching the correct use of these tools, their rationale, strengths and weaknesses as well as the interpretation of outputs, due to the variegated scientific background of each attendee (e.g. poor expertise on crop ecophysiology).

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Conclusions

As general comment, this experience allows some important consideration about knowledge transfer on crop modeling to developing countries by highlighting good practices to achieve effective results in creating local modelers' community and guiding them in producing more effective analysis. As further remark, we believe the importance of collecting reliable raw data from the field, for instance by setting up trial experiments aimed at retrieving crop data to calibrate models. The lack of crop and environmental data represents generally the main limiting factor in producing accurate crop simulations in these countries. Moreover, it is essential to promote the organization of dedicated multisectoral and system-approach trainings activities on these topics for allowing users to better understand and interpret outputs of modeling tools and maximize the results from these instruments. Learners' needs are very heterogeneous and the challenge for the international scientific community is to find innovative solutions and flexible modalities of training able to reach effective results in knowledge transfer.

Keywords: Sub Saharan Africa, Decision makers, Capacity building, adaptation, climate change.

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S5-P.61

Coupling a soil-crop model with tools for bio-economic analysis to assess the costs of soil compaction

Parvin Nargish[1] (nargish.parvin@slu.se), Coucheney Elsa[1], Elofsson Katarina[2], Gren Ing-Marie[2], Keller Thomas[1], Jarvis Nicholas[1]

[1] *Soil and Environment, Swedish Uni. of Agricultural Sci., Uppsala, Sweden*; [2] *Department of Economics, Swedish Uni. of Agricultural Sci., Uppsala, Sweden*

Introduction

Soil-crop models are useful tools to assess the effects of climate and soil management practices (e.g. tillage, fertilization) on crop production as well as environmental impacts such as greenhouse gas emissions and nutrient leaching. Bio-economic models can be used to analyze the value of these management inputs in terms of crop yields and environmental effects and how they depend on the interacting effects of other production factors such as labour and machinery costs. The aim of our project, is to develop a coupled soil-crop-economics modelling framework to assess the costs of soil compaction. Despite a loss of soil quality due to traffic compaction, farmers are able to maintain yields by fertilizer inputs, but at costs to the environment in terms of enhanced nitrogen losses by leaching and gas emissions and surface runoff.

Materials and Methods

We will calculate and compare private and socially-optimal net values, where the latter include not only the effects of soil compaction on production, but also on environmental impacts (e.g. carbon sequestration, flooding, water quality). This will enable model-users to identify policies and instruments that can optimize soil management to meet both private and societal aims. We will use the SoilFlex model to calculate soil compaction by different farm machinery and the soil-crop model STICS to simulate the effects of changes in bulk density on crop yields, losses of nitrogen and runoff. Based on data from long-term field trials in Sweden, simulations will be carried out for a range of fertilizer rates and soil management systems involving contrasting machinery use. We will construct simplified statistical meta-models summarizing the relationships between model inputs (machinery and fertilizer use) and outputs (crop yields, nitrogen losses in leaching and gas emissions, runoff) simulated with SoilFlex and STICS. These meta-models will be incorporated into a numerical bio-economic using the GAMS software for economic analysis of the costs of soil compaction and the optimal policies needed to promote changes in farm management practices to sustain soil quality.

Results and Discussions

The project is at initial phase. However, we already observed yield losses due to compaction in a medium textured soil in Sweden. The nitrogen leaching and surface runoff of water were also increased due to compaction. All these changes will be incorporated Bio-economic models (ongoing) to calcaulate the cost of compaction.

Conclusions

We expect that farmers and society both will loss economically due to soil compaction.

Acknowledgements

This study is supported by the grant from FORMAS (Swedish government research council for sustainable development).

Keywords: Soil compaction, Soil-crop model, bio-economic analysis.

S5-P.62

Integrative trade-off analysis between agricultural land requirements, food security and biodiversity

Schneider Julia M.[1] (j.schneider@iggf.geo.uni-muenchen.de), Zabel Florian[1], Mauser Wolfram[1], Delzeit Ruth[2], Seppelt Ralph[3], Václavík Tomáš[4]

[1] *Department of Geopgraphy, Ludwig-Maximilians-Universität München, Munich, Germany*; [2] *Kiel Institute for the World Economy, Kiel, Germany*; [3] *Dep. of Computational Landscape Ecology, Helmholtz Centre for Environm. Research, Leipzig, Germany*; [4] *Dep. of Ecology and Environm. Sciences, Palacký University Olomouc, Olomouc, Czech Republic*

Introduction

With rising demand of food and biomass for an increasing population with changing lifestyle and consumption patterns, the pressure on land as an agricultural resource and production factor increases. At the same time, preservation of land for biodiversity, carbon sequestration and other ecosystem services is crucial to tackle the challenges of the 21st century that are e.g. addressed in the Sustainable Development Goals. Cropland expansion and intensification represent the main strategies to boost agricultural production, but in turn are also major drivers of biodiversity decline. The presented integrative study investigates and contrasts different effects of expansion and intensification to increase agricultural production on biodiversity.

Materials and Methods

Therefore, an integrated global approach (Mauser et al., 2015; Zabel et al., 2019), which couples the biophysical crop growth model PROMET with the economic computable general equilibrium model DART-BIO, was developed. By iteratively linking both models, profitable areas for both, expansion and intensification are identified under specific future socio-economic and climate scenarios. Hotspots where biodiversity could be most affected by either expansion or intensification are identified (see Fig. 1).

Results and Discussion

The results show that both expansion and intensification increase global production and lead to lower crop prices in all regions, even where production decreases, while the effects on biodiversity differ spatially: Cropland intensification affects biodiversity hotspots especially in Sub-Saharan Africa, India and China, whereas expansion of cropland threatens biodiversity mainly in Central and South America. Thus, the conclusion can be drawn that while all regions benefit from lower world market prices, the production gains will occur predominantly at the costs of biodiversity in developing tropical regions.

Conclusion

The identified potential future conflict hotspots of agriculture and biodiversity indicate where conservation prioritization is needed to reconcile agricultural production with conservation goals. Further, the results highlight the importance of research on options to reduce negative effects of agricultural production increase especially on biodiversity, e.g. local and regional potentials of land sparing.

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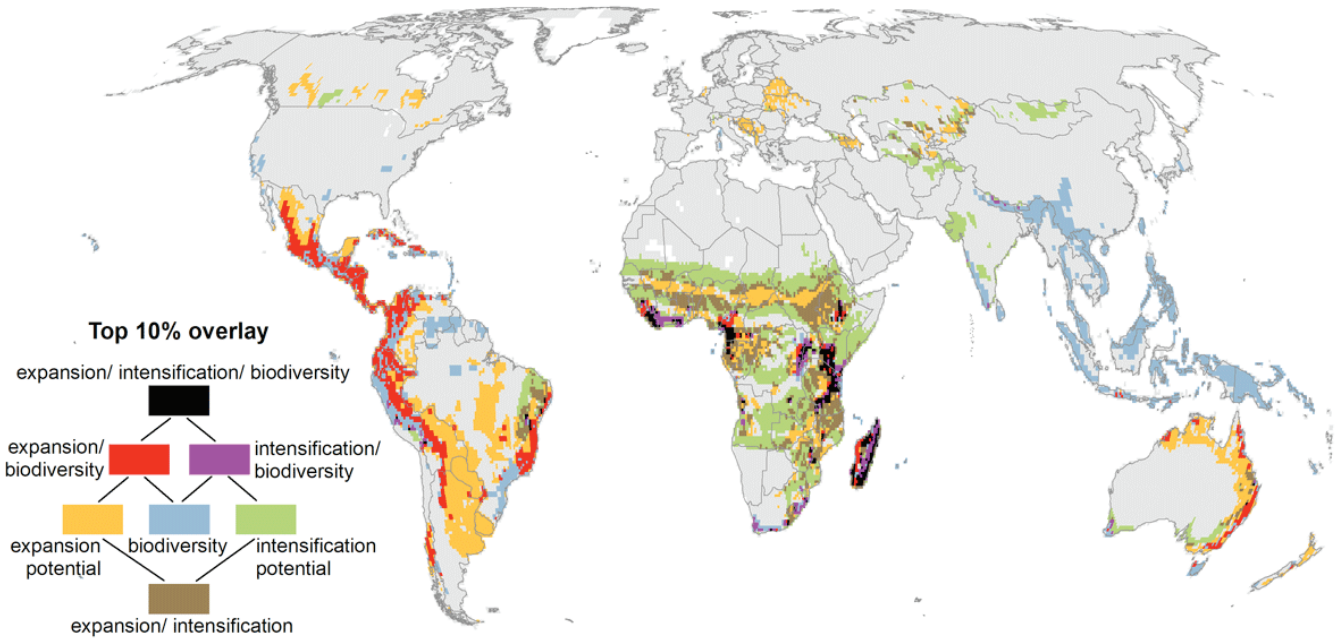

Quantile overlay of expansion potential, intensification potential and endemism richness. The red areas highlight hotspots, where high biodiversity may be particularly threatened by future cropland expansion. The purple areas highlight hotspots, where high biodiversity may be particularly affected by future cropland intensification. The black areas pinpoint places where high biodiversity is particularly threatened by both agricultural scenarios simultaneously. The orange, green and blue colors indicate regions with the top 10% of expansion potential, intensification potential and biodiversity that do not overlap with any other top 10% of data. The brown areas indicate regions where the top percentile of expansion and intensification potential overlap without overlapping the top percentile areas of biodiversity.

Keywords: Crop Modelling, Integrative Assessment, Trade-Offs, Food Security, Biodiversity.

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ABSTRACTS POSTERS

SESSION VI

METHODS AND SOFTWARE TO SUPPORT MODELLING ACTIVITIES

S6-P.01

Enabling data exchange between crop growth models and PHIS information system for phenomics through ICASA and AgMIP data standards and tools

Vargas-Rojas Felipe[1] (luis-felipe.vargas-rojas@inra.fr), Cabrera-Bosquet Llorenç[1], Sibylle Dueri[1], Manceau Loïc[1], Porter Cheryl[2], Martre Pierre[1]

[1] *LEPSE, INRA, Montpellier, France*; [2] *Agricultural & Biological Engineering, University of Florida, Gainesville, Florida, United States*

Introduction

In recent years, plant phenomics has generated unprecedented datasets including hundreds of genotypes tested in a number of environmental scenarios and crop management practices, which can be used to test novel mechanisms and models. However, integration of these datasets into crop models is challenging, since every model use different data formats and granularities. Therefore, adopting open standards becomes necessary. The ontology-driven information system for plant phenomics PHIS (Neveu et al. 2019) offers a suitable framework for organizing multi-source and multi-scale datasets whilst keeping flexibility and data interoperability. Here we propose a two-way data exchange framework enabling data interoperability between crop growth models and PHIS using the ICASA Master Variables List (ICASA-MVL; White et al. 2013) and the AgMIP data standards and data translator tools (Porter et al. 2014).

Results and Discussion

In a first step, PHIS ontologies were extended by incorporating terms and concepts listed in the ICASA-MVL V2 (White et al. 2013) which provides a comprehensive list of standardized vocabularies describing management practices, treatments, environmental conditions and measurements of crop responses. These terms were formalized in the form of ontology and incorporated into the PHIS Triple Store and mapped into the existing ones when applied. A revision of existing reference ontologies and other semantic resources (e.g. AGRO ontology, UO ontology, AGROVOC) was necessary. This was particularly true for variables, which required the definition of specific attributes such as units.

In a second step, a simplified and flexible version of the AgMIP translator Excel spreadsheet was used to transform experimental data into a JSON AgMIP file. JSON files were then scanned to extract specific subsets (e.g. experiments, management) and inserted into PHIS using the different available web services (Fig. 1A). The integration of data in PHIS enabled to centralize experimental data in a unique database and organize it following the AgMIP-ICASA standards, facilitating the interoperability between PHIS and the crop model *SiriusQuality* (Martre et al. 2006). This permitted to extract (i) specific data to run simulations and (ii) observed data, allowing assessing the performance of model simulations (Fig. 1B).

Conclusions

Overall, the framework presented here based on the ICASA-AgMIP data standards facilitated data exchange between PHIS and *SiriusQuality*, providing a flexible schema that can easily be extended to any crop models for which an AgMIP Crop Experiment data schema translators exist.

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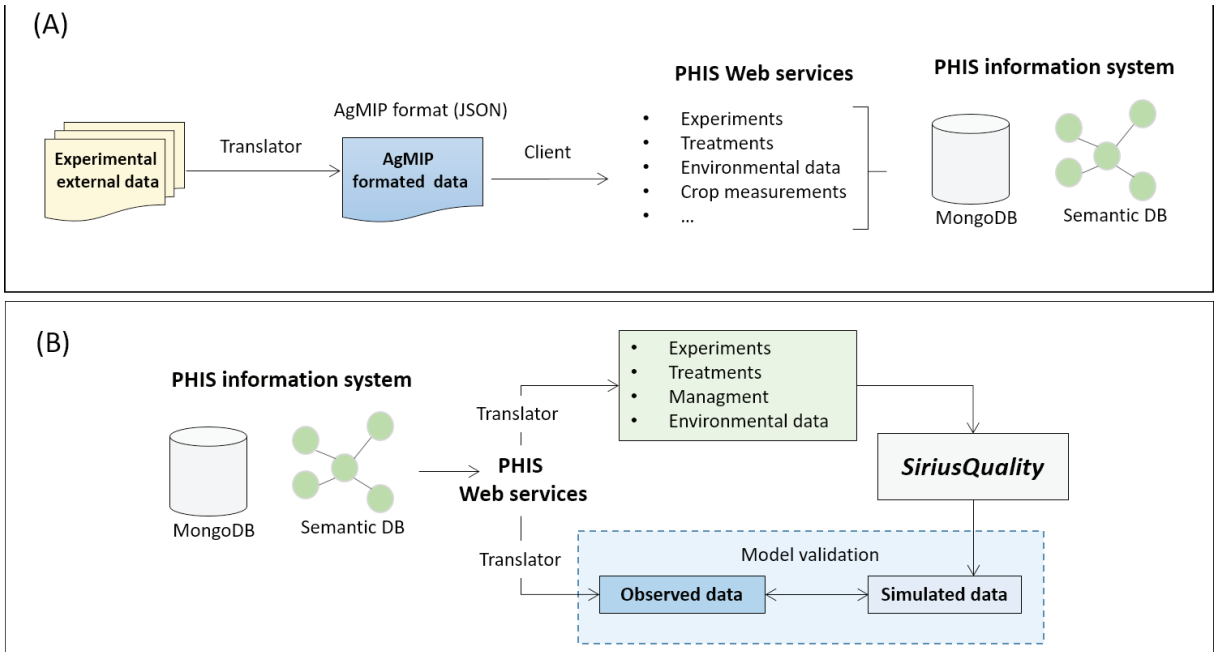

Figure 1. (A) Data gathering, formating and integration into PHIS information system.
(B) Data exchange between PHIS information system and crop models.

Keywords: AgMIP, crop modelling, data-exchange, ICASA, ontologies, phenomics.

References:

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S6-P.02

Database Sensitivity of the Biome-BGCMAg Biogeochemical Model

Fodor Nándor[1] (fodor.nandor@agrar.mta.hu), Pásztor László[2], Szabó Brigitta[2], Barcza Zoltán[3], Hidy Dóra[3], Hollós Roland[3], Kristóf Erzsébet[3], Kern Anikó[3], Kis Anna[3]

[1] *Agricultural Institute, Centre for Agricultural Research, Martonvásár, Hungary*; [2] *Inst for Soil Sciences and Agr Chem, Centre for Agricultural Research, Budapest, Hungary*; [3] *Department of Meteorology, Eötvös Loránd University, Budapest, Hungary*

Introduction

Crop models are designed to calculate important parameters of the soil-plant system as a function of weather and soil conditions, plant-specific characteristics as well as a choice of agricultural management practices. Model results could be highly dependent on the datasets that are used to provide input parameters for the model calculations. The aim of this study is to demonstrate the database (DB) sensitivity of the Biome-BGCMAg model.

Materials and Methods

The Biome-BGCMAg model has been created by merging the CERES-based 4M crop model with the Biome-BGCMuSo biogeochemical model. The hybrid model is capable of simulating all major land use types, several agro-management operations, and the full C and N cycle of the plant-soil system.

The key plant (maize) parameters of the model were calibrated by using NUTS-3 level Hungarian yield data available for the 1991-2018 period. Basic soil data (bulk density, SOM, etc.) were retrieved from the DOSoReMI DB (Pásztor et al., 2018). Using these characteristics two sets of hydraulic parameters (max. water holding capacity; field capacity; wilting point) were derived by using two pedotransfer function sets: EU-PTF (Tóth et al., 2015) and HU-PTF (Szabó et al., 2019) that were developed by using independent soil hydraulic DBs. Daily weather input data (solar radiation, max and min temperature, precipitation) were retrieved from the CARPATCLIM (Spinoni et al., 2015) and FORESEE (Dobor et al., 2014) DBs. Both the soil and the climatic gridded DBs have data at a 10 km spatial resolution covering the study area (Hungary) with 1104 grid cells. Four 50-year-long (1961-2010) simulations (4×1104, to be exact) were carried out with the calibrated Biome-BGCMAg model by using the four climate×soil parameter set combinations. Net Primary Production (NPP) results were compared across the simulations. Spatial characteristics of the model output differences were also investigated. For every cell (indexed with i) and year (indexed with j), differences in the simulated NPP were compared to the minima of the four corresponding results obtained with the four different inputs datasets. Climate (DIFclim) and soil (DIFsoil) DB related differences were calculated by the following way and used as indicators of DB sensitivity. FS, CC, HU and EU superscripts denote model results obtained by using the FORESEE, CARPATCLIM, HU-PTF and EU-PTF DBs, respectively.

Results and Discussion

On average, the climate and soil DB related sensitivity of the model is 4.31 and 1.25%, respectively. In some cells and in some years the differences caused by the selection of the input DB could reach DIFsoil=56% and DIFclim=247%.

Conclusions

Problematic cells are located in highland areas (altitude>300 m a.s.l.) that are typically not used for crop production. The large differences between the simulation results might be related to problems with the climate data interpolation methods used in complex terrain and the low number of meteorological stations that are used for interpolation. The selection of soil input DB introduces only minor uncertainty in the model results while the selection of climatic input DB could cause systematically large uncertainty (in most years) in the simulation results.

Acknowledgements

The study was supported by the following grants: Széchenyi 2020 - ERDF - Hungarian Gov.: GINOP-2.3.2-15-2016-00028; János Bolyai Research Scholarship (BO/00088/ 18/4); Hungarian Scientific Research Fund (FK-128709 and K-129118).

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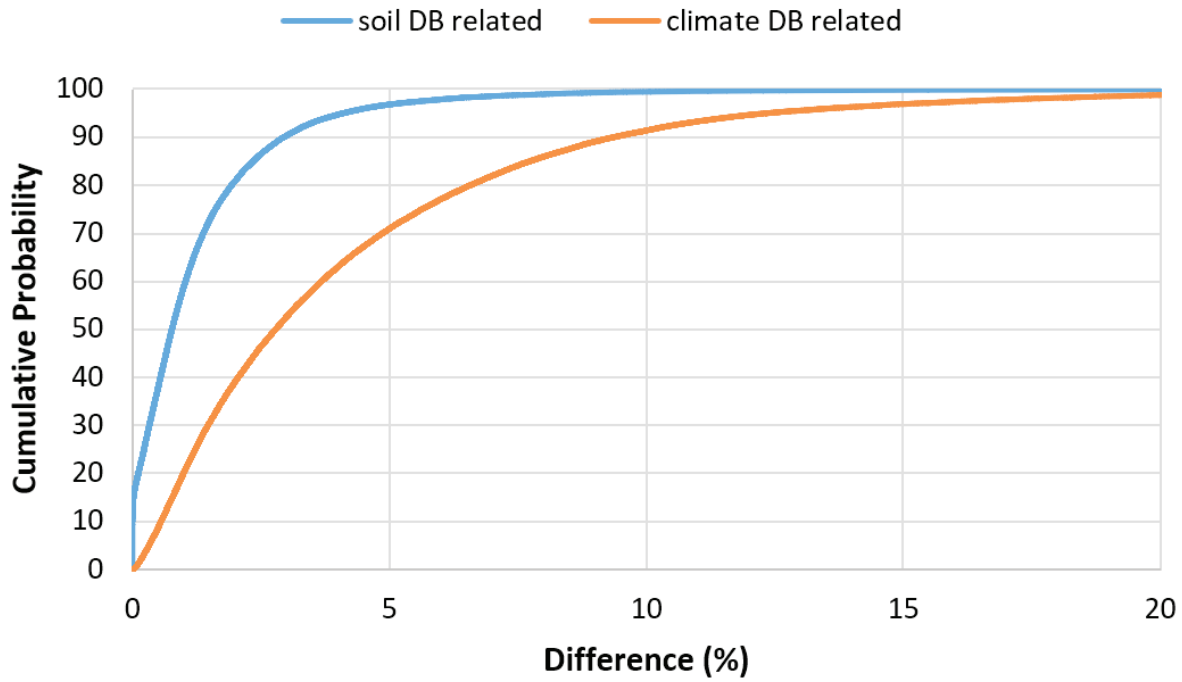

Figure 1. Distribution of the climate (DIFclimi,j) and soil (DIFsoili,j) database related differences across the 1104 cells and 50 years (55,200 data per plot).

Keywords: input data, gridded data, hydraulic parameters, climatic parameters, model sensitivity.

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S6-P.03

An online database of plant and crop computational models

Saint Cast Clément[1] (clement.saintcast@uclouvain.be), Lobet Guillaume[2], Couvreur Valentin[1], Tardieu François[3], Draye Xavier[1]

[1] *Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium*; [2] *IBG3, Agrosphere, Forschungszentrum Jülich, Jülich, Germany*; [3] *MontpellierSupAgro, UMR LEPSE, Université de Montpellier, INRA, Montpellier, France*

Background and Aims

With the increasing number of phenotyping platforms and affordable image acquisition, images have become a commonly used data type in plant sciences (Tardieu et al., 2017). As a direct result, many plant image analysis tools have been developed in recent years for data extraction and treatment (Lobet et al., 2013). In the future, information extracted from phenotyping data will be used increasingly as parameters or variables of mathematical models, thereby broadening the scope of information extracted from phenomics data (Muller and Martre, 2019). Feeding such data to process-based crop simulation models (CSMs) and functional-structural plant models (FSPMs) in ad hoc pipelines could be a way to derive high-throughput predictions of integrated (e.g. yield) or functional traits (e.g. root system architecture) across a wide range of target environments or management practices (Chen et al., 2019). Unfortunately, it is currently challenging for phenomics researchers to become aware of the diversity of models and their applications. The objective of this project was to develop an online portal referencing plant and crop simulation models to raise awareness and explore the diversity of models and their applications.

Materials and Methods

The plant model database was built as a web-based repository extending the "Plant Image Analysis" website (Lobet et al., 2013). It was populated with models identified in a thorough review of the literature. The models were selected according to several descriptors, in particular process-based crop simulation models and functional-structural plant models. We selected models available, usable, supported by an active community, mainly developed for crops and with a potential for using phenomics data and improving plant traits analysis. Model developers were then involved in the writing of a model synopsis with its main specifications.

Results and Discussion

We present a manually curated database referencing plant and crop simulation models. The database is accessible online in a website, quantitative-plant.org (Figure 1), which presents each model concisely in a consistent framework. Models are described by their general characteristics (e.g. programming language, plant part studied…) and uses (e.g. species studied, success-stories involving model and phenomics data…). In this way, quantitative-plant.org provides an overview of available plant image analysis software and models enabling users to identify available solutions for their project. The website also enables user feedback, evaluations and new model submissions.

Conclusions

The quantitative-plant.org website will maintain a catalogue of plant models that could be used to access or simulate new variables from phenomics data. We hope that this website will engage the interest of the phenomics community in model-assisted phenotyping. In the future, a long-term cooperation between the phenomics and modeling communities towards harmonizing data formats (e.g. ICASA; White et al., 2013) will be needed to enable transparent data exchange from models to experiments and vice-versa.

Acknowledgements

This research has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 739514, EMPHASIS-PREP. The authors would like to thanks many model developers for their contribution.

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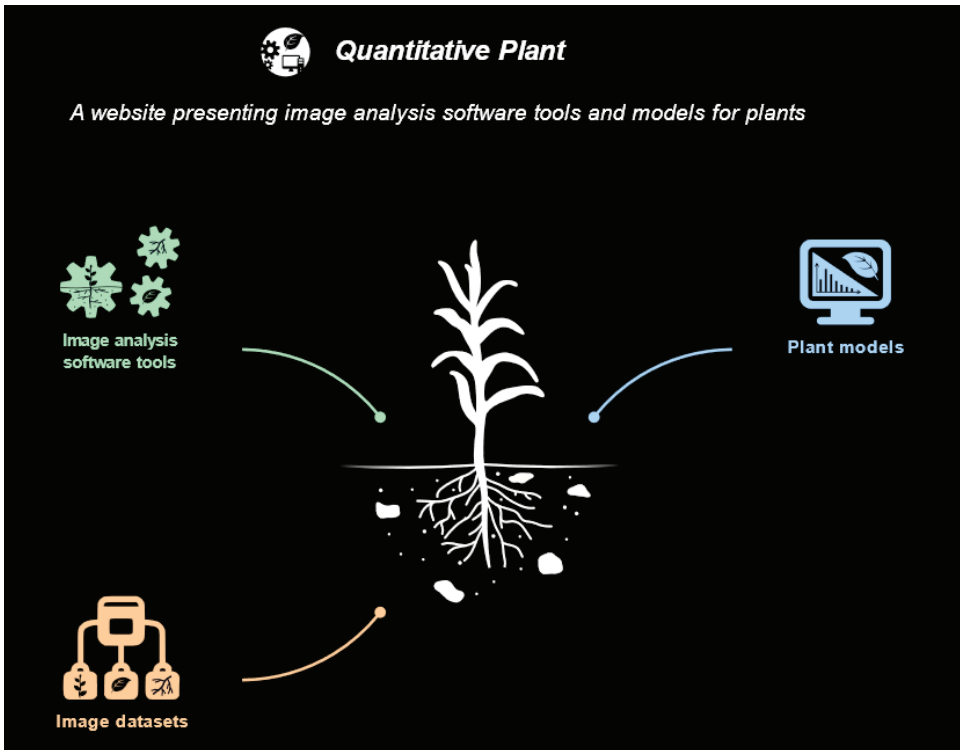

Figure 1. Home page of the quantitative-plant.org website.

Keywords: Website repository, Modeling, Phenotyping, Virtual plant.

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S6-P.04

Using open weather data for crop modeling? It is possible!

Zaka Serge (serge.zaka@itk.fr), Tisseyre Laurent, Varella Hubert Vincent

ITK, Clapiers, France

Introduction
Assessing the impacts of climate change on crop production requires large datasets of weather scenarios. However, getting such data is generally a time-consuming process that is often poorly documented. Nonetheless, since the 2010s, research institutions have released weather data under an open data policy.

Materials and Methods
The aim of this work is to compare accessibility (format, automatization, server reliability), large-scale exploitability, period (past, short/long-term forecasts and climate change scenarios) and usefulness for crop modelling (inputs provided, data continuity) of more than 20 global and national forecast models (GFS, AREPEGE, ICON, IFS-ECMWF etc.) and worldwide data providers (Infoclimat.fr, NASA, NOAA etc.).

Results and Discussion
Results are encouraging: (1) *Accessibility*: all providers gave simple accessibilities, with the exception for AROME/ARPEGE models, which had few minor server overloads. FTP and APIs connections were reliable and could be fully automatized. (2) *Period*: Open weather data covered the whole period from observations of the 1880s (historic stations from ECA/NOAA databases) to projections of 2100s (climate change scenarios from IPCC/DRIAS). (3) *Large-scale exploitability*: As it stores a collection of self-contained records of 2D-data in the same file (*.grib*), gridded formats is the most useful for large scale crop models. However, only short (5 days) and long-term (2 weeks) weather forecast models provided this format from high resolution for local model (2km²) to larger scales for global model (25km²). Historical weather data (1880-2019) and climate change projections (2020-2100) are only provided by one-location files (*.json*). (4) *Usefulness*: in most cases temperatures, humidity, wind and precipitation are provided, while global radiation is more challenging to obtain.

Conclusions
Open weather data can provide whole range of new research opportunities for crop modelling. For instance, simulation of past years for calibration issues, testing agricultural decision tools or assessing the impact of global warming at different spatial scales. These opportunities are still underestimated and must be highlighted.

Keywords: opendata, weather, agroclimatology.

S6-P.05

Evaluation of mitigation practices to reduce N_2O and increase soil C; multi-model assessment in five croplands worldwide

Carozzi Marco[1] (marco.carozzi@inra.fr), Bellocchi Gianni[2], Ehrhardt Fiona[3], Brilli Lorenzo[4], Bathia Arti[5], De Antoni Migliorati Massimiliano[6], Doltra Jordi[7], Dorich Chris[8], Doro Luca[9], Fitton Nuala[10], Grace Peter[6], Grant Brian[11], Giacomini Sandro[12], Leonard Joël[13], Loubet Benjamin[1], Massad Raia Silvia[1], Pattey Elizabeth[11], Sharp Joanna[14], Smith Peter[10], Smith Ward[11], Zhang Qing[15], Recous Sylvie[16]

[1] *EcoSys, INRA, THIVERVAL-GRIGNON, france*; [2] *UREP, INRA, Clermont-Ferrand, France*; [3] *INRA, Paris, France*; [4] *University of Florence, Florence, Italy*; [5] *Indian Agricultural Research Institute, New Delhi, India*; [6] *Queensland University of Technology, Birsbane, Australia*; [7] *Cantabrian Agricultural Research and Tr, Muriedas, Spain*; [8] *Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, United States*; [9] *University of Sassari, Sassari, Italy*; [10] *University of Aberdeen, Aberdeen, United Kingdom*; [11] *Agriculture and Agri-Food Canada, Ottawa, Canada*; [12] *Universidade Federal de Santa Maria, Santa Maria, Brazil*; [13] *AgroImpact, INRA, Laon, France*; [14] *Plant and Food Research, Aukland, New Zealand*; [15] *Chinese Academy of Sciences, Beijing, China*; [16] *FARE, INRA, Reims, France*

Introduction

Understanding the impacts of the agronomic practices on greenhouse gas (GHG) emissions and soil carbon (C) storage is a key aspect to counteract climate change, mitigate emissions and develop adaptation strategies. Modelling an uncertain future provides stakeholders with a range of potential outcomes to better lead decision making, facilitating the construction and analysis of future scenarios. Notwithstanding mitigation strategies to attenuate GHG emission as nitrous oxide (N_2O) and increase soil C stock are well known, their inclusion in process-based models is still limited (Brilli et al., 2017), as well as an exhaustive evaluation based on a variety of model outputs (e.g. crop productivity).

The objective of this work is to evaluate the response and uncertainties of predictions from an ensemble of crop models, which were run with a set of management options recognized for GHG mitigation and soil C sequestration, i.e., nitrogen (N) fertilisation regimes, irrigation amount and the handling of crop residues. This work was carried out in the framework of the FACCE-JPI project CN-MIP (C and N Models Inter-comparison and Improvement to assess management options for GHG mitigation in agrosystems worldwide; Ehrhardt et al., 2018, Sándor et al., 2018).

Material and Methods

We based this assessment on a set of 13, fully-calibrated process-based crop models (APSIM 7.6, Agro-C 1.0, CERES-EGC, DailyDayCent, DAYCENT [v4.5.2013, v4.5.2010, v4.5.2006], DNDC CAN, DSSAT GHG, EPIC 0810, FASSET v2.5, INFOCROP v2.1 and STICS v.831), managed by an equal number of modelling teams worldwide. Calibration was performed against N_2O emissions and biomass production data at five long-term crop rotations including wheat, soybean, canola, maize, triticale, rice and oat) located in India, France, Australia, Canada and Brazil (Ehrhardt et al., 2018).

Mitigation options were identified for each site based of the current practices of local farmers. They include: i) crop-specific N fertilisation regimes ranging from the maximum to the minimum applied dosages, ii) irrigation amounts from +50% to -50% of the baseline values, and iii) management of crop residues, exported or recycled to the field. With each model included in the ensemble, these options were assessed over a gradient of intensities using the parameter settings obtained with the site-specific calibration. The median of the multi-model ensemble was taken as an indicator of the central tendency of the model outputs, while the variability among models was assumed as an uncertainty measure.

Results and Discussions

Results highlight that a reduction of fertilizer N input is accompanied by a more than proportional reduction of N_2O emissions compared to a decline in biomass production: A fertilization at 20% of the maximum N dose for each crop and in each site is expected to reduce N_2O emissions of about 25% (0.3 kg N_2O-N ha^{-1} y^{-1}), with a reduction of 6% of the aboveground biomass (AGB; 0.6 t DM ha^{-1} y^{-1}). Furthermore, the effect of N dose reduction decreases by 25% and 30% nitrate leaching and ammonia emission, respectively.

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High irrigation volumes (up to +50% from the baseline) combined with high N rates increase N_2O emissions by about 3% with respect to the baseline irrigation, accompanied by a 3% increase in AGB. Reducing both irrigation to -50% from the baseline and N to the lowest doses causes a reduction down to 60% in N_2O emissions compared to the high N input and +50% of irrigation, with 18% reduction in AGB. A significant effect on N_2O emissions and soil C stock was observed with crop residues management. Multi-model uncertainty varied with the output and generally increased with low N doses and high irrigation volumes.

Conclusions

This work demonstrates the capability of multi-modelling assessment to quantify the impact of mitigation options on N_2O emissions, crop production and soil C stocks, providing an estimate of the uncertainties associated with the ensemble modelling.

Keywords: multi-modelling, greenhouse gas emission, soil carbon stock, management practices, cropland.

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S6-P.06

Historical and current approaches to decompose uncertainty in crop model predictions

Chapagain Ranju[1] (chapagainranju@gmail.com), Ojeda Jonathan[1], Mohammed Caroline[1], Brown Jaclyn[2], Remenyi Tomas[3], Harris Rebecca[3]

[1] *Tasmanian Institute of Agriculture, University of Tasmania, Hobart, TAS, Australia*; [2] *Agriculture and Food, CSIRO, Hobart, TAS, Australia*; [3] *School of Geography and Spatial Sciences, University of Tasmania, Hobart, TAS, Australia*

Cropping systems models have become an essential tool to simulate crop growth and yield at different scales to produce actionable information related to climate change, food security, land use and market dynamics (*e.g*. Waha et al., 2015; Wallach et al., 2016; Porwollik et al., 2017). Despite their increased usage and importance, various sources of uncertainty exist in the modelling process due to the "impossibility to model the cropping system with complete determinism" (Ramirez-Villegas et al. 2017).

In this article, by uncertainty we mean "any departure from the unachievable ideal of complete determinism" (Walker et al., 2003). Uncertainty is prevalent in every step of crop modelling, starting from the field observations used for model development to value of inputs and parameters to the structure and design of model (Fig. 1). Therefore, uncertainty can be grouped into three categories:

1. **Observation/measurement uncertainty:** error in observations/measurements (*e.g.* instrument error, operator error etc.) causes uncertainty in the value of measured quantity
2. **Prediction uncertainty:** the discrepancy between observations and simulations
3. **Model uncertainty:** the variance in simulations (model outputs)

These three categories of uncertainty (right side in Fig. 1) are closely related but different from one another. It is important to address these uncertainties, because not knowing the level of reliability of the output impedes the user's ability to implement actionable practices with confidence.
As such, this article has assessed the historical and current research gaps, trends and challenges in estimating uncertainty in crop modelling. For this, we adopted the approach as mentioned below:

1. **Resources:** two databases, Scopus and Web of Science, were used to find the current studies focusing on uncertainty in crop modelling
2. **Eligibility and exclusion criteria:** journal articles written in English were considered for the study and other literature type and languages were excluded
3. **Review process:** carried out in four stages- a) identifying the keywords, b) screening, c) eligibility checking and d) inclusion of journal articles for qualitative analysis.
4. **Data abstraction and analysis:** the included papers were assessed and analyzed qualitatively.

We use this data to map the current research space in crop modelling uncertainty. Our findings indicate the following recurring common themes about crop model uncertainty:

1. Structure uncertainty is principally quantified by using multi-model ensemble;
2. Climate and soil data resolution and data sources are the most commonly considered source of input uncertainty while estimating input uncertainty;
3. Sensitivity analysis is used technique to find the contribution of each source of uncertainty.
4. There is a lack of standard/guidelines/procedure for estimating uncertainty and evaluating estimates;
5. There are only a few papers which have attempted to consider all the possible sources of uncertainty in crop models.

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Decomposition of uncertainty is extremely important in uncertainty studies. Only when we know the contribution of each source of uncertainty in the total uncertainty, we will be able to derive more efforts in uncertainty reduction for the main sources. Additionally, uncertainty analysis provides the stakeholders (*e.g.* next and end-users of crop models) with confidence level on model outputs, which would help them in effective planning.

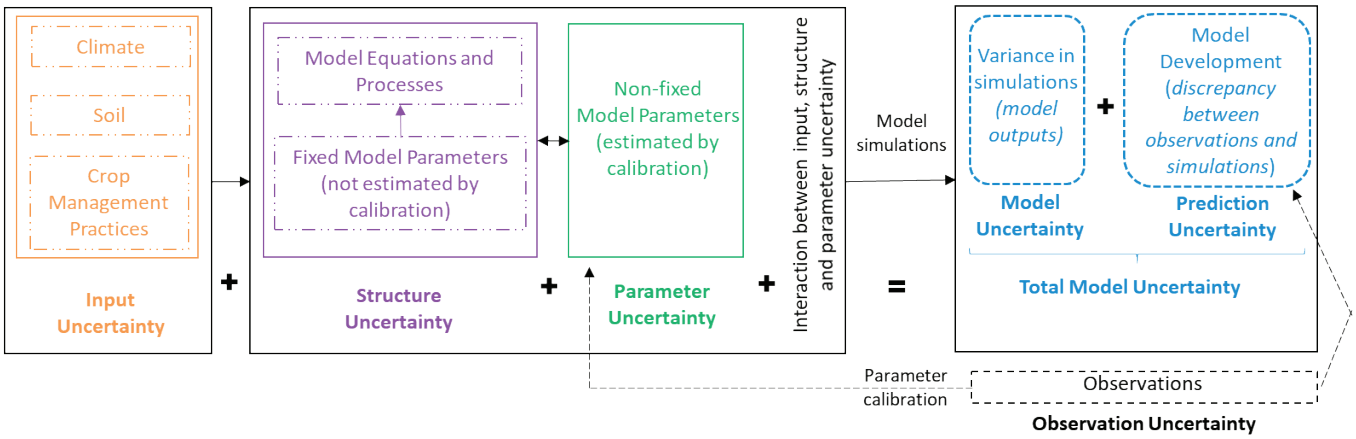

Figure 1. Schematic representation of crop model uncertainty decomposition including Total Model Uncertainty (Input Uncertainty + Structure Uncertainty + Parameter Uncertainty + Interactions) and Observation Uncertainty.

Keywords: Modelling, Input Uncertainty, Structure Uncertainty, Parameter Uncertainty, Data.

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S6-P.07

Comparison of sugarcane STICS model calibrations to simulate growth response to climate variability

Christina Mathias[1] (mathias.christina@cirad.fr), Chaput Maxime[2], Strullu Loïc[3], Versini Antoine[2], Soulié Jean-Christophe[2]

[1] *UPR 115 AIDA, CIRAD, Sainte-Clotilde, Réunion*; [2] *UPR 78 Recyclage & Risques, CIRAD, Sainte-Clotilde, Réunion*; [3] *ASAE, Reims, France*

Introduction

The key role of crop models is to help understand and predict the effects and interactions between climate, soil, management, species facilitation and competition on crop development and yield. Several process-based sugarcane models have been developed, such as DSSAT-Canegro, Canesim, Mosicas, or APSIM-Sugar, which differ through the nature of input parameters and constituent process algorithms. Assuming that the choice of model should be questioned each time according to the desired application, we present here the calibration of a new growth model for sugar cane (STICS). This model is particularly suitable for studies on species associations or the agrosystem's response to the supply of organic matter residues.

In the present study, we present and compare three different calibrations of the sugarcane crop growth in STICS, each of which can be applied to a different situation and objectives:

- Cane stalk conceptualized as a grain, in order to simulate sugar yield (STICS v9): "Sugarcane_grain"
- Cane stalk conceptualized as a stem, in order to simulate fresh cane yield variability (STICS v9): "Sugarcane_stem"
- Cane with perennial reserves, in order to simulate multiple regrowth (STICS vX): "Sugarcane_regrowth"

Methods

The database used for calibration consisted in 8 trials performed in the ICSM projects. These trials, described in Jones et al. 2019, included 2 years of sugarcane monitoring in four countries (Reunion, South Africa, Zimbabwe and USA) and followed the same measurement protocols. Additionally, 6 trials performed in Reunion between 1994 and 1997, used for the initial sugarcane prototype calibration, were used.

In the present study, we choose to parameterized the sugarcane species using field measurements or measurements in the literature as a priority. In cases where this information was not available, the model parameters were calibrated. The calibration was performed using an R package (Rgenoud) with a genetic algorithm and a RRMSE like scored function. The trials available in the ECOFI database (Christina et al., 2019) were used as a set of validation. This database includes 95 trials (1988-2018) performed with the R570 variety in Reunion Island.

Results and Discussion

An illustration of STICS simulations on the ICSM trials is presented in Figure 1. All three calibrations ("Sugarcane_grain", "Sugarcane_stem" and "Sugarcane_regrowth") satisfactorily simulated the leaf area index, and carbon allocation to aerial, leaf and stalk dry mass in the ECOFI trials. The "Sugarcane_grain" was currently the only one accurately simulating sugar yield in the cane stalk, but it failed to simulate fresh cane yield, which is an essential information for farmers and sugar industries. The "Sugarcane_stem" was the most accurate calibration to simulate fresh cane yield and thus should be applied to yield forecast studies. Finally, the "Sugarcane_regrowths" had strong potential, while simulating fresh cane yield and potentially sugar yield (still under development). Additionally, the possibility to simulate multiple regrowth with STICS vX could make it possible to assess the yield decline with ratoon age commonly observed by farmers as the evolution of soil organic matter in function of agricultural practices.

Perspectives

The potential applications of the STICS model for sugarcane simulations will be discussed with two focus on sugarcane / legume associations, and sugarcane response to organic residue applications.

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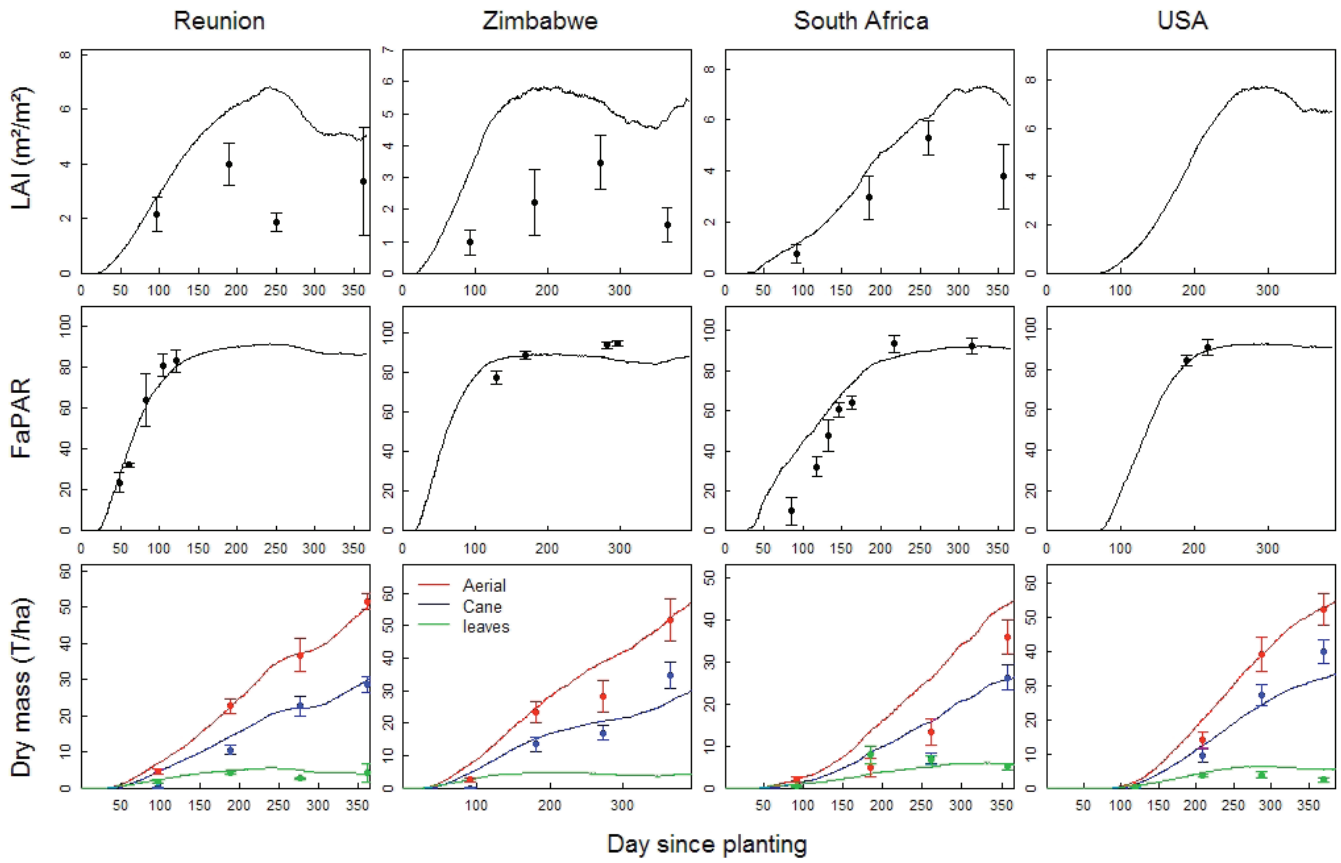

Figure 1. Example of simulations obtained with the STICS model in the ICSM project ("Sugarcane_stem").

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S6-P.08

Sensitivity of soil-crop models to spatial variation in soil-management interactions across Southern Sweden

Coucheney Elsa[1] (elsa.coucheney@slu.se), Blombäck Karin[1], Eckersten Henrik[1], Engström Lena[1], Larsolle Anders[1], Lewan Elisabet[1], Myrbeck Åsa[2], Stenberg Bo[1]

[1] *SLU, Uppsala, Sweden*; [2] *RISE, Uppsala, Sweden*

Introduction

The continuous development of process-based soil-crop models intend to integrate newest knowledge about soil - crop - climate - management interaction but model parameterization is often limited to certain conditions and model performance evaluation in a wide range of agronomic conditions remains scarce. We performed an evaluation of a model ensemble performance applied to a range of soil-management practises across southern Sweden. Our results aim to guide improvement of model calibration strategies for regional scale modelling representing a mosaic of agronomic situations and for supporting decision-making in precision agriculture.

Material and Methods

In this study, we combined field experiments and three soil-crop models (CoupModel, STICS and Sirius) to study the spatial variation in the potential and in the water (W) and nitrogen (N) limited winter wheat yield between and within sites. Field experiments including a total of 6 varieties of winter wheat were conducted (2015-2017) in four major agricultural regions of Sweden following a fractional factorial design in terms of different management practices, i.e. water, nutrient and pesticide supply. One treatment using irrigation and high inputs of nutrients and pesticides was furthermore applied to estimate the potential attainable wheat yield at each site, i.e. under *non-limiting* conditions. The experiment was repeated in different part of the field to access the effect of different soil properties.

The parameters driving the phenology and crop growth of the models under potential yield conditions were first calibrated against observed crop phenology, biomass accumulation and yield under the high input treatment (i.e. potential yield) at each site. Three sets of calibrations were performed using different years for calibration and validation. Extrapolated predictions of the potential yield from the different models x calibrations were compared to national varietal trials in Sweden (http://sortval.se/). Thereafter, the ability of the models to reproduce the observed yield reductions under different soil properties and management practices (limited water and nutrient supply) at the different locations was evaluated with no recalibration but using pedotransfert functions available in the literature.

Results and Discussion

Model validation in estimating the potential yield were equally good for the three models when including all 6 varieties and despite variation between models. The model ensemble was found to be a good predictor of the between site x variety variation observed in national trials (Fig1A&B). The CoupModel simulations were able to reproduce soil water storage in the different soil profiles but the yield reductions caused by water and nitrogen stresses in only 50% of the situations (e.g. for water Fig1C).

Conclusions

Can the model ensemble explain more of the WxN stress effects at the various places? Or, do we need further model parameter calibration? If so, looking into the relationship between model residuals (errors) and measured data will support further calibration strategies that should involve parameters of the spatial distribution of water and roots within the soil profile as well as crop response to water and N stresses.

Aknowledgments

The study was conducted in the frame of the AquaAgri program 'Effective and sustainable production systems within aquaculture and agriculture' (https://www.aquaagri.se/en) conjointly funded by FORMAS, MISTRA and Lantmännen.

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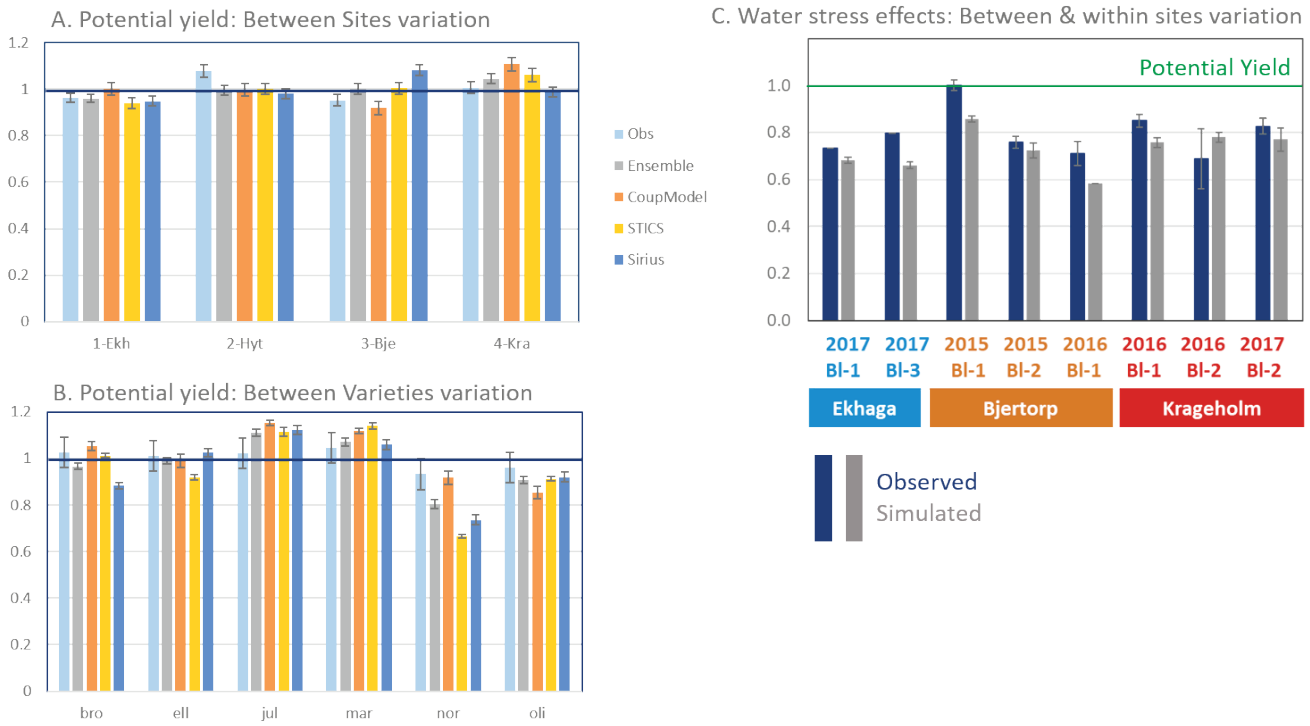

Figure 1: Variation of models and models ensemble predictions of the potential yield between sites and varieties (Fig1A&B) and of the yield reduction caused by water stress (Fig.1C) in regards to observations.

Keywords: yield gap, soil variation, model ensemble, regional scale.

S6-P.09

Identifiability analysis to improve experimental design for crop model calibration

Coudron Willem[1] (Willem.Coudron@ilvo.vlaanderen.be), Lootens Peter[1], De Cuypere Tim[2], Gobin Anne[3], Verheyen Kris[4], De Frenne Pieter[4], De Swaef Tom[1]

[1] *Plant Sciences Unit, ILVO, Melle, Belgium*; [2] *Inagro, Roeselare, Belgium*; [3] *VITO, Mol, Belgium*; [4] *Departement environment, UGent, Gontrode, Belgium*

Introduction

Crop models representing the interactions between the crop and its environmental conditions (meteorological variables, soil characteristics, biotical interactions, farming practices…) tend to be very complex. They simulate crop growth, yield formation and quality under a range of environmental conditions through a plethora of inter-connected bio-physical mechanisms. Consequently, these models contain a large number of parameters, of which a large proportion cannot be measured directly and need estimation based on a large amount of empirical data. In many cases the calibration process is largely over-looked, leading to unidentifiable parameter sets and a limited applicability or confidence in the model.

Materials and Methods

We here propose the identifiability analysis (De Swaef et al., 2019) that allows assessing which model parameters can be estimated from an empirical dataset. The analysis is based on a generation of sensitivity functions and subsequent collinearity analysis (Brun et al., 2001). As such, a parameter set is 'identifiable' if each parameter has a substantial effect on the model output and can be estimated independently from the observations. Although its application in crop modelling is still limited, practical identifiability analysis has great potential for model calibration practices.

Using the FME package (Soetaert and Petzoldt, 2010) for sensitivity and collinearity analysis in R, we applied this technology to the AquaCrop model for potato (Steduto et al., 2009). This enables designing experiments such that sufficient meaningful data are collected for model calibration. Therefore, we conducted virtual experiments with various weather and soil conditions. More specifically, we used 40 years of Belgian meteorological data with three different soil types as input to the model, and the successive projection algorithm (SPA) (Araújo et al., 2001) to find the optimal sampling scheme (Figure 1).

Results and Discussion

The virtual experiments conducted for different years and soil types provide insights in the required frequency of phenotypic field observations, the number (and soil type) of locations in a multi-location field trial and the required levels of drought stress. Basically, it comes down to maximizing the variation in model output dynamics, by altering the soil characteristics and meteorological conditions and then maximizing the capture of these dynamics by a smart timing of phenotypic observations. A major advantage is that this analysis can be conducted without the need for actual phenotypic data, and thus before the actual data collection.

Conclusions

This approach can help maximize the utilization of the generated phenotypic data for model calibration and assist in a more cost-effective overall multi-location experimental design. More specifically, field trial locations can subsequently be selected based on climate and soil data that provide maximum variations in model output.

Additionally, this search for maximum variation and the knowledge that is included in crop models can be utilized to improve phenotyping experiments.

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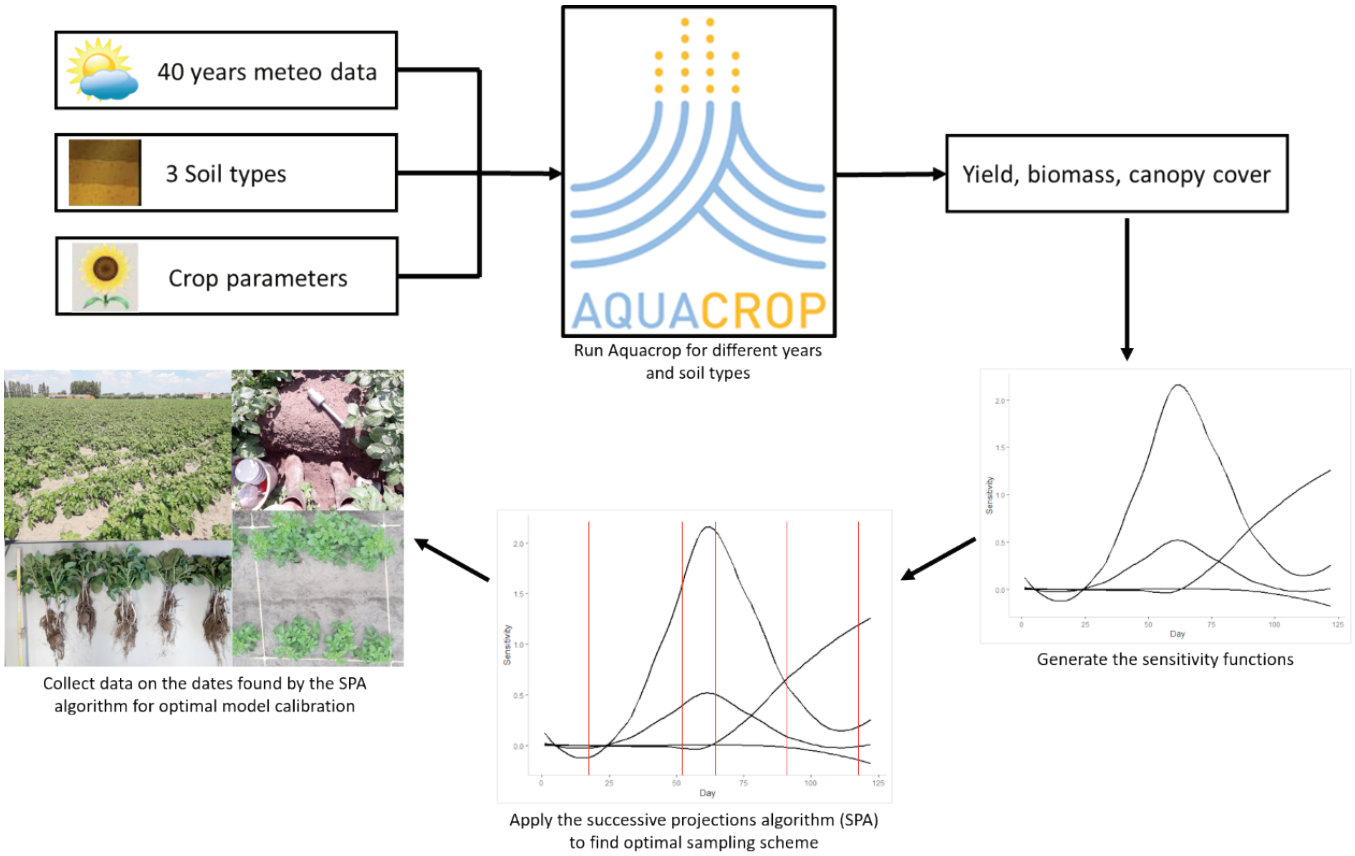

Figure 1. Application of the successive projections algorithm in identifiability analysis of Aquacrop to find the optimal sampling scheme for model calibration.

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S6-P.10

Comparison of three calibration methods for modeling rice phenology

Gao Yujing[1] (ygao820@ufl.edu), Wallach Daniel[2], Liu Bing[3], Dingkuhn Michael[4], Boote Kenneth[1], Singh Upendra[5], Asseng Senthold[1], Kahveci Tamer[6], He Jianqiang[7], Zhang Ruoyang[8], Confalonieri Roberto[9], Hoogenboom Gerrit[1]

[1] *Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States*; [2] *AGIR, INRA, Castanet-Tolosan, France*; [3] *Ministry of Agriculture, Nanjing Agricultural University, Nanjing, China*; [4] *Department of Biological Systems, CIRAD, Montpellier, France*; [5] *IFDC, Muscle Shoals, AL, United States*; [6] *Computer and Information Science, University of Florida, Gainesville, FL, United States*; [7] *College of Water Resources, Northwest A&F University, Yangling, China*; [8] *Department of Statistics, University of Florida, Gainesville, FL, United States*; [9] *Cassandra lab, University of Milan, Milan, Italy*

Calibration is an essential step for all crop modeling studies. The goal of this study was to compare three commonly-used calibration methods including Ordinary Least Square (OLS), Markov chain Monte Carlo (MCMC), and Generalized Likelihood Uncertainty Estimation (GLUE) as applied to the CSM-CERES-Rice phenology model of the Decision Support System for Agrotechnology Transfer (DSSAT). The analysis was performed by considering goodness-of-fit to observations, calibrated parameter values, uncertainty of parameter estimates and predictions, and the practical implementation of methods. The results showed that the selection of the calibration method has some impacts on parameter estimates and uncertainty quantifications. In the situations where goodness-of-fit is the main criterion, OLS is the fastest and most effective method. When the uncertainty of parameter estimates and model predictions are important, the MCMC method is more reliable in quantifying uncertainties. We found that for predicting phenology in our study, the GLUE method was unrealistic in quantifying model uncertainty, because the default model error variance was unlikely small. This study showed that MCMC for model calibration, coupled with estimation of model error variance, is a promising method for quantifying prediction uncertainty and that MCMC should be incorporated into crop modeling platforms.

Keywords: CSM-CERES-Rice, Parameter estimation, GLUE, MCMC, OLS.

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S6-P.11

Calibration of the phenology sub-model of APSIM-Oryza and validation for rice varieties: going beyond goodness of fit

Nissanka Sarath[1] (spn@pdn.ac.lk), Karunaratne Asha[2], Piyasiri Champa[3], Weerakoon Wijayasiri[4], Punyawardena Ranjith[5], Wallach Daniel[6]

[1] *Department of Crop Science, University of Peradeniya, Peradeniya, Sri Lanka*; [2] *Department of Export Agriculture, Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka*; [3] *Rice Research and Development Institute, Bathalagoda, Sri Lanka*; [4] *Department of Agriculture, Peradeniya, Sri Lanka*; [5] *Natural Resources Management Centre, Department of Agriculture, Peradeniya, Sri Lanka*; [6] *INRA, Toulouse, France*

Introduction

A key challenge in crop modelling is the accurate estimation of genetic coefficients. Physiological processes depend on phenological stages, the output of crop models is very sensitive to the use of accurate phenological parameters. Therefore, estimation of phenological parameters and evaluation for the APSIM-Oryza crop model for selected rice varieties grown in multiple locations in Sri Lanka was conducted.

Methodology

Data of Coordinated Rice Variety Trials (CRVT) conducted for 3 months (Bg300) and 3.5 months (Bg357, Bg358, Bg379-2) old rice varieties grown in two seasons of major [October-February] and minor [April-September] at three locations of Batalagoda (BG) (7^0 32' N, 80^0 27 E; agro-ecological region (AER) of IL1), Mahailluppallama (8^0 06' N, 80^0 27' E; AER of DL1b) and Amabalantota (6^0 7' N, $81^0$1' E; AER of DL5) were used. The study used CRVT data from 2000 to 2008 for calibration and 2009 to 2018 for model evaluation.

The phenology sub-model of APSIM-Oryza, is calibrated by a static model, replacing the original dynamic model, with just three equations, for DD to PI, to heading and to maturity. Although this involves an approximation (replacing daily day length with an average day length), it was evident that this approximation is quite good. Any standard statistical package (i.e R) can then easily be used to estimate the parameters. It is then straightforward to estimate the parameters using any standard statistical software package (Nissanka et al. 2015; Wallach et al., 2017).

Results and Discussion

The test of the effect of seasons on DD to PI is showed that the difference between major and minor seasons is significant at the 5% level for all varieties indicating all the varieties considered a significant effect of day length on time from emergence to PI. Four of the parameters are quite well estimated (small standard errors), but the standard error of the estimator of PPSE is large for all varieties; the coefficients of variation range from 0.56 to 0.73. The estimators for MOPP and PPSE are highly correlated, with correlation coefficients ranging from 0.98 to 0.99 depending on the cultivar. MAE is in the range 2-4 days for both the 4 and 5 parameter models. The RMSE values are very similar to those for the same model programmed in R (Tables 1), counting about 18 DD per calendar day. The evaluation of above parameters from four parameter model showed that simulated phenology and the yields for the 3 locations are in good agreement with the observed data.

Conclusions

This study emphasizes the importance of information about parameter uncertainty, in addition to information on goodness of fit. Goodness of fit indicates how well the model fits the data. Parameter uncertainty gives information about how well the model will perform for conditions different than those in the calibration data. An approach similar to that followed here could be applied to phenology models other than APSIM-Oryza. It should be a goal for the future to apply rigorous statistical methods to full crop models as well. We have shown that the recorded model gives results very similar to those of APSIM-Oryza, and also that when the estimated parameters are plugged into APSIM-Oryza, the model gives good agreement with the observed data. We thus conclude that static model could be used for APSIM-Oryza.

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Model parameter	Cultivar			
	Bg 300	Bg 357	Bg 358	Bg 379-2
$DVRI_{maha}$	0.00112	0.000919	0.000891	0.000816
	(0.0000368)	(0.0000219)	(0.0000193)	(0.0000233)
$DVRI_{yala}$	0.000948	0.000795	0.000783	0.000674
	(0.0000251)	(0.0000148)	(0.0000160)	(0.0000171)
DVRP	0.000646	0.000636	0.000641	0.000638
	(0.0000272)	(0.0000225)	(0.0000243)	(0.0000334)
DVRR	0.00176	0.00173	0.00187	0.00179
	(0.0000704)	(0.0000581)	(0.0000699)	(0.0000916)
AIC	953.5	670.4	458.2	488.8
RMSE	82	59	50	72

Estimated parameter values and standard errors (in parenthesis) of the estimators for the 4 parameter model using OLS. The last row shows root mean squared error (RMSE) in DD, averaged over all predictions

Keywords: Genetic coefficients, crop model, rice phenology.

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S6-P.12

Impact of different sets of climate variables on regional Maize yield simulations- A case study in Sub-Saharan Africa

Srivastava Amit Kumar[1] (amit.srivastava@uni-bonn.de), Ceglar Andrej[2], Zeng Wenzhi[3], Mboh Cho Miltin[1], Gaiser Thomas[1], Ewert Frank[1]

[1] *Crop Science, University of Bonn, INRES, Bonn, NRW, Germany*; [2] *Joint Research Centre, Europ. Commission, Ispra, Italy*; [3] *Wuhan University, Wuhan, China*

Introduction

High resolution and consistent Grid-based historical weather data series are of major importance for agricultural planning and risk assessment. However, the application of models at regional scale are frequently constrained by lack of required high-quality weather data which may be retrieved from different sources. This can potentially introduce large uncertainties into the crop simulation results. Therefore, in the current study we examined the impacts of grid-based time series of weather variables assembled from the same data source (Approach 1) and from the different sources (Approach 2) on regional scale maize yield simulations in Nigeria.

Materials and Methods

Maize yields were simulated for approach 1 and 2 using LINTUL5 embedded into the modeling framework SIMPLACE (Scientific Impact Assessment and Modelling Platform for Advanced Crop and Ecosystem Management) (Gaiser et al. 2013) for maize in three states in Nigeria (Figure 1).

Results and Discussion

There was 45.6 % less variability in the simulated yield under Approach 1 compared to those simulated using datasets retrieved under Approach 2. In the two sources of climate data tested here, Approach1 resulted in a RMSE value of 0.31 Mg ha-1 while a RMSE value of 0.51 Mg ha-1 was obtained for Approach 2.

Conclusions

The obtained results suggest that Approach 1 introduces less uncertainty to the yield estimates in large-scale regional simulations and that, physical consistency between meteorological input variables are relevant factors to consider for crop yield simulations under rainfed conditions.

Acknowledgements

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Figure 1: Map showing the simulation points covering three states in Nigeria.

Keywords: Climate data, regional scale, yield, uncertainty.

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S6-P.13

Associated tools for STICS testing and development towards agro-ecology, mitigation and adaptation to climate change

Beaudoin Nicolas[1] (nicolas.beaudoin@inra.fr), Buis Samuel[2], Lecharpentier Patrice[3], Ruget Françoise[2], Ruiz Laurent[4], Morissette Rene[5], Duval Jérôme[1], Dubrulle Pascal[6], Giner Michel[7], Léonard Joël[1], Ripoche Dominique[3]

[1] *AgroImpact, INRA, Barenton-Bugny, France*; [2] *UMR EMMAH, INRA, Avignon, France*; [3] *Agroclim, INRA, Avignon, France*; [4] *UMR SAS, INRA, Bangalore, India*; [5] *Agriculture and Agri-Food Canada, Quebec, Quebec, Canada*; [6] *AgroImpact, INRA, Estrées-Mons, France*; [7] *Persyst, CIRAD, Montpellier, France*

Introduction

The STICS crop model has evolved since 1996 thanks to the collective efforts of a scientific and software engineering community (Beaudoin et al., 2019). It simulates the impact on the soil-crop system of weather, soil, crop and management practices (*e.g.* fertilization and irrigation) for single crops, associations and crop rotations. It computes the water, C and N balances and outputs include both agricultural and environmental variables (*e.g.* crop yield, N leaching and soil organic carbon dynamics). It is generic for various crops and convenient for numerous pedoclimatic conditions. It can «stand alone» (JAVA interface), be coupled with GIS, or integrated into modelling platforms.

Four illustrations show how STICS use can be to addressed to water management and food security: i) impact prognosis of global climate change (GCC) on crop feasibility and disease risk (Brisson, Levrault, 2010); ii) advice about forage system sensitivity to drought and GCC (Ruget et al., 2006); iii) multiscale evaluation of improved cropping systems on yield and water resource quality (Beaudoin et al., 2016); iv) adaptation of farming systems to water scarcity and GCC in India (Atcha project https://anr.fr/Projet-ANR-16-CE03-0006). Therefore, STICS became a partnership tool used as a «cropping system model» for evaluation and / or optimization of crop management strategies based on agro-environmental criteria, at short and long time scales.

Material and Methods

STICS governance combines the creativity of research to foster the evolution of the conceptual framework and the rigor of the software engineering for maintaining the code and testing model performance (i.e organizational ambidexterity). Several tools (R packages) are proposed to either STICS users or experimenters, for assessing the quality of development, evaluating model performance and model regression checking, through building R routines (*Fig. 1*). A version control system under SubVersioN is used for collaborative development and traceability of the STICS source codes. A continuous integration platform under Jenkins automates tests and performance evaluations each time the source codes are modified, using the stored French datasets. The International Database for Evaluation of STICS (IDE-STICS) aims to gather datasets in contrasting world regions (Europe, Africa, Asia, North and South America). IDE-STICS integrates metadata which will permit to standardize the soil parameterization between all the datasets, to upgrade model inputs for a new version and finally to feed another model. A collaboration agreement is proposed to experimenters who share their dataset.

Two motivations stand out for improving and extending the IDE-STICS database:

- to include tropical and agro-ecological systems among the test cases;
- to test performance for new variables of interest that are scarce in the current STICS database (i.e N_2O emissions, soil C stocks which are of the first interest in climate change).

Conclusion

The release of the last version of STICS (v.10; this congress), is expected to contribute to world-wide cropping system design to meet of agro-ecology, mitigation and adaptation to climate change. Ensuring the robustness of the standard version remains the priority challenge. These two purposes will positively interact by augmenting IDE-STICS, which will be open for users who want to calibrate or to compare STICS with another model.

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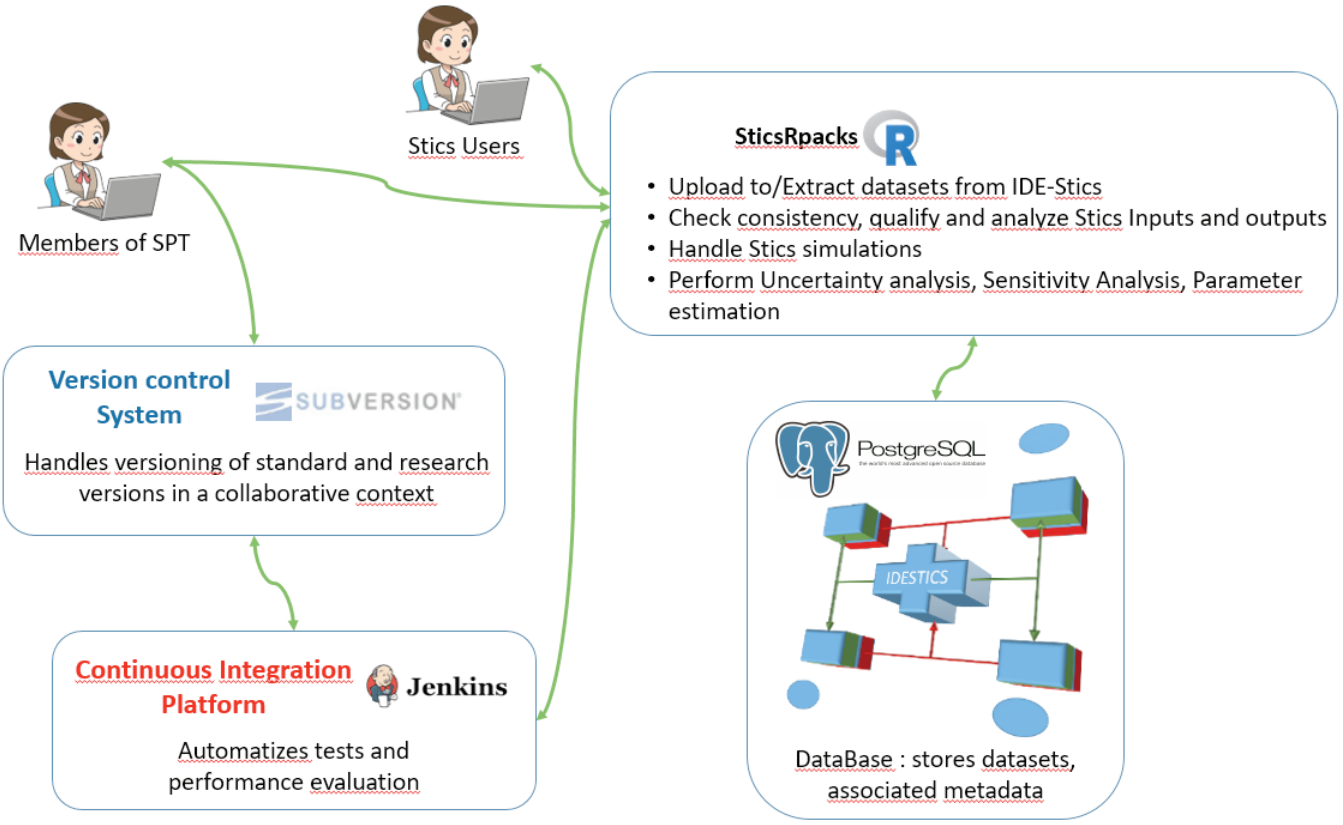

Figure. 1: Scheme of the test bench of the STICS model.

Keywords: experimental database, performance test, integration platform, genericity, robustness.

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S6-P.14

Combining crop modelling and machine learning for rapid provision of crop yield estimates and externalities

Folberth Christian[1] (folberth@iiasa.ac.at), Baklanov Artem[2], Juraj Balkovič[1], Skalský Rastislav[1], Khabarov Nikolay[1], Obersteiner Michael[1]

[1] *Ecosystem Services and Management, IIASA, Laxenburg, Austria*; [2] *Advanced Systems Analysis, IIASA, Laxenburg, Austria*

Introduction

Large-scale crop models are important tools to inform climate impact assessments, agro-economic models, and increasingly also stakeholders directly. Yet, process-based crop modelling is highly data and computationally demanding, requiring a wide range of environmental and management variables in specific formats besides substantial expertise. This results in long lead times to obtain location-specific information and limits the usability for non-specialists. To overcome these limitations, we have trained and evaluated crop meta-models based on state-of-the-art machine learning (ML) algorithms and global gridded crop model (GGCM) simulations for provision of non-nutrient limited crop yield potentials at high resolutions (Folberth et al., 2019). Here, we present results of this study and the framework for further developments.

Material and Methods

We selected two of the most prominent ML algorithms, extreme gradient boosting (XGB; Chen and Guestrin, 2016) and random forests (RF; Breiman, 2001), to train meta-models for predicting crop yield potentials at the extent of Mexico at high spatial resolutions of 1 km x 1 km (see figure). Target variables for algorithm training were produced by running the GGCM EPIC-IIASA (Balkovič et al., 2013) globally with a spatial resolution of 0.5° x 0.5°. ML algorithms were trained using crop model input data with temporally aggregated climate variables and crop model outputs with a total training sample size of approx. 2 million simulations.

Results and Discussion

Meta-model predictions compare extremely well with biophysical crop model simulations performed at the high spatial resolution (R2=0.97-0.99, ME<1%). Essential covariates are substantially sparser than those required by the crop model and can be provided in a generic format, rendering the retrieval of crop yield predictions highly efficient. XGB showed higher accuracy than RF if all features were used, whereas the latter had higher skills with sparser feature subsets. Besides crop yields, this was also the case for predictions of selected agricultural externalities. Bias was largest for (semi-)arid locations with extremely low simulated yields, indicating that the range of climate conditions considered in model training may need to be expanded.

Conclusions and Outlook

This proof-of-concept study showed that crop meta-models based on ML algorithms can well emulate the biophysical crop model for yield potentials. In upcoming experiments, extended dimensions on management and climate conditions will be included based on a synthetic cube (Ruane et al., 2017). Further exploration will cover data assimilation of crop model outputs and field observations as training data to improve meta-model skills, methods to detect data ranges for safe application of meta-models, and additional externalities including the input requirements and fate of nutrients such as nitrogen and phosphorus or soil organic matter.

Acknowledgements

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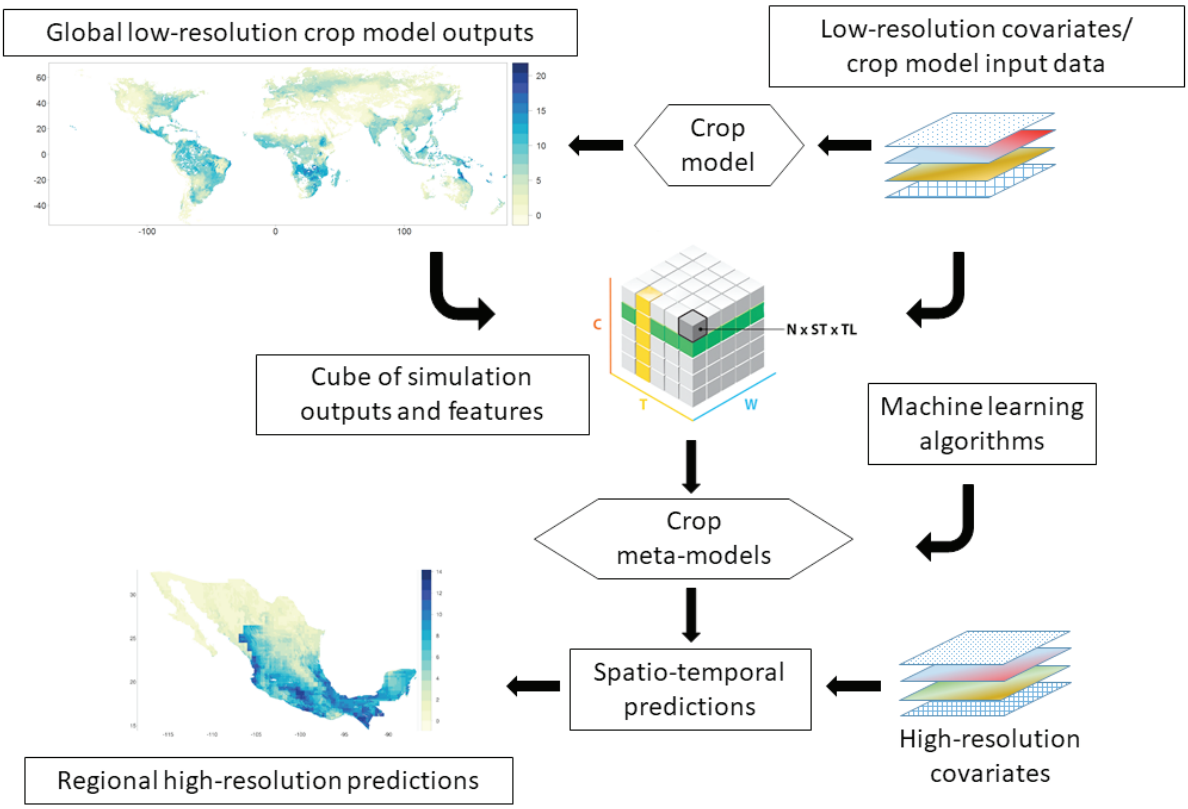

Framework for crop meta-model training and predictions including a multi-dimensional cube of training data along the dimensions atm. CO_2 (C) x temperature (T) x water (W) x nutrient input (N) x soil (ST) x tillage regime (TL). Modified from Folberth et al. (2019).

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S6-P.15

A machine learning pipeline for climate impacts: crop models versus deep learners

Gallear Joseph[1] (eejg@leeds.ac.uk), Challinor Andrew[1], Cohen Netta[2], Cohn Anthony[2], Franke James[3], Ruane Alexander[4], Müller Christoph[5]

[1] *School of earth & environment, University of Leeds, Leeds, United Kingdom*; [2] *School of Computing, University of Leeds, Leeds, United Kingdom*; [3] *Department of the Geophysical Sciences, University of Chicago, Chicago, United States*; [4] *NASA Goddard Institute for Space Studies, New York, United States*; [5] *Institute for Climate Impact Research, Potsdam, Germany*

Introduction

Crop models are widely used for informing policy and have shown great results when predicting crop response to environmental change (Rosenzweig et al. 2013, Droutsas et al. 2019). Machine learning may improve crop modelling due to its capacity to generalize and function approximation. Deep learning has shown significant advancements in recent years and has been applied to climate modelling with great success (e.g. Liu et al. 2016). The aim of this study is to determine whether machine learning models can outperform the General large area model for annual crops (GLAM) model- a regional scale process-based crop model - at explaining interannual variability in crop yields. The study also determines how much data is required for machine learning to do this, and intercompares the skill of various machine learning methods of various degrees of complexity. This is determined with synthetic data, making use of a perfect model assumption, whereby crop model output is taken as real data.

Methodology

Methods seek to determine which machine learning frameworks best explain interannual yield variation in comparison to the GLAM crop model. Figure 1 displays the methodological framework for this study, Data used includes Agmerra weather data, country level FAOstat yield observations and simulated data from the Global gridded crop model intercomparison (GGCMI) phase 2 dataset (Franke et al.) The GGCMI phase 2 dataset is an ensemble of global simulations from up to 12 different crop models and 4 crops which runs from 1980 to 2010 at the 0.5-degree global scale. The data are used as part of a perfect model assumption using the results from the crop models in the ensemble.

Crop yield variability simulated by the ensemble is taken as a proxy for real world observed variability where statistically significant correlations are found with FAOstat observations. This effectively downscales the FAO data to the grid scale. The assumption is made that grid cells within the ensemble that show significant correlations with FAOstat data for that country are realistic. A perfect model is chosen from the ensemble on a country basis by choosing the crop model which varies closest with FAOstat data. This process results in a training and validation data set for a range of machine learning frameworks.

Machine learning methods assessed include linear regression models, feed forward, recurrent and convolutional neural networks, decision tree and random forest, support vector regression and Bayesian regression. Machine learning frameworks range in complexity from a linear model to a deep neural network. Machine learning models are trained on two thirds of the data before successively removing training years of the detrended time series. Finally, a spatially distributed deep learning model is used to determine spatial generalization of predictions.

Results and Discussion

This study will benchmark deep and machine learning algorithms against GLAM to determine the variance explained of each model. Comparisons are delivered for a range of geographic regions.

Conclusions

We aim to discover the threshold at which data quantity enables machine learning to provide a comparable prediction of yield variability to a process-based crop model, and a level of complexity which enables such comparison with process-based models. Such results would have implications for future benchmarking of process-based crop models and the use of statistical crop models.

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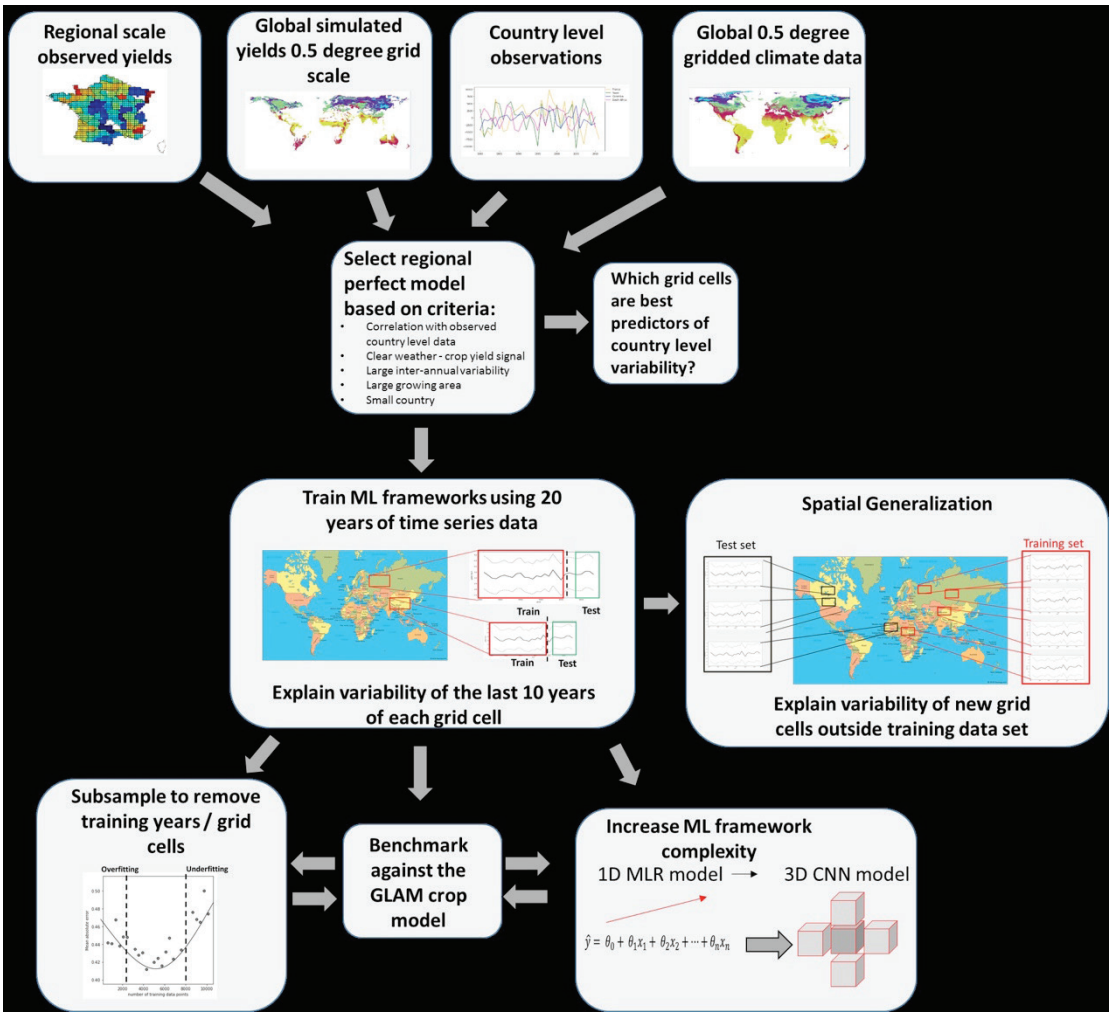

Fig 1. Methodological framework for this study using a perfect model approach. Data from a country and 0.5-degree grid cell scale is used to select a perfect model on a country by country basis. This is used as training data for machine learning algorithms. Machine learning frameworks are bench marked against the GLAM crop model.

Keywords: Machine Learning, Crop Model, Neural Networks.

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S6-P.16

Tools to Support Computational Crop Model Analysis and Comparison

Hoogenboom Gerrit[1] (gerrit@ufl.edu), Morrison Clayton[2], Porter Cheryl[1], Hein Paul[2], Pyarelal Adarsh[2]

[1] *Agricultural and Biological Engineering, University of Florida, Gainesville, FL, United States*; [2] *School of Information, University of Arizona, Tucson, AZ, United States*

Computational implementations of crop system models provide a basis for precise comparison of different model components. However, model comparison is still a labor-intensive process: although source code for models is increasingly publicly available, it is often implemented in different programming languages and different software frameworks, requiring a significant manual software engineering to expose model components in a form amenable to direct analysis and comparison. Sometimes this comparison even requires re-implementing models in the same programming language, with manual normalization and alignment of variable names (Carmargo and Kemanian, 2016). Furthermore, even for models implemented within the same framework, complexity of the component models themselves may make comparison a challenge.

We present an overview of the AutoMATES system for facilitating analysis of models implemented ase software (Pyarelal et al., 2019). AutoMATES performs program analysis directly on source code (Fortran) to extract a representation of a program that abstracts away the program's control flow, isolating variables and their functional relations. AutoMATES compares two models by analyzing the overlap between the graph representations of the models, followed by sensitivity analysis to identify differences in model outputs as functions of the shared inputs (Saltelli et al., 2008).

The figure presents an example of model comparison for two code components from the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al., 2003; Hoogenboom et al. 2019). The two components come from the PET module of DSSAT for computing *potential evapotranspiration*: the Priestley-Taylor (PT) and American Society for Civil Engineering (ASCE) models. Ovals (nodes) in the graph represent variables that are present in source code, and directed arrows from a set of variables (the parents) to another variable (child) indicate that the parent variables are directly involved in determining the state of the child variable. Blue nodes represent variables that are shared by both the PT and ASCE models, with potential evapotranspiration rate (EO) as the output of both. The directed paths (the collection of black arrows and nodes) between these shared input and output variables perform different computations, and the crop modeler will want to understand how these two models behave differently as a function of the shared input variables. In this case, the ASCE model is much more complex and includes a number of additional inputs and computations compared to the PT model. AutoMATES automatically identifies green nodes as the additional variables in ASCE that must be controlled in order to isolate just the directed paths of ASCE's computation that overlaps with Priestley-Taylor's. Controlling these variables then allows the modeler to ignore the red variables when directly comparing the overlapping components. Any subgraph of the AutoMATES graph representation can be executed, so the modeler may now perform sensitivity analysis on the isolated overlapping components to explore differences in the functional behavior of the two models, without having to write new code.

AutoMATES provides the model overlap identification tool among other model analysis methods. The goal is to ease the software engineering burden of working with complex models so that domain experts can focus on model analysis, comparison, and augmentation.

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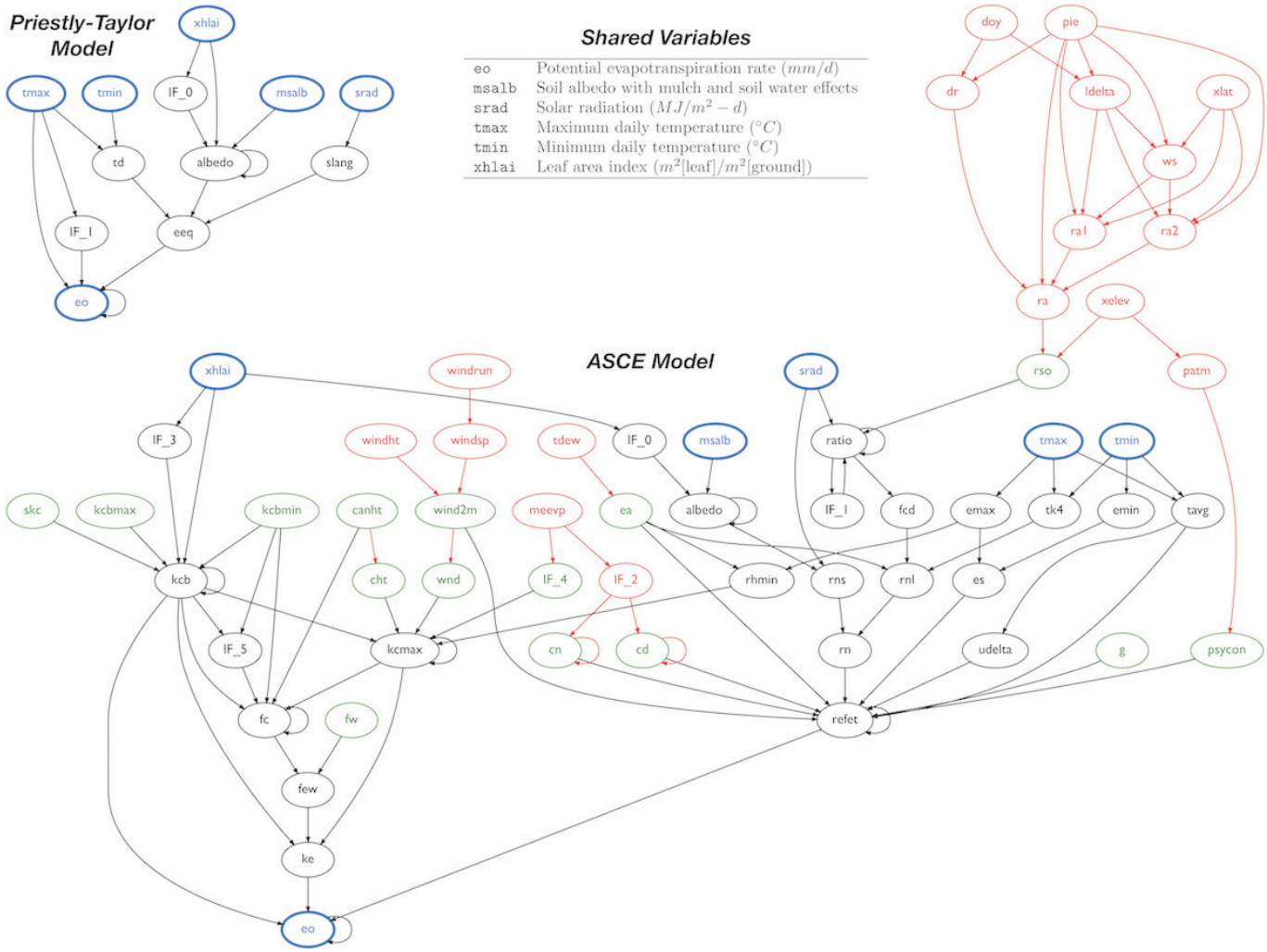

AutoMATES representation of model comparison of the DSSAT PT and ASCE models.

Keywords: Program Analysis, Model Comparison, Sensitivity Analysis, DSSAT.

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S6-P.17

Application of a gridded crop growth simulation support system to a Raspberry Pi cluster computer

Kim Kwang Soo[1] (luxkwang@snu.ac.kr), Park Jinew[1], Kim Junhwan[2]

[1] *Department of Plant Science, Seoul National University, Seoul, South Korea*; [2] *Rice Research Division, National Institute of Crop Science, Jeonju, South Korea*

Introduction

A cluster computer, which consists of high performance personal computers or workstations connected by a network, has been used to perform spatial simulations of crop yields under climate change (Rosenzweig et al., 2014). Still, such a cluster computer would require considerably high cost and electricity for construction and operation, respectively. Instead, microcomputers, e.g., Raspberry Pi, have been used to build an alternative computing platform to high end cluster computers (Bernabe et al., 2016). The objective of this study was to evaluate a low cost Raspberry Pi cluster for gridded crop growth simulations, which would be useful for identification of climate change adaptation options, e.g., optimum sowing date in a region, using a process-based crop growth model.

Materials and Methods

In the present study, five Raspberry Pi 4 boards were connected to create a loosely-coupled cluster. The cluster computer consisted of one master node and four computation nodes. A software tool for gridded crop growth simulation written in C++ was installed to the Raspberry Pi cluster. As a case study, the Raspberry Pi cluster was used to perform crop growth simulations at about 100,000 cells in each year from 2001-2010. The ORYZA2000 model was used to perform 5.8x107 simulations using gridded weather data at 1 km spatial resolution as inputs to the model in Korea. The optimum sowing dates were determined to have the maximum yield by each grid cell using the simulation outputs from 2001-2010.

Results and Discussion

The weather input files were converted from the gridded weather data in about 3,000 seconds on average for a given year. The wall time for relocation of weather data to computing nodes and all the simulations of the rice growth were about 200 and 3,000 seconds per year, respectively. These results suggested that the Raspberry Pi cluster would become an affordable computing platform for spatial assessment of climate change on crop production and design of adaptation strategies.

Still, performance analysis for storage and network devices would be needed to identify the bottle-necks that would delay computation time. In addition, the optimization of source code would be preferred to reduce the wall time, which merits further development study.

Conclusions

The use of micro-computer such as Raspberry Pi boards would allow to perform gridded crop growth simulations at low cost and electricity, which merits further evaluation studies under a diverse set of simulation settings.

Acknowledgements

This study was supported by Cooperative Research for Agriculture Science Technology Development (PJ013837032019)" program. We would like to thank Phillip Alderman at Oklahoma State University for discussion usion on using micro-computers for crop growth models.

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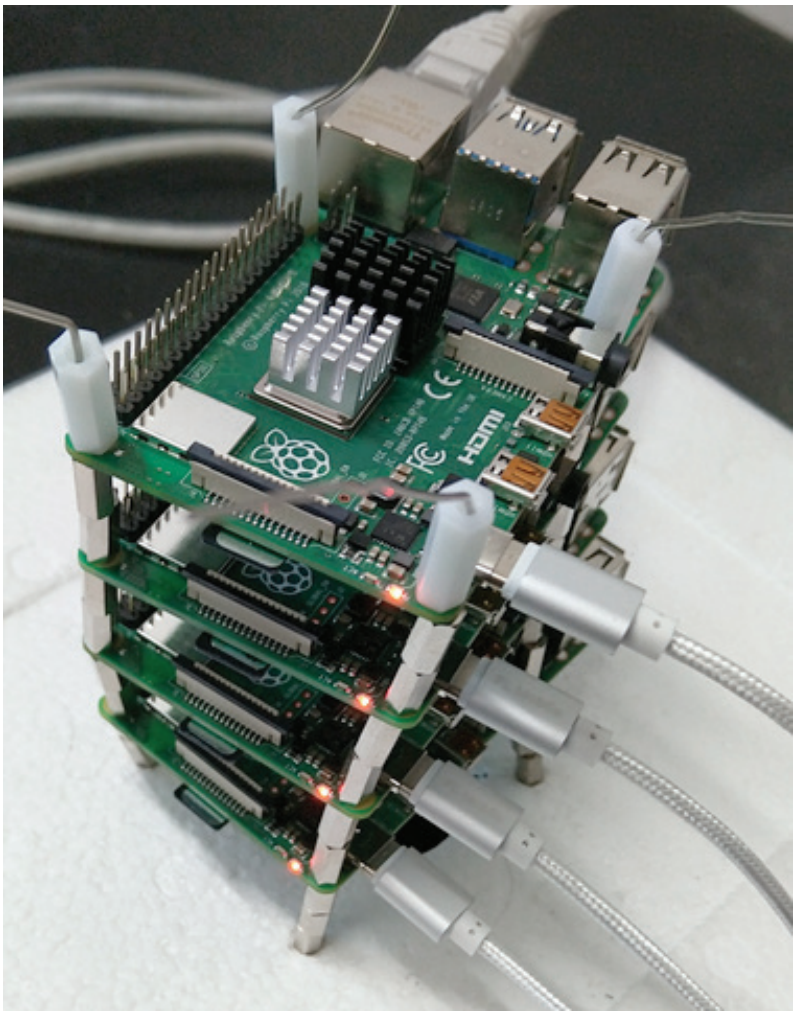

The cluster computer that consists of five Raspberry Pi 4 boards.

Keywords: High performance computing, GIS, crop model, netCDF, climate change adaptation.

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S6-P.18

CyML language and transpiler: Re-using biophysical processes in crop growth models across multiple platforms

Midingoyi Cyrille[1] (cyrille.midingoyi@inrae.fr), Martre Pierre[1], Pradal Christophe[2]

[1] *LEPSE, Univ Montpellier, INRAE, INSAAE, Montpellier, France*; [2] *AGAP, Univ Montpellier, CIRAD, INRAE, INSAAE, Montpellier, France*

Introduction

A model component implements a biophysical process in a given language within a specific simulation platform using its specific design patterns and architectural constraints. Several studies focused on component exchange and reuse by different platforms (Holzworth et al., 2014). However, current methods reuse existing components from different platforms by re-implementing them in different languages. To avoid a combinatorial increase of the number of component conversions between platforms, we propose CyML, an abstract representation of components shared by simulation platforms. This language allows encoding a model through its recurrent equations or mathematical expressions with control structure. We also provide a transpiler to convert CyML models in different languages.

Materials and Methods

A model component can be represented by a composition of functions with inputs/outputs. We propose an approach where each function is implemented in CyML and can then be automatically translated into different languages. CyML uses a subset of Cython language, which is able to encode discrete-time dynamic models and reuse implementation into procedural (Fortran), object-oriented (Java, C#, C++) and scripting or functional (R, Python) languages. Our approach relies on language specialization pattern (Spinellis, 2001) as Domain-Specific Embedded Language for Cython. The workflow of transpilation is mainly based on Abstract Syntax Tree (AST) transformations and takes into account platforms' design patterns.

We developed a web application, based on the Jupyter Notebook, to transpile a CyML model into a target language, and to test interactively the produced model with the provided unit tests using Jupyter kernels for the different languages supported. Users can edit and execute a model, modify its input values, and visualize both the model structure and the generated outputs using interactive web widgets.

Results and Discussion

The transpiler workflow (Fig. 1) is an interactive process that allows observing intermediate results during (1) the parsing phase where the CyML code is transformed into Cython AST and analyzed to check its conformance with CyML; (2) the transformation of Cython AST into CyML and target language ASTs; and (3) the generation of codes in a target language or in a specific simulation platform. We tested the framework with two crop model components, a crop energy balance and a wheat phenology models available as standalone BioMA components. We implemented these components in CyML and converted them into target languages to make them reproducible regardless of their implementation platform. We also exported them into different simulation platforms for reuse through the transpiler workflow.

Conclusions

We demonstrated the possibility to implement a model component in a common language and to translate it automatically in other languages and simulation platforms. Our work contributes to model reuse by an automated translation workflow instead of recoding model or using wrapping approach and can be used for model reproducibility. Currently, CyML implements discrete-time models mainly represented by recurrent equations and control structures. However, it can be used to transpile any function libraries that belong to the limitations of its syntax and semantics. The architecture of the language design and the workflow toolchain is modular allowing to extend it with new target languages and crop simulation platforms.

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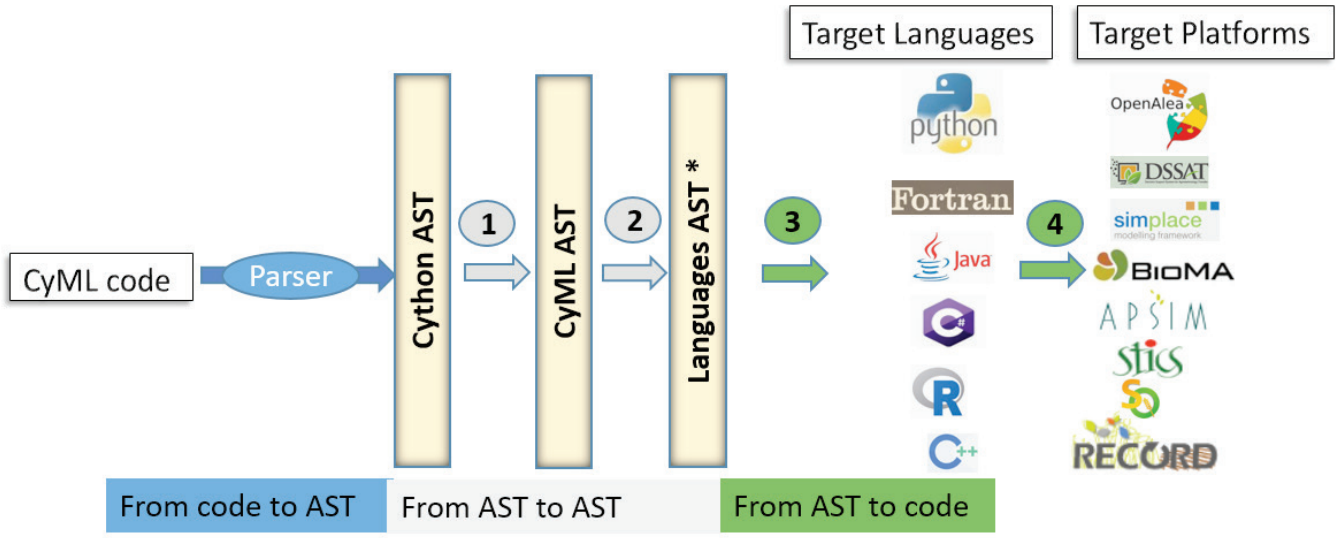

Figure 1. Schematic workflow of the CyML transpiler.

Keywords: Crop growth model, CyML, crop simulation platform, programming language, transpiler.

References:

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S6-P.19

Computationally-intensive crop model simulations using serverless computing for Mars colonization

Rodríguez Alfredo[1] (alfre2ky@gmail.com), Vázquez-Poletti José Luis[2], Ruiz-Ramos Margarita[1], Sanz-Cobena Alberto[1], Grishakina Ekaterina[3], Makovchuk Vladislav[3], Ezhelev Zakhar[4], Cheptsov Vladimir[4], Belov Andrei[4], Martín Ignacio[2]

[1] *CEIGRAM, Universidad Politécnica de Madrid, Madrid, Spain*; [2] *Universidad Complutense de Madrid, Madrid, Spain*; [3] *Vernadsky Institute of Geo. An. Chem., RAS, Moscow, Russia*; [4] *Lomonosov Moscow State University, Moscow, Russia*

Introduction

The use of crop models allows assessing different management options and also to analyse how crops behave under a wide range of environmental conditions, being a crucial tool to evaluate a high number of situations in a short amount of time. Nevertheless, when the number of options to test is very high, especially when different options want to be tested in combination with others, the number of required simulations may cause than a common computer would be not enough to fulfil the task. In the other hand, budget restrictions difficult the availability of equipment with high computing capacity. To solve this situation, serverless computing offers an alternative, providing support to execute data-intensive tasks in almost real time. The user only needs to pay for the required services according with the pay-as-you-go pricing model, with affordable costs. Here we present an application to illustrate the use of this serverless computing approach: the architecture designed to explore the best conditions to initiate future crop production to support an eventual Mars colonization by testing different combinations of environmental variables to design an efficient greenhouse on Martian soil.

Materials and Methods

This simulation experiment relies on a simulant of Martian soil (Grishakina et al., 2018) that can be used as input in the crop model (maize model from DSSAT), reproducing the properties of the Martian regolith (e.g. depth, texture, field capacity, organic matter). The environmental conditions to be tested will be controlled are radiation, temperatures, humidity, wind speed, precipitation (irrigation). Also, different crop varieties and fertilization managements will be tested. The FORTRAN source code of the DSSAT (Jones et al., 2003) crop simulation model was compiled for the Amazon Linux virtual machine architecture and is executed using the Amazon Web Services Lambda serverless framework (AWSL). An Amazon S3 input bucket is ready for the user to start the simulations by uploading compressed file containing 1) the file structure required by the model and the files configured for the current base simulation and 2) a text file with a list of values and input files to be modified prior to the execution, and the desired outputs. Then, an Amazon Lambda wrapper function written in Python, is triggered, configuring each simulation, and then running the simulations and gathering the results, which will be made available at the Amazon S3 output bucket.

Results and Discussion

The chosen AWSL framework was already been proved to be a good alternative in performance and cost for similar applications (Vázquez-Poletti and Martín, 2018). The preliminary simulation results show an improvement in both cost and execution time when comparing this methodology with a conventional architecture. Further steps include the comparison of this simulation experiment with experimental data (Grishakina et al. 2018).

Conclusions

Serverless computing stands as a useful alternative for performing crop model simulations, allowing to accomplish a huge amount of executions within a reasonable time, without needing a server management or capacity planning and paying only for the required services.

Acknowledgments

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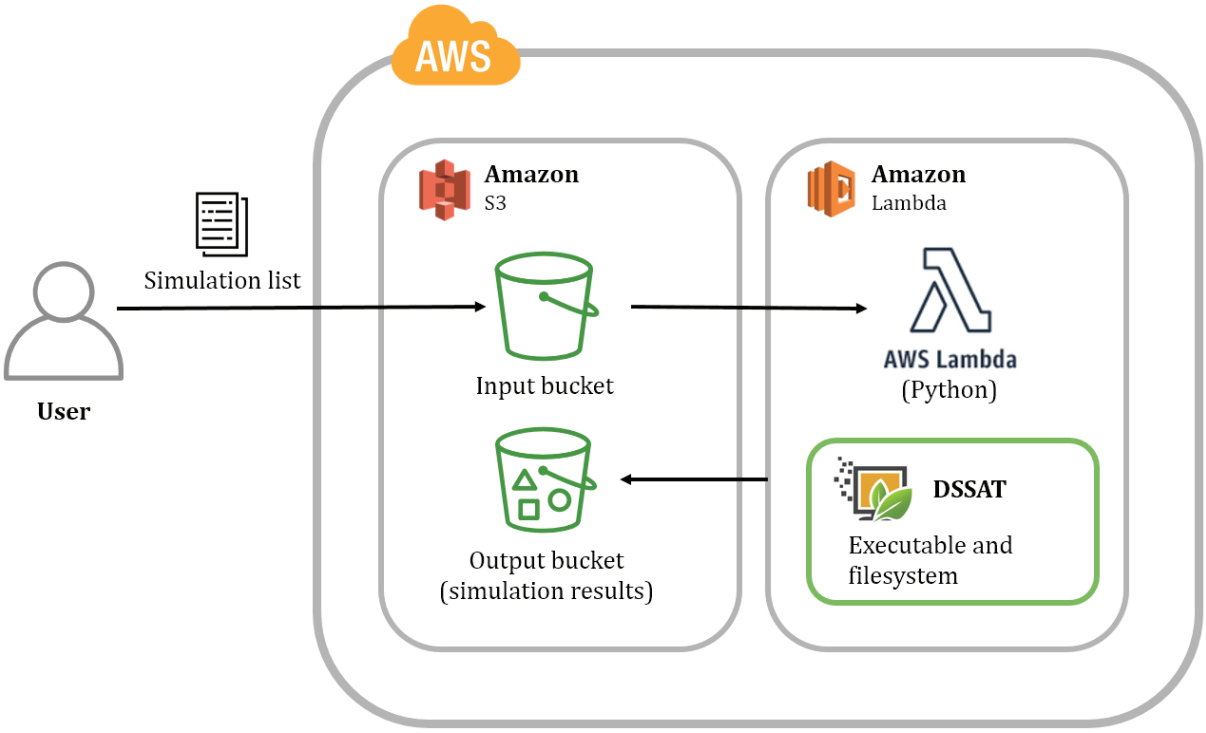

Proposed serverless computing architecture for the crop model simulation environment using Amazon Web Services (AWS)

Keywords: Cloud computing, Serverless computing, Crop simulation, DSSAT, Mars colonization.

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S6-P.20

Exploit the Panel: Combining Agronomic Weather Measures and Year Effect in a Spatial Study

Marton Tibor[1] (martontiborandras@gmail.com), Kiss Anna[2], Zubor-Nemes Anna Anna[3], Fodor Nándor[4]

[1] *Crop Production, Center for Agricultural Research/HAS, Martonvásár, Fejér, Hungary*; [2] *Department of Meteorology, Eötvös Loránd University, Budapest, Pest, Hungary*; [3] *Research Institute of Ag. Economics, Budapest, Pest, Hungary*; [4] *Crop, Center for Agricultural Research/HAS, Martonvásár, Fejér, Hungary*

Introduction

Crop yield models are often used on Global scale and thus provide great overview about potential future challenges that humanity face. We argue for covering smaller areas for two reasons: availability of more robust and precise datasets; and emerging interest in particular regions, sub-regions or countries. We analyze the conformation of Hungarian corn yield on fine-resolution of 10x10 km grid over the period of 1970-2018 by employing three regression models. The aim of the study is to show that accounting for spatial bias of the error term is an important aspect of statistical crop models; and also to exploit the panel structure of the data. We explicitly model the combined effects of observed weather impact and the derived year-specific effect compared to the widely used pooled OLS models.

Materials and Methods

However, the data used for the abstract is a simplistic version of the AgroMo data system which compiles the sets of long time series on various crop yields, detailed weather structures, soil parameters, landuse and farm management data layers in a spatially explicit way. For predicting corn yield, currently, we include five weather variables: cumulated rainfall and the number of optimal growth days in the vegetative (May-June) and in the reproductive (July-Sep) phases as well as the number of extreme heat days when the daily average temperature exceeded 30°C.
Regression models:
(1) Pooled OLS model (e.g. Roberts et al., 2012)
(2) Time Fixed effect Panel model (e.g. Auffhammer et al., 2013) to account for the unobserved sources of variation that are common across the grid cells but varied nonlinearly over time
(3) Spatial Error Panel model with temporal fixed effect (Elhorst, 2010; Baylis et al., 2011):
Neglecting spatial correlation of the error term is expected to lead to an underestimation of the true variance-covariance matrix and therefore an overestimation of t-values as the error terms are falsely assumed to be independent (Schlenker et al., 2006). By applying spatial econometric approach (SEM model), we build spatial correlation between the error terms across grid cells with the spatial weighting matrix, W. The performed Moran's I test suggests the existence of spatial autocorrelation with a significant value of 0.6. For modeling, we plan to use the 'queen' matrix to account for almost eight linkages to each grid cells at average.

Results and Discussion

The panel model gives a good approximation to the observed "LogYield", compared to the pooled model, when we consider the aggregated country averages (Figure 1). However, the aggregated annual averages do not show significant deviation from the observed yields except for Budapest under both models (Figure 2). Explaining Hungarian corn yield can be developed by either improving the set of explanatory variables and/or accounting for the detected spatial error correlation with enhanced model setting. Spatial (auto-) correlation is inherently part of agronomic weather measures, which may be also addressed with e.g. the spatial Durbin model.

Conclusions

We possess a great selection of simulated data on future weather determinants that we aim to use for predicting Hungarian corn yield over the period of 2071-2100. We plan to construct statistical ground stone models that may serve as parts of an ensemble.

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Acknowledgements
The research was supported by the European Regional Development Fund «Investing in your future» and the Hungarian Government (GINOP-2.3.2-15-2016-00028).

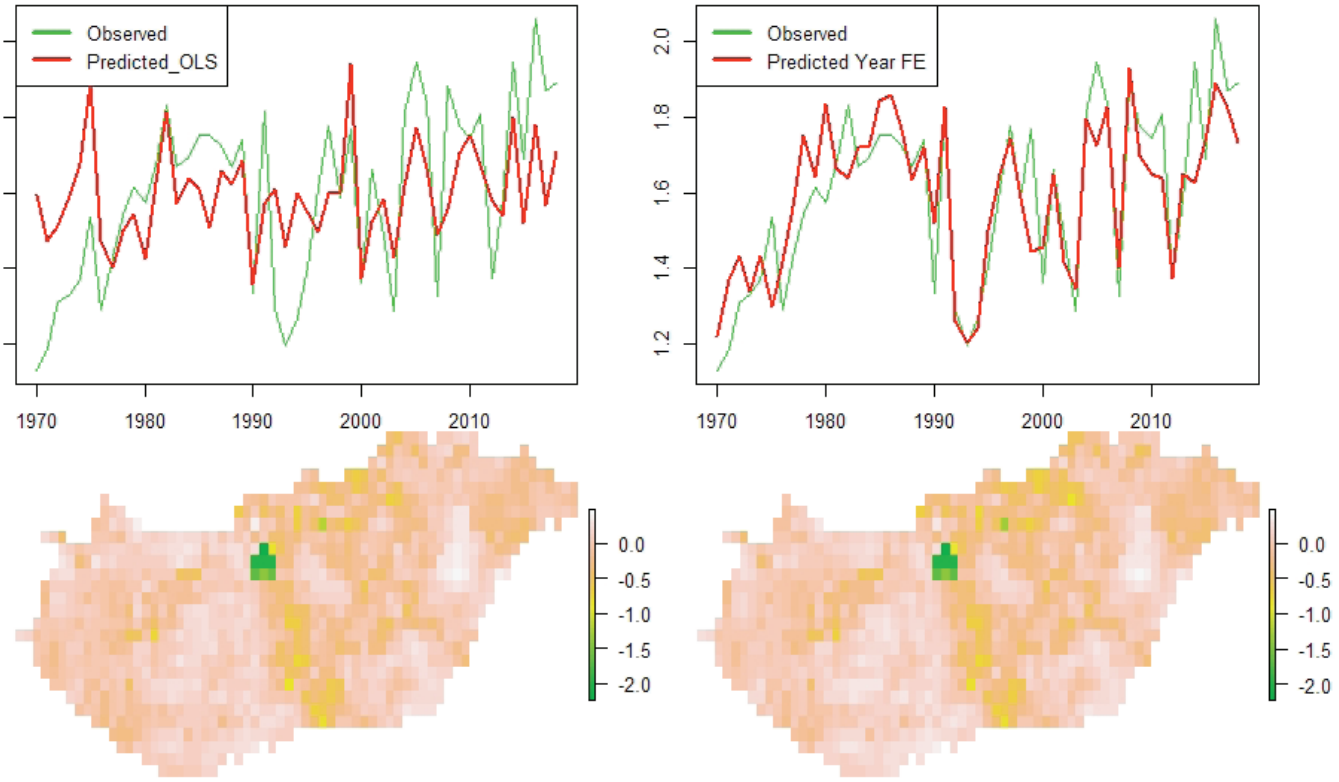

Figure 1: The Spatial Average of Observed Annual Log Yield in Hungary with OLS and FE model predictions.
Figure 2: Deviations of annual averages of the OLS and Fixed Effect Panel model predictions from the observed corn yield

Keywords: spatial econometrics, panel data, year effect, predicting crop yield.

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S6-P.21

Using spatial data for running and validating process-based models. A case study for a Spanish province

Rodriguez Alfredo (alfre2ky@gmail.com), Lassaletta Luis, Sanz-Cobena Alberto, Ruiz-Ramos Margarita

CEIGRAM, Universidad Politécnica de Madrid, Madrid, Spain

Introduction

Crop and agricultural models are useful tools to provide insight into future projections. These models require several variables as inputs (e.g. weather data, management information, soil properties). In recent years, the variety and the amount of information available in a spatialized format has remarkably grown. Following this trend, many crop models have been applied taking this spatial information as inputs for generating spatial results. Tabular information, accordingly spatialized, is also needed for validating the spatial results obtained by using process-based models, and methodologies for such validation are required. This study develops an example to illustrate the validation of crop models spatially by using downscaled regional information for Spain.

Materials and Methods

The information available from the Spanish Soil Occupation Information System (SIOSE, 2018) was used as base layer with their polygons (scale 1:25000) defining the resolution working level. Spatial information for illustrating some inputs for the models were taken from the Harmonized World Soil Database v1.2 (FAO, 2012), specifically pH, soil texture, soil bulk density and soil organic carbon. The information was assigned to the base polygons by using R code. For the validation of the outputs, a downscaling process was applied by taking provincial information (NUTS3 from Eurostat) from national statistics (provided by the Spanish Ministry of Agriculture) disaggregated for different years, crops and for rainfed/irrigated. First, each crop was assigned to its corresponding category from the SIOSE information. Then, each polygon was assigned to a province. Finally, according to the provincial information for, yield or nitrogen inputs, and proportionally to the categories and the polygon areas, the provincial information was then downscaled to polygon size. The produced information consists of a database ready for validating some relevant soil processes within process-based models (e.g. DSSAT, DNDC) or empirical models (e.g. MANNER).

Results and Discussion

The followed downscaled approach is itself useful to detect areas with high concentration of emissions or where intensively managed crops are concentrated or not sustainable approaches are being followed. Some authors already proved the usefulness of this spatialization approaches (Lassaletta et al., 2012; Romero et al., 2016). When the input variables for the model come from reliable sources, this process can be used not only to validate but for supporting model calibration. The calibration and validation can encompass a higher number of variables; e.g. in our case, related to N balance. Once the calibration and validation process are complete, information under future (e.g. using climate model simulations under climate change scenarios) or/and management scenarios can be obtained at polygon level.

Conclusions

The spatialization and the downscaling techniques depicted here, when applied to a robust database allow validating internal model process (i.e. soil dynamics) within the models. This complements the classic validation of crop phenology and yield, resulting in more robust simulation results. This is of special relevance for applications relying on other simulated variables than yield and phenological dates (e.g. N balance).

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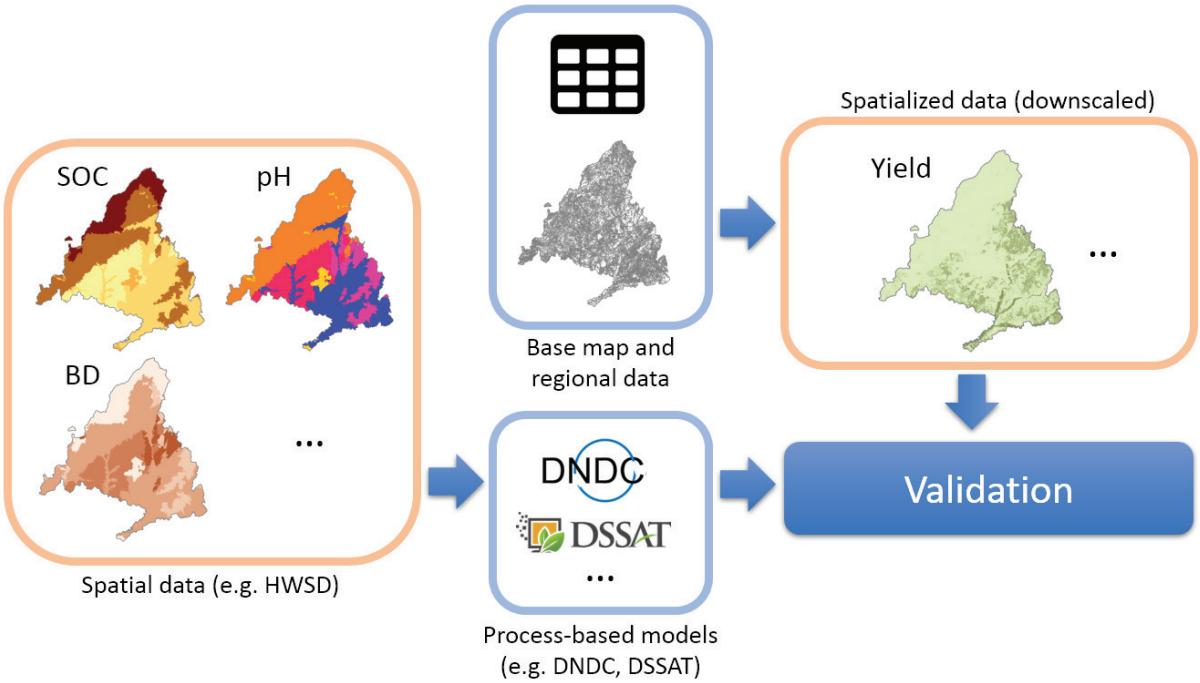

Example of the validation of process-based models, for the Madrid province (Spain), selecting a common base layer, and using as input spatial information (e.g. soil organic carbon, SOC; pH and bulk density, BD) from the Harmonized World Soil Database (HWSD), and as validation data a downscaled provincial data

Keywords: Spatial data, SIOSE, Model validation, Downscaling, Nitrogen balance.

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LIST OF PARTICIPANTS

ADAM Myriam
Cirad
MONTPELLIER – FRANCE
myriam.adam@cirad.fr

AFFHOLDER François
Cirad
MONTPELLIER – FRANCE
francois.affholder@cirad.fr

AHMED Mukhtar
Swedish University of Agricultural Sciences
UMEÅ – SWEDEN
mukhtar.ahmed@slu.se

AKINSEYE Folorunso
ICRISAT
TARAUNI – NIGERIA
f.akinseye@cgiar.org

ALBASHA Rami
ITK
CLAPIERS – FRANCE
rami.albasha@itk.fr

ALDERMAN Phillip
Oklahoma State University
STILLWATER – USA
phillip.alderman@okstate.edu

ANDRIANASOLO Fety
Arvalis - Institut du végétal
BOIGNEVILLE – FRANCE
f.andrianasolo@arvalis.fr

ANNANDALE John
University of Pretoria
PRETORIA – SOUTH AFRICA
john.annandale@up.ac.za

APPIAH Mercy
University of Göttingen
GÖTTINGEN – GERMANY
mercy.appiah@uni-goettingen.de

ARCHONTOULIS Sotirios
Iowa State University
AMES – USA
sarchont@iastate.edu

ASSENG Senthold
University of Florida
GAINESVILLE – USA
sasseng@ufl.edu

BACCAR Mariem
INRAE
CASTANET-TOLOSAN – FRANCE
mariem.baccar@inrae.fr

BACCI Maurizio
Institute of BioEconomy CNR
FLORENCE – ITALY
maurizio.bacci@cnr.it

BAHR Christopher
Hochschule Geisenheim University
GEISENHEIM – GERMANY
christopher.bahr@hs-gm.de

BANCAL Marie-Odile
AgroParisTech - Université Paris-Saclay
THIVERVAL-GRIGNON – FRANCE
marie-odile.bancal@inrae.fr

BARANOWSKI Piotr
Institute of Agrophysics PAS
LUBLIN – POLAND
pbaranow@ipan.lublin.pl

BARON Christian
Cirad
MONTPELLIER – FRANCE
christian.baron@cirad.fr

BASSO Bruno
Michigan State University
EAST LANSING, MI – USA
basso@msu.edu

BASSU Simona
European Commission
Joint Research Centre
ISPRA – ITALY
simona.bassu@ec.europa.eu

BATTISTI Rafael
Universidade Federal de Goiás
GOIÂNIA – BRAZIL
battisti@ufg.br

BAYER Joanne
IIASA
LAXENBURG – AUSTRIA
bayer@iiasa.ac.at

BEDNARÍK Martin
Global Change Research Institute
BRNO – CZECH REPUBLIC
bednarik.mart@gmail.com

BELLO Nora
Kansas State University
MANHATTAN – USA
nbello@ksu.edu

BEN MUSTAPHA Ali
University of Nottingham
NOTTINGHAM – UK
ali.benmustapha@nottingham.ac.uk

BERG-MOHNICKE Michael
ZALF
MÜNCHEBERG – GERMANY
michael.berg-mohnicke@zalf.de

BERGER Andres
INIA
LA ESTANZUELA – URUGUAY
aberger@inia.org.uy

BERGHUIJS Herman
Swedish University of Agricultural Sciences
UPPSALA – SWEDEN
herman.berghuijs@slu.se

BERTUZZI Patrick
INRAE - Centre de recherche PACA
AVIGNON – FRANCE
patrick.bertuzzi@inrae.fr

BLANC Emmanuelle
INRAE
GIF-SUR-YVETTE – FRANCE
emmanuelle.blanc@inra.fr

BOER Martin
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
martin.boer@wur.nl

BONGIOVANI Paola
University of Sao Paulo - ESALQ
PIRACICABA – BRAZIL
paola.f.bongiovani@gmail.com

BOOGAARD Hendrik
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
hendrik.boogaard@wur.nl

BOOTE Kenneth J.
University of Florida
GAINESVILLE – USA
kjboote@ufl.edu

BOUDON Frédéric
Cirad
MONTPELLIER – FRANCE
frederic.boudon@cirad.fr

BOULC'H Guénolé
UniLaSalle
BEAUVAIS – FRANCE
guenole.boulch@unilasalle.fr

BOUNAFFAA Myriam
HIPHEN
AVIGNON – FRANCE
acomar@hiphen-plant.com

BRACHO MUJICA Gennady
University of Göttingen
GÖTTINGEN – GERMANY
gennady.brachomujica@uni-goettingen.de

BRADSHAW Catherine
UK Met Office
EXETER – UK
catherine.bradshaw@metoffice.gov.uk

BRANCHERIAU Loïc
Cirad
MONTPELLIER – FRANCE
loic.brancheriau@cirad.fr

BREGAGLIO Simone
Council for Agricultural Research and Economy
BOLOGNA – ITALY
simoneugomaria.bregaglio@crea.gov.it

BRINGHENTI Thomas
Georg-August - Universität Göttingen
GÖTTINGEN – GERMANY
thomas.bringhenti@uni-goettingen.de

BRUNEL-MUGUET Sophie
INRAE
CAEN – FRANCE
sophie.brunel-muguet@inrae.fr

BRUNET Jérôme
HIPHEN
AVIGNON – FRANCE
acomar@hiphen-plant.com

BUIS Samuel
INRAE
AVIGNON – FRANCE
samuel.buis@inrae.fr

BUSTOS-KORTS Daniela
Biometris - Wageningen UR
WAGENINGEN – THE NETHERLANDS
daniela.bustoskorts@wur.nl

CABEZAS LUQUE José Manuel
IFAPA
CÓRDOBA – SPAIN
josem.cabezas@juntadeandalucia.es

CABRERA-BOSQUET Llorenç
INRAE
MONTPELLIER – FRANCE
llorenc.cabrera-bosquet@inrae.fr

CAMMARANO Davide
Purdue University
WEST LAFAYETTE – USA
dcammar@purdue.edu

CARON Patrick
I-SITE MUSE
MONTPELLIER – FRANCE
patrick.caron@umontpellier.fr

CAROZZI Marco
INRAE
THIVERVAL-GRIGNON – FRANCE
marco.carozzi@inrae.fr

CASADEBAIG Pierre
INRAE
CASTANET-TOLOSAN – FRANCE
pierre.casadebaig@inrae.fr

CASTILLO Oscar
University of Florida
GAINESVILLE – USA
ocastilloromero@ufl.edu

CASTRO ALVARADO Enzo
INRAE - Cirad
MONTPELLIER – FRANCE
enzo.castro_alvarado@cirad.fr

CELLIER Pierre
INRAE
GRIGNON – FRANCE
pierre.cellier@inra.fr

CHALLINOR Andy
University of Leeds
LEEDS – UK
a.j.challinor@leeds.ac.uk

CHAPAGAIN Ranju
University of Tasmania
HOBART – AUSTRALIA
ranju.chapagain@utas.edu.au

CHAPMAN Scott
University of Queensland
GATTON – AUSTRALIA
scott.chapman@uq.edu.au

CHATZIPAPADOPOULOS Fotios
Neuropublic
PIRAEUS – GREECE
f_chatzipapadopoulos@neuropublic.gr

CHEN Charles
Oklahoma State University
STILLWATER – USA
charles.chen@okstate.edu

CHEN Tsu-Wei
Leibniz Universität Hannover
HANNOVER – GERMANY
chen@gem.uni-hannover.de

CHENU Karine
University of Queensland
TOOWOOMBA – AUSTRALIA
karine.chenu@uq.edu.au

CHIMONYO Vimbayi Grace Petrova
University of KwaZulu-Natal
DURBAN – SOUTH AFRICA
ChimonyoV@ukzn.ac.za

CHRISTINA Mathias
Cirad
SAINTE-CLOTILDE – FRANCE
mathias.christina@cirad.fr

COLBACH Nathalie
INRAE
DIJON – FRANCE
nathalie.colbach@inrae.fr

COLLIAUX David
Sony CSL
PARIS – FRANCE
koddda@gmail.com

COMAR Alexis
HIPHEN
AVIGNON – FRANCE
acomar@hiphen-plant.com

CONFALONIERI Roberto
University of Milan
MILAN – ITALY
roberto.confalonieri@unimi.it

CONNOR David
University of Melbourne
MADRID – SPAIN
djconnor@unimelb.edu.au

CONRADT Sarah
SCOR
ZÜRICH – SWITZERLAND
sconradt@scor.com

CONSTANTIN Julie
INRAE
CASTANET-TOLOSAN – FRANCE
julie.constantin@inrae.fr

CONSTANTINESCU Dario
AVIGNON – FRANCE
dario.constantinescu@gmail.com

COOPER Mark
University of Queensland
ST LUCIA – AUSTRALIA
mark.cooper@uq.edu.au

CORBEELS Marc
CIMMYT & Cirad
NAIROBI – KENYA
corbeels@cirad.fr

CORNELIUS Alex
Assimila
READING – UK
alex.cornelius@assimila.eu

CORRALES David Camilo
INRAE
AUZEVILLE-TOLOSANE – FRANCE
davidcamilo.corralesmunoz@inrae.fr

COUCHENEY Elsa
Swedish University of Agricultural Sciences
UPPSALA – SWEDEN
elsa.coucheney@slu.se

COUDRON Willem
ILVO - Plant
MELLE – BELGIUM
willem.coudron@ilvo.vlaanderen.be

COUSSEMENT Jonas
Ghent University
GHENT – BELGIUM
jonas.coussement@ugent.be

COUVREUR Valentin
University of Louvain
LOUVAIN-LA-NEUVE – BELGIUM
valentin.couvreur@uclouvain.be

CURNEL Yannick
CRA-W
GEMBLOUX – BELGIUM
y.curnel@cra.wallonie.be

DE ANTONI Max
Queensland University of Technology
BRISBANE – AUSTRALIA
max.deantoni@qut.edu.au

DE SCHEPPER Veerle
BASF
GENT – BELGIUM
veerle.de-schepper@basf.com

DE SOUZA NOIA JUNIOR Rogerio
University of Florida
GAINESVILLE – USA
rogeriosouzanoia@gmail.com

DE SWAEF Tom
ILVO - Plant
MELLE – BELGIUM
tom.deswaef@ilvo.vlaanderen.be

DE WIT Allard
Wageningen Environmental Research
WAGENINGEN – THE NETHERLANDS
allard.dewit@wur.nl

DEBAEKE Philippe
INRAE
CASTANET-TOLOSAN – FRANCE
philippe.debaeke@inrae.fr

DECHMI Farida
Agrifood Research and Technology Centre
ZARAGOZA – SPAIN
fdechmi@aragon.es

DEIHIMFARD Reza
Shahid Beheshti University
TEHRAN – ISLAMIC REPUBLIC OF IRAN
deihim@sbu.ac.ir

DELHEZ Laura
Gembloux Agro-Bio Tech
GEMBLOUX – BELGIUM
laura.delhez@uliege.be

DENTENER Frank
European Commission
ISPRA – ITALY
frank.dentener@ec.europa.eu

DESTA Abera
Hawassa University
HAWASSA – ETHIOPIA
aberatsion2008@gmail.com

DESWARTE Jean-Charles
Arvalis - Institut du végétal
VILLIERS-LE-BACLE – FRANCE
jc.deswarte@arvalis.fr

DEVA Chetan
University of Leeds
LEEDS – UK
eecd@leeds.ac.uk

DIAMANTOPOULOS Efstathios
Copenhagen University
COPENHAGEN – DENMARK
ed@plen.ku.dk

DIANCOUMBA Madina
ICRISAT
BAMAKO – MALI
m.diancoumba@cgiar.org

DIAS Henrique
ESALQ - USP
PIRACICABA – BRAZIL
henrique.bdias@yahoo.com.br

DONATELLI Marcello
CREA Agriculture and Environment
BOLOGNA – ITALY
marcello.donatelli@crea.gov.it

DROUTSAS Ioannis
University of Leeds
LEEDS – UK
eegdr@leeds.ac.uk

DUAN Yun-Feng
University of Copenhagen
FREDERIKSBERG – DENMARK
duan@plen.ku.dk

DUERI Sibylle
INRAE
MONTPELLIER – FRANCE
sibylle.dueri@inrae.fr

DUMAS Anne-Valérie
Limagrain Europe
CHAPPES – FRANCE
anne-valerie.dumas@limagrain.com

DURAND Jean-Louis
INRAE
LUSIGNAN – FRANCE
jean-louis.durand@inrae.fr

DUSSERRE Julie
Cirad
MONTPELLIER – FRANCE
julie.dusserre@cirad.fr

EDOUARD Sylvain
INRAE - EDF R&D
ÉCUELLES – FRANCE
sy.edouard@gmail.com

ELLI Elvis Felipe
ESALQ - USP
PIRACICABA – BRAZIL
elvisfelipeelli@usp.br

EVERINGHAM Yvette
James Cook University
TOWNSVILLE – AUSTRALIA
yvette.everingham@jcu.edu.au

EVERS Jochem
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
jochem.evers@wur.nl

EWERT Frank
Leibniz Centre for Agric. Landscape Research
MÜNCHEBERG – GERMANY
frank.ewert@zalf.de

EYSHI REZAEI Ehsan
University of Göttingen
GÖTTINGEN – GERMANY
ehsan.eyshi-rezaei@uni-goettingen.de

FAJARDO Andrea Catalina
GERICS (Climate Service Center)
HAMBURG – GERMANY
andrea.fajardo@hzg.de

FALCONNIER Gatien
Cirad
MONTPELLIER – FRANCE
gatien.falconnier@cirad.fr

FALLOON Pete
UK Met Office
EXETER – UK
pete.falloon@metoffice.gov.uk

FASIL MEQUANINT Rettie
University of Hohenheim
STUTTGART – GERMANY
fasil.mequanint@uni-hohenheim.de

FAYE Babacar
IRD
MONTPELLIER – FRANCE
babacar.faye@ird.fr

FEIKE Til
Julius Kühn-Institut
KLEINMACHNOW – GERMANY
til.feike@julius-kuehn.de

FER Istem
Finnish Meteorological Institute
HELSINKI – FINLAND
istem.fer@fmi.fi

FERRISE Roberto
University of Florence
FLORENCE – ITALY
roberto.ferrise@unifi.it

FIIL SVANE Simon
Copenhagen University
COPENHAGEN – DENMARK
sfs@plen.ku.dk

FISCHER Kim
Ferrero International
SENNINGERBERG – LUXEMBOURG
kim.fischer@ferrero.com

FODOR Nándor
Centre for Agricultural Research
MARTONVÁSÁR – HUNGARY
fodor.nandor@agrar.mta.hu

FOLBERTH Christian
IIASA
LAXENBURG – AUSTRIA
folberth@iiasa.ac.at

FOURNIER Christian
INRAE
MONTPELLIER – FRANCE
christian.fournier@inrae.fr

GABALDÓN-LEAL Clara
IFAPA - Alameda del Obispo
CÓRDOBA – SPAIN
cgabaldonleal@gmail.com

GALLEAR Joe
University of Leeds
LEEDS – UK
eejg@leeds.ac.uk

GANEME Aminata
Cirad
OUAGADOUGOU – BURKINA FASO
amiganame@yahoo.fr

GARCIA DE CORTAZAR Iñaki
INRAE
AVIGNON – FRANCE
inaki.garciadecortazar@inrae.fr

GASO Deborah
Wageningen University
WAGENINGEN – THE NETHERLANDS
deborah.gasomelgar@wur.nl

GAWINOWSKI Meije
INRAE
GIF-SUR-YVETTE – FRANCE
meije.gawinowski@inrae.fr

GAYLER Sebastian
University of Hohenheim
STUTTGART – GERMANY
sebastian.gayler@uni-hohenheim.de

GÉRARDEAUX Edward
Cirad
MONTPELLIER – FRANCE
gerardeaux@cirad.fr

GERVOIS Sébastien
Terres Inovia
THIVERVAL-GRIGNON – FRANCE
s.gervois@terresinovia.fr

GIANSILY Carole
Digitag
MONTPELLIER – FRANCE

GILLER Ken
Wageningen University
WAGENINGEN – THE NETHERLANDS
ken.giller@wur.nl

GINER Michel
Cirad
MONTPELLIER – FRANCE
michel.giner@cirad.fr

GIUNTA Francesco
University
SASSARI – ITALY
giunta@uniss.it

GOBIN Anne
VITO
MOL – BELGIUM
anne.gobin@vito.be

GRAEFE Jan
Leibniz Inst. of Veg. and Ornamental Crops
GROSSBEEREN – GERMANY
graefe@igzev.de

GRIMALDI Juliette
INRAE
MONTPELLIER – FRANCE
juliette.grimaldi@inrae.fr

GU Chunfeng
Wageningen University
WAGENINGEN – THE NETHERLANDS
chunfeng.gu@wur.nl

GUARIN Jose
University of Florida
GAINESVILLE – USA
jguarin@ufl.edu

GUNZENHAUSER Robert
Granular
JOHNSTON – USA
bobgunzenhauser@granular.ag

GURKAN Hudaverdi
Ankara University
KECIOREN, ANKARA – TURKEY
hudaverdigurkan@hotmail.com

GUTIÉRREZ GARCÍA Alberto
Agro Technological Institute of CyL
VALLADOLID – SPAIN
bertogu@gmail.com

HAJJARPOOR Amir
IRD
MONTPELLIER – FRANCE
amiragro65@gmail.com

HAMMER Graeme
University of Queensland
BRISBANE – AUSTRALIA
g.hammer@uq.edu.au

HAUMONT Jérémie
KU Leuven
HEVERLEE – BELGIUM
jeremie.haumont@kuleuven.be

HEIDSIECK Gaetan
Inria
MONTPELLIER – FRANCE
gaetan.heidsieck@inria.fr

HEINLEIN Florian
Helmholtz Center Munich
NEUHERBERG – GERMANY
florian.heinlein@helmholtz-muenchen.de

HELMAN David
Hebrew University of Jerusalem
REHOVOT – ISRAEL
david.helman@mail.huji.ac.il

HINSINGER Philippe
INRAE
MONTPELLIER – FRANCE
philippe.hinsinger@inrae.fr

HOCHMAN Anita
BRISBANE – AUSTRALIA

HOCHMAN Zvi
CSIRO
BRISBANE – AUSTRALIA
zvi.hochman@csiro.au

HOFFMANN Holger
BASF Digital Farming
KOELN – GERMANY
holger.hoffmann@xarvio.com

HOLLÓS Roland
Eötvös Loránd University
BUDAPEST – HUNGARY
hollorol@gmail.com

HOOGENBOOM Gerrit
University of Florida
GAINESVILLE – USA
gerrit@ufl.edu

HUBER Laurent
INRAE - Agro Paris Tech
THIVERVAL-GRIGNON – FRANCE
laurent.huber@inrae.fr

HUCHAHANUMEGOWDANAPALY Sanjeevaiah Shivaramu
University of Agricultural Sciences
BENGALURU – INDIA
hssramu@yahoo.co.in

HUGGI Lingaraj
INRAE
AVIGNON – FRANCE
lingarajhuggi@gmail.com

IIZUMI Toshichika
NARO
TSUKUBA – JAPAN
iizumit@affrc.go.jp

INGWERSEN Joachim
Institute of Soil Science
STUTTGART – GERMANY
joachim.ingwersen@uni-hohenheim.de

JAEGER Marc
Cirad
MONTPELLIER – FRANCE
marc.jaeger@cirad.fr

JAEGERMEYR Jonas
NASA
NEW YORK – USA
jaegermeyr@uchicago.edu

JÉGO Guillaume
Agriculture et Agroalimentaire Canada
QUÉBEC – CANADA
guillaume.jego@canada.ca

JENNINGS Stewart
University of Leeds
LEEDS – UK
s.a.jennings@leeds.ac.uk

JONES Matthew
Sugarcane Research Institute
MOUNT EDGECOMBE – SOUTH AFRICA
matthew.jones@sugar.org.za

JUSTES Éric
Cirad
MONTPELLIER – FRANCE
eric.justes@cirad.fr

KAMALI Bahareh
ZALF
MÜNCHEBERG – GERMANY
bahareh.kamali@zalf.de

KANSO Hussein
INRAE
MONTFAVET – FRANCE
hussein.kanso@inrae.fr

KAPSAMBELIS Dorothée
Caisse Centrale de Reassurance
PARIS – FRANCE
dkapsambelis@ccr.fr

KARUNARATNE Asha
Sabaragamuwa University
BELIHULOYA – SRI LANKA
ashas@agri.sab.ac.lk

KEMANIAN Armen
Pennsylvania State University
UNIVERSITY PARK – USA
kxa15@psu.edu

KERSEBAUM Kurt-Christian
Leibniz Centre for Agric. Landscape Research
MÜNCHEBERG – GERMANY
ckersebaum@zalf.de

KHOLOVA Jana
ICRISAT
PATANCHERU – INDIA
j.kholova@cgiar.org

KIM Kwang Soo
Seoul National University
SEOUL – REPUBLIC OF KOREA
luxkwang@snu.ac.kr

KIMBALL Bruce
USDA - Agricultural Research Service
MARICOPA – USA
bruce.kimball@usda.gov

KIS Anna
Eötvös Loránd University
BUDAPEST – HUNGARY
kisanna@nimbus.elte.hu

KOBAYASHI Kazuhiko
Ibaraki University
AMI – JAPAN
k.kobayashi.ut@gmail.com

KOO Jawoo
International Food Policy Research Institute
WASHINGTON – USA
j.koo@cgiar.org

KORHONEN Panu
Natural Resources Institute Finland
KUOPIO – FINLAND
panu.korhonen@luke.fi

KOTHARI Kritika
University of Kentucky
LEXINGTON – USA
kritikakothari@uky.edu

KRISTÓF Erzsébet
Eötvös Loránd University
BUDAPEST – HUNGARY
ekristof86@caesar.elte.hu

KRZYSZCZAK Jaromir
Institute of Agrophysics PAS
LUBLIN – POLAND
jkrzyszczak@ipan.lublin.pl

KÜHL Kersten
Ludwig-Maximilians - Universität München
MUNICH – GERMANY
kersten.kuehl@lmu.de

KULESZA Stacey
Kansas State University
MANHATTAN – USA
sekulesza@ksu.edu

KUMAR Pankaj
UPL
MUMBAI – INDIA
pankaj.niam@gmail.com

KUPISCH Moritz
University of Bonn
BONN – GERMANY
mkupisch@uni-bonn.de

LAIREZ Juliette
Cirad
MONTPELLIER – FRANCE
juliette.lairez@cirad.fr

LAMMOGLIA Karen
Cirad
MONTPELLIER – FRANCE
karen.lammoglia@cirad.fr

LANA Marcos
SLU
UPPSALA – SWEDEN
marcos.lana@slu.se

LANG Meagan
University of Illinois Urbana-Champaign
URBANA – USA
langmm.astro@gmail.com

LANGE Bastien
UniLaSalle
BEAUVAIS – FRANCE
bastien.lange@unilasalle.fr

LANGENSIEPEN Matthias
University of Bonn
BONN – GERMANY
matthias@langensiepen.net

LARUE Florian
Cirad
MONTPELLIER – FRANCE
florian.larue@cirad.fr

LAUNAY Marie
INRAE
AVIGNON – FRANCE
marie.launay@inrae.fr

LAURENT Cécile
Fruition Sciences
MONTPELLIER – FRANCE
cecile@fruitionsciences.com

LAUWERS Simon
Ghent University
GHENT – BELGIUM
simon.lauwers@ugent.be

LE GOUIS Jacques
INRAE
CLERMONT-FERRAND – FRANCE
jacques.le-gouis@inrae.fr

LEAUTHAUD Crystele
Cirad
MONTPELLIER – FRANCE
crystele.leauthaud@cirad.fr

LECERF Rémi
Joint Research Center - EC
ISPRA – ITALY
remi.lecerf@ec.europa.eu

LECHARPENTIER Patrice
INRAE
AVIGNON – FRANCE
patrice.lecharpentier@inrae.fr

LEOLINI Luisa
University of Florence
FLORENCE – ITALY
luisa.leolini@unifi.it

LEROUX Louise
Cirad - CSE
DAKAR – SENEGAL
louise.leroux@cirad.fr

LESCOURRET Françoise
INRAE
AVIGNON – FRANCE
francoise.lescourret@inrae.fr

LEVEAU Stéphane
INRAE
MONTPELLIER – FRANCE
stephane.leveau@inrae.fr

LIU Shouyang
INRAE
AVIGNON – FRANCE
shouyang.liu@inrae.fr

LIZARAZO Clara
University of Helsinki
HELSINKI – FINLAND
clara.lizarazotorres@helsinki.fi

LOPEZ-BERNAL Alvaro
Universidad de Cordoba
CÓRDOBA – SPAIN
g42lobea@uco.es

LORITE-TORRES Ignacio
IFAPA - Junta de Andalucía
CÓRDOBA – SPAIN
ignacioj.lorite@juntadeandalucia.es

LOUARN Gaëtan
INRAE
LUSIGNAN – FRANCE
gaetan.louarn@inrae.fr

LUQUET Delphine
Cirad
MONTPELLIER – FRANCE
luquet@cirad.fr

MACCARTHY Dilys
University of Ghana
ACCRA – GHANA
dmaccarthy@ug.edu.gh

MAGNO MASSUIA DE ALMEIDA Lethicia
INRAE
CAEN – FRANCE
lethicia.magno-massuia-dealmeida@unicaen.fr

MAHARJAN Ganga Ram
Yara
DÜLMEN – GERMANY
ganga.ram.maharjan@yara.com

MAIRECH Hanene
Institute for Sustainable Agriculture
CÓRDOBA – SPAIN
mairech.hanene@gmail.com

MANCEAU Loic
INRAE
MONTPELLIER – FRANCE
loic.manceau@inrae.fr

MANSCHADI Ahmad M.
BOKU University
TULLN – AUSTRIA
manschadi@boku.ac.at

MARSHALL-COLON Amy
University of Illinois Urbana-Champaign
URBANA – USA
amymc@illinois.edu

MARTON Tibor András
ELKH Agricultural Institute
MARTONVÁSÁR – HUNGARY
marton.tibor@agrar.mta.hu

MARTRE Pierre
INRAE
MONTPELLIER – FRANCE
pierre.martre@inrae.fr

MASUTOMI Yuji
Ibaraki University
AMI – JAPAN
yuji.masutomi@gmail.com

MATHISON Camilla
UK Met Office
EXETER – UK
camilla.mathison@metoffice.gov.uk

MCCORMICK Ryan
Corteva Agriscience
JOHNSTON – USA
ryan.mccormick@corteva.com

MCLEAN Greg
The University of Queensland
GATTON – AUSTRALIA
g.mclean@uq.edu.au

MEHMANDOOSTKOTLAR Ali
University of Sao Paulo
PIRACICABA – BRAZIL
aliko@usp.br

MESBAH Morteza
Agriculture and Agri-Food Canada
CHARLOTTETOWN – CANADA
morteza.mesbah@canada.ca

MESSINA Charlie
Corteva Agriscience
JOHNSTON – USA
charlie.messina@corteva.com

MEYER Nicolas
INRAE
AUZEVILLE-TOLOSANE – FRANCE
nicolas.meyer@inrae.fr

MEZA Francisco
Pontificia Universidad Catolica de Chile
SANTIAGO – CHILE
fmeza@uc.cl

MIDINGOYI Cyrille Ahmed
INRAE
MONTPELLIER – FRANCE
cyrille.midingoyi@inrae.fr

MINGUEZ Ines
CEIGRAM - UPM
MADRID – SPAIN
ines.minguez@upm.es

MINOLI Sara
Potsdam Institute for Climate Impact Research
POTSDAM – GERMANY
sara.minoli@pik-potsdam.de

MITTER Hermine
University of Natural Resources & Life Science
VIENNA – AUSTRIA
hermine.mitter@boku.ac.at

MOELETSI Mokhele
Agricultural Research Council
PRETORIA – SOUTH AFRICA
moeletsim@arc.agric.za

MOLERO Gemma
CIMMYT
TEXCOCO – MEXICO
g.molero@cgiar.org

MONCOULON David
Caisse Centrale de Reassurance
PARIS – FRANCE
dmoncoulon@ccr.fr

MOUALEU-NGANGUE Dany
Institute of Horticultural Production System
HANNOVER – GERMANY
moualeu@gem.uni-hannover.de

MULLER Bertrand
INRAE
MONTPELLIER – FRANCE
bertrand.muller@inrae.fr

MÜLLER Christoph
Institute for Climate Impact Research
POTSDAM – GERMANY
cmueller@pik-potsdam.de

MUNARO Eugenia
Granular
CÓRDOBA – ARGENTINA
munaro@agro.uba.ar

MYSTAKIDIS Stefanos
Swiss Re
ZÜRICH – SWITZERLAND
stefanos_mystakidis@swissre.com

NAUDIN Krishna
Cirad
MONTPELLIER – FRANCE
naudin@cirad.fr

NAVES MASCHIETTO Gabriela
Veolia Research and Innovation
PUTEAUX – FRANCE
gabriela.naves-maschietto@veolia.com

NDIAYE Malick
ISRA - CNRA de Bambey
BAMBEY – SENEGAL
agromalick@yahoo.fr

NEHMEH Alissar
University
SASSARI – ITALY
alissar.nehmeh@outlook.com

NELSON William
Georg-August - Universität Göttingen
GÖTTINGEN – GERMANY
wnelson@gwdg.de

NENDEL Claas
ZALF
MÜNCHEBERG – GERMANY
nendel@zalf.de

NGUYEN Hong Anh
INRAE
MONTPELLIER – FRANCE
honganhnguyen0110@gmail.com

NGUYEN Thuy Huu
INRES - University of Bonn
BONN – GERMANY
tngu@uni-bonn.de

NGWIRA Amos
ICRISAT
LILONGWE – MALAWI
a.ngwira@cgiar.org

NISSANKA Sarath
University of Peradeniya
PERADENIYA – SRI LANKA
spn@pdn.ac.lk

NORIEGA José Luis
Universidad Autónoma Chapingo
TEXCOCO – MEXICO
luisnoriegan@hotmail.com

OJEDA Jonathan
University of Tasmania
HOBART – AUSTRALIA
jonathan.ojeda@utas.edu.au

OLESEN Jørgen E.
Aarhus University
TJELE – DENMARK
jeo@agro.au.dk

ONWUCHEKWA-HENRY Chinaza
University of Sydney
SYDNEY – AUSTRALIA
conw5681@sydney.edu.au

PABST Brigitte
SCOR
ZÜRICH – SWITZERLAND
bpabst@scor.com

PADOVAN Gloria
University of Florence
FLORENCE – ITALY
gloria.padovan@unifi.it

PAFF Kirsten
INRAE
MONTPELLIER – FRANCE
kirsten.paff@inrae.fr

PALEARI Livia
University of Milan
MILAN – ITALY
livia.paleari@unimi.it

PALOSUO Taru
Natural Resources Institute Finland
HELSINKI – FINLAND
taru.palosuo@luke.fi

PAO Yi-Chen
Leibniz Universität
HANNOVER – GERMANY
pao@gem.uni-hannover.de

PARENT Boris
INRAE
MONTPELLIER – FRANCE
boris.parent@inrae.fr

PARVIN Nargish
Swedish University of Agricultural Sciences
UPPSALA – SWEDEN
nargish.parvin@slu.se

PATTEY Elizabeth
Agriculture and Agri-Food Canada
OTTAWA – CANADA
elizabeth.pattey@canada.ca

PEQUENO Diego
CIMMYT
EL BATAN - TEXCOCO – MEXICO
d.pequeno@cgiar.org

PERSONNE Manuel
Limagrain
GERZAT – FRANCE
manuel.personne@limagrain.com

PERTHAME Laurène
INRAE
DIJON – FRANCE
laurene.perthame@inrae.fr

PICARD Coralie
ITK
CLAPIERS – FRANCE
coralie.picard@itk.fr

PIQUEMAL Benoit
Arvalis - Institut du végétal
BOIGNEVILLE – FRANCE
b.piquemal@arvalis.fr

POFFENBARGER Hanna
University of Kentucky
LEXINGTON – USA
hanna.poffenbarger@uky.edu

POHANKOVÁ Eva
Global Change Research Institute
BRNO – CZECH REPUBLIC
eva.pohankova@seznam.cz

PORTER Cheryl
University of Florida
GAINESVILLE – USA
cporter@ufl.edu

PORTER John R.
University of Copenhagen
TAASTRUP – DENMARK
jrp@plen.ku.dk

POTOPOVÁ Vera
Czech University of Life Sciences
PRAGUE – CZECH REPUBLIC
potop@af.czu.cz

PRADAL Christophe
Cirad & Inria
MONTPELLIER – FRANCE
christophe.pradal@cirad.fr

PRIESACK Eckart
Helmholtz Center Munich
OBERSCHLEISSHEIM – GERMANY
priesack@helmholtz-muenchen.de

PRIGENT Sylvain
INRAE
VILLENAVE-D'ORNON – FRANCE
sylvain.prigent@inrae.fr

PULLENS Johannes
Aarhus University
TJELE – DENMARK
jwmp@agro.au.dk

QIAN Budong
Agriculture and Agri-Food Canada
OTTAWA – CANADA
budong.qian@canada.ca

RANAIVOSON Lalaina
Fofifa - Cenraderu
ANTANANARIVO – MADAGASCAR
lalainabakotiana@yahoo.fr

RASCHE Livia
Universität Hamburg
HAMBURG – GERMANY
livia.rasche@uni-hamburg.de

RASHID Muhammad Adil
Copenhagen University
COPENHAGEN – DENMARK
mar@plen.ku.dk

RAYNAL Helene
INRAE
CASTANET-TOLOSAN – FRANCE
helene.raynal@inrae.fr

RIOU Christine
INRAE
MONTPELLIER – FRANCE
christine.riou@inrae.fr

RIPOCHE Dominique
INRAE
AVIGNON – FRANCE
dominique.ripoche@inrae.fr

ROBIN Marie-Hélène
INRAE
CASTANET-TOLOSAN – FRANCE
mh.robin@purpan.fr

ROBOCK Alan
Rutgers University
NEW BRUNSWICK, NJ – USA
robock@envsci.rutgers.edu

RODRÍGUEZ Alfredo
UPM & UCLM
MADRID – SPAIN
alfre2ky@gmail.com

ROQUETTE TENREIRO Tomás
Spanish Council for Scientific Research
CÓRDOBA – SPAIN
roquettetenreiro@gmail.com

RÖTTER Reimund
University of Göttingen
GÖTTINGEN – GERMANY
reimund.roetter@uni-goettingen.de

ROUX Lucille
INRAE
MONTPELLIER – FRANCE
lucille.roux@inrae.fr

ROUX Sebastien
INRAE
MONTPELLIER – FRANCE
sebastien.roux@inrae.fr

ROZENDAAL Danae
Wageningen University
WAGENINGEN – THE NETHERLANDS
danae.rozendaal@wur.nl

RUANE Alexander
NASA Goddard Institute
NEW YORK – USA
alexander.c.ruane@nasa.gov

RUELLE Elodie
Teagasc
FERMOY – IRELAND
elodie.ruelle@teagasc.ie

RUGET Françoise
INRAE
AVIGNON – FRANCE
francoise.ruget@inrae.fr

RUIZ-RAMOS Margarita
Universidad Politécnica de Madrid
MADRID – SPAIN
margarita.ruiz.ramos@upm.es

RUTJENS Rik
University of Nottingham
NOTTINGHAM – UK
rik.rutjens@nottingham.ac.uk

SABATIER Sylvie
Cirad
MONTPELLIER – FRANCE
sylvie-annabel.sabatier@cirad.fr

SAINT CAST Clément
Université Catholique de Louvain
LOUVAIN-LA-NEUVE – BELGIUM
clement.saintcast@uclouvain.be

SALMERON Montse
University of Kentucky
LEXINGTON – USA
msalmeron@uky.edu

SAMPAIO Leila
Universidade Federal Amazônia
BELEM – BRAZIL
lsobralsampaio@gmail.com

SCHMIDT Dominik
Hochschule Geisenheim University
GEISENHEIM – GERMANY
dominik.schmidt@hs-gm.de

SCHNEIDER Julia
Ludwig-Maximilians - Universität München
MUNICH – GERMANY
j.schneider@iggf.geo.uni-muenchen.de

SCHOVING Céline
INRAE
CASTANET-TOLOSAN – FRANCE
celine.schoving@inrae.fr

SEIDEL Sabine
University of Bonn
BONN – GERMANY
sabine.seidel@uni-bonn.de

SEMENOV Mikhail
Rothamsted Research
HARPENDEN – UK
mikhail.semenov@rothamsted.ac.uk

SENAPATI Nimai
Rothamsted Research
HARPENDEN – UK
nimai.senapati@rothamsted.ac.uk

SENGHOR Yolande
Cirad
MONTPELLIER – FRANCE - SENEGAL
senghoryoyo15@yahoo.fr

SENTELHAS Paulo
University of São Paulo
PIRACICABA – BRAZIL
pcsentel.esalq@usp.br

SESTER Mathilde
Cirad
PHNOM PENH – CAMBODIA
mathilde.sester@cirad.fr

SHARP Joanna
Plant and Food Research
CHRISTCHURCH – NEW ZEALAND
joanna.sharp@plantandfood.co.nz

SHAWON Ashifur
Julius Kühn-Institut
KLEINMACHNOW – GERMANY
ashifur.shawon@julius-kuehn.de

SHIRSATH Paresh Bhaskar
BISA - CIMMYT
NEW DELHI – INDIA
p.bhaskar@cgiar.org

SILVA João Vasco
Wageningen University
WAGENINGEN – THE NETHERLANDS
joao.silva@wur.nl

SINGH Paramveer
New Mexico State Univeristy
LAS CRUCES – USA
param@nmsu.edu

SOLDEVILLA Maria
Yara
DÜLMEN – GERMANY
maria.soldevilla@yara.com

SOULIÉ Jean-Christophe
Cirad
SAINT-DENIS, LA RÉUNION – FRANCE
jean-christophe.soulie@cirad.fr

SPARKS Erin
University of Delaware
NEWARK – USA
esparks@udel.edu

SRIVASTAVA Amit Kumar
University of Bonn, INRES
BONN – GERMANY
amit.srivastava@uni-bonn.de

STAGER Adam
University of Delaware
NEWARK – USA
astager@udel.edu

STELLA Tommaso
ZALF
MÜNCHEBERG – GERMANY
tommaso.stella@zalf.de

STICKLER Yvonne
Federal Institute of Agricultural Economics
VIENNA – AUSTRIA
yvonne.stickler@bab.gv.at

STÖCKLE Claudio
Washington State University
PULLMAN – USA
stockle@wsu.edu

STRECK Thilo Achim
University of Hohenheim
STUTTGART – GERMANY
tstreck@uni-hohenheim.de

STYCZEN Merete
University of Copenhagen
FREDERIKSBERG – DENMARK
styczen@plen.ku.dk

SULTAN Benjamin
IRD
MONTPELLIER – FRANCE
benjamin.sultan@ird.fr

SUMAN Saurav
United Nations World Food Programme
KATHMANDU – NEPAL
saurav.suman@wfp.org

TAN Meixiu
Wageningen University
WAGENINGEN – THE NETHERLANDS
meixiu.tan@wur.nl

TAO Fulu
National Research Institute Finland
HELSINKI – FINLAND
fulu.tao@luke.fi

TARDIEU François
INRAE
MONTPELLIER – FRANCE
francois.tardieu@inrae.fr

TEN DEN Tamara
Wageningen university
WAGENINGEN – THE NETHERLANDS
tamara.tenden@wur.nl

TEWES Andreas
Forschungszentrum
JUELICH – GERMANY
a.tewes@fz-juelich.de

THORBURN Peter
CSIRO
ST LUCIA – AUSTRALIA
peter.thorburn@csiro.au

TIXIER Philippe
Cirad
MONTPELLIER – FRANCE
tixier@cirad.fr

TODA Yusuke
University of Tokyo
TOKYO – JAPAN
toda@ut-biomet.org

TORO MUJICA Paula
Universidad de O'Higgins
SAN FERNANDO – CHILE
paula.toro@uoh.cl

TOSTO Ambra
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
ambra.tosto@wur.nl

TRAORE Abdou
Cirad
TAMBACOUNDA – SENEGAL
abdou.traore@cirad.fr

TRUONG Sandra
Corteva Agriscience
JOHNSTON – USA
sandra.huynhtruong@corteva.com

TSUTSUMI-MORITA Yutaka
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
yutaka.tsutsumi@wur.nl

TURC Olivier
INRAE
MONTPELLIER – FRANCE
olivier.turc@inrae.fr

VADEZ Vincent
IRD
MONTPELLIER – FRANCE
vincent.vadez@ird.fr

VALERIANO Taynara
CREA
BOLOGNA – ITALY
taynara.valeriano@crea.gov.it

VAN DER LAAN Michael
University of Pretoria
PRETORIA – SOUTH AFRICA
michael.vanderlaan@up.ac.za

VAN DER VELDE Marijn
European Commission
ISPRA – ITALY
marijn.van-der-velde@ec.europa.eu

VAN EEUWIJK Fred
Wageningen University - Biometris
WAGENINGEN – THE NETHERLANDS
fred.vaneeuwijk@wur.nl

VAN EVERT Frits
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
frits.vanevert@wur.nl

VAN LOON Marloes
Wageningen University
WAGENINGEN – THE NETHERLANDS
marloes.vanloon@wur.nl

VAN OORT Pepijn
Wageningen Plant Research
WAGENINGEN – THE NETHERLANDS
pepijn.vanoort@wur.nl

VAN OOSTEROM Erik
University of Queensland
ST LUCIA – AUSTARLIA
erik.van.oosterom@uq.edu.au

VARGAS-ROJAS Felipe
INRAE
MONTPELLIER – FRANCE
luis-felipe.vargas-rojas@inrae.fr

VARRAILLON Thierry
Syngenta
GUYANCOURT – FRANCE
thierry.varraillon@syngenta.com

VERDENAL Alban
Limagrain
SAINT-BEAUZIRE – FRANCE
alban.verdenal@limagrain.com

VEREECKEN Harry
Forschungszentrum
JUELICH – GERMANY
h.vereecken@fz-juelich.de

VEZY Rémi
Cirad
MONTPELLIER – FRANCE
remi.vezy@cirad.fr

VIAUD Pauline
Cirad
SAINTE-CLOTILDE – FRANCE
paulineviaud@yahoo.fr

VILLA Ana
Swedish University of Agricultural Sciences
UPPSALA – SWEDEN
ana.villa@slu.se

VILLERS Selwyn
Ghent University
GHENT – BELGIUM
selwyn.villers@ugent.be

VISWANATHAN Michelle
University of Hohenheim
STUTTGART – GERMANY
michelle.viswanathan@uni-hohenheim.de

WALLACH Daniel
INRAE
CASTANET-TOLOSAN – FRANCE
daniel.wallach@inrae.fr

WANG Tien-Cheng
Institut für Gartenbauliche Produktionssyste
HANNOVER – GERMANY
tien.wang@gem.uni-hannover.de

WEBBER Heidi
ZALF
MÜNCHEBERG – GERMANY
webber@zalf.de

WEBER Tobias
Soil Science and Land Evaluation
STUTTGART – GERMANY
tobias.weber@uni-hohenheim.de

WELCH Stephen
Kansas State University
MANHATTAN – USA
welchsm@ksu.edu

WELLENS Joost
Université de Liège
ARLON – BELGIUM
joost.wellens@uliege.be

WIEGAND Kerstin
University of Göttingen
GÖTTINGEN – GERMANY
KWiegan1@gwdg.de

WILLIAMS Karina
Met Office & University of Exeter
EXETER – UK
karina.williams@metoffice.gov.uk

WU Alex
University of Queensland
BRISBANE – AUSTRALIA
c.wu1@uq.edu.au

YIN Xinyou
Wageningen University and Research
WAGENINGEN – THE NETHERLANDS
xinyou.yin@wur.nl

YUN Kyungdahm
University of Washington
SEATTLE – USA
kdyun@uw.edu

ZABEL Florian
Ludwig-Maximilians - Universität München
MUNICH – GERMANY
f.zabel@lmu.de

ZAKA Serge
ITK
CLAPIERS – FRANCE
serge.zaka@itk.fr

ZARE Hossein
University of Hohenheim
STUTTGART – GERMANY
hossein.zare@uni-hohenheim.de

ZHANG Yinsuo
Agriculture and Agri-Food Canada
OTTAWA – CANADA
yinsuo.zhang@canada.ca

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