

**FACCE MACSUR**

**CropM International Symposium and Workshop:**

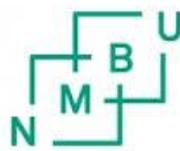
**Modelling climate change impacts on crop  
production for food security**

**10-12 February 2014**

**Oslo, Norway**

**Abstract Book**

## Conference sponsors and hosts:



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## Preface

Continued pressure on agricultural land, food insecurity and required adaptation to climate change have made integrated assessment and modelling of future development of sustainable agrosystems increasingly important. Various modelling approaches and tools are used to support the decision making and planning processes in agriculture. An important component in this is crop modelling. The FACCE MACSUR project aims at an advanced and detailed climate change risk assessment for European agriculture and food security. Such assessment depends on robust and reliable modelling approaches and tools.

Among the various empirical-statistical and mathematical simulation techniques in agricultural modelling, process-based crop simulation models play a central role as they are at the core of any climate impact assessment for the agricultural sector. Yet, recent reviews revealed that neither the modelling approaches nor the crop simulation tools are fully up to the task. For example, many crop simulation models do not account for crop-specific heat stress impacts or miss to simulate limitations by plant nutrients other than nitrogen. Apart from these and other deficiencies in process descriptions, crop models have typically been developed and evaluated at field scale and their application for large area assessments using proper scaling methods is not well understood. These and other deficiencies lead to uncertainties, which are often not quantified.

The crop modelling (CropM) component of FACCE JPI knowledge hub MACSUR ([www.macsur.eu](http://www.macsur.eu)) and other agricultural research projects and networks, such as AgMIP<sup>1</sup> and CCAFS<sup>2</sup> have the ambition to advance crop modelling to meet these new challenges. The last international symposium dedicated to crop models capabilities, gaps and challenges dates back more than ten years ago and there is an urgent need to facilitate exchange among ongoing initiatives on crop modelling for food security under climate change.

This first CropM International Symposium and Workshop, held at Oslo, 10-12 February 2014 attempts to fill this gap and has four major goals:

- to discuss the state-of-the-art and future perspectives of crop modelling and approaches for climate change risk assessment, including the challenges of integrated assessments for the agricultural sector
- to develop a joint vision and research agenda for crop modelling for the future
- to present and discuss CropM highlights and related activities and identify next steps to achieve its contribution to MACSUR goals
- to foster international collaboration in the interconnected research areas of food security, climate change and agrosystems modelling

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<sup>1</sup> [www.agmip.org](http://www.agmip.org);

<sup>2</sup> <http://ccafs.cgiar.org/>

How can we better capture impacts of climatic variability and extreme weather events in crop models? How can we improve the simulation of interactions between CO<sub>2</sub>, temperature, and limitations of water and nutrient supply? How can we introduce genotypes into the modelling of phenotypes? What experiments and experimental data do we need to improve current models? Can monitoring data from fields, farms and regional scale (e.g., remote sensing or flux measurements) be used for improving models? Do we need fundamentally new modelling approaches?

These are some of the research questions dealt with in the scientific sessions, including two keynotes and 20 oral presentations during the symposium, eight oral presentations on scientific highlights during the workshop sessions on CropM Progress and Highlights with six status reports on ongoing research by the Work Package Leaders, and the more than 30 poster presentations. The event is co-hosted and organized by CropM /MACSUR and Bioforsk, the Norwegian Institute for Agricultural and Environmental Research (NILF) and Norwegian University of Life Sciences (NMBU), in close collaboration with AgMIP, CCAFS, the European Society of Agronomy<sup>3</sup> and other international partners.

Symposium and workshop are sponsored by the Research Council of Norway, with additional support from University of Bonn and MTT Agrifood Research Finland. Special thanks for the strong support by the Research Council of Norway, which made this event possible.

We are very grateful to the managers and coordinators of FACCE MACSUR knowledge hub, and the members of the International Scientific Steering Committee, for sharing their ideas, council and support the setting up of the programme, reviewing (> 100) paper abstracts and organizing the different sessions. Without this involvement the event would not have been realized.

We hope that you will enjoy your time in Oslo, listening to new ideas and concepts, meeting old friends as well as new colleagues, and reflecting on the critical issues of climate change and food security, and which contribution crop modelling can and should make.

Best wishes,

Reimund P. Rötter,

MTT Agrifood Research Finland

Frank Ewert,

University of Bonn

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<sup>3</sup> <http://www.european-agronomy.org/>

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**Opening session:**

**Keynotes**

## **John R Porter**

*Professor PhD DSc, Climate and Food Security, University of Copenhagen*



John R Porter is an internationally known scientist in crop ecology and physiology, biological modelling and agricultural ecology. Main contribution has been multi-disciplinary and collaborative work in the response of arable crops, energy crops and complex agro-ecosystems to their environment with an emphasis on climate change and ecosystem services. He has published more than 100 papers in reviewed journals out of a total of about 350 publications and has personally received three international prizes for his research and teaching. His H index is 38 and with 75 papers receiving over 10 citations and his average citation number per paper is 40. Recently he has led the writing of the ground-breaking report for the IPCC 5th Assessment in Working Group 2 on food production systems and food security.

### **Keynote abstract:**

## **State-of-the-art and future perspectives of crop modelling for climate risk assessment**

This paper is part review and part opinion piece; it has three parts of increasing novelty and speculation in approach. The first presents an overview of how some of the major crop simulation models approach the issue of simulating the responses of crops to changing climatic and weather variables, mainly atmospheric CO<sub>2</sub> concentration and increased and/or varying temperatures. It illustrates an important principle in models of a single cause having alternative effects and vice versa. The second part suggests some features, mostly missing in current crop models, that need to be included in the future, focussing on extreme events such as high temperature or extreme drought. The final opinion part is speculative but novel. It describes an approach to deconstruct resource use efficiencies into their constituent identities or elements based on the Kaya-Porter identity, each of which can be examined for responses to climate and climatic change. We give no promise that the final part is 'correct', but hope it can be a stimulation to thought, hypothesis and experiment, and perhaps a new modelling approach.

**Gerald C. Nelson**  
*Professor Emeritus, UIUC*



Gerald C. Nelson, Professor Emeritus, University of Illinois, Urbana-Champaign, currently serves as a member of the Global Agenda Council on Measuring Sustainability with the World Economic Forum. Jerry retired in 2013 but most recently served as a Senior Research Fellow at the International Food Policy Research Institute (IFPRI) in Washington, DC. His research includes global modeling of the interactions among agriculture, land use, and climate change; consequences of macro-economic, sector and trade policies and climate change on land use and the environment using remotely sensed, geographic and socioeconomic data; and the assessment of the effects of genetically modified

crops on the environment.

**Keynote abstract:**

## **Critical Challenges for Integrated Modelling of Climate Change and Agriculture: Addressing the Lamppost Problem**

Economists are often accused of being two handed (ref: Harry Truman). But predictions of the increase in the price of corn by 2050 ranging from zero to 100 percent are discomfiting, even to the most ambidextrous of them. This presentation reports on the recently completed AgMIP global economic model intercomparison exercise that attempted to provide explanations for this range, from different perspectives on the future to model structure. It also highlights what's missing in all research on the effects of climate change on food security and why this makes the high end of the results most plausible.



## **Symposium session 1.1:**

**Uncertainties in model-based impact assessments (including entire modelling chain, i.e. from climate via impact to economic/trade modelling)**

# How have uncertainties in projected yields changed between AR4 and AR5?

Andy Challinor<sup>1</sup>, James Watson<sup>2</sup>, David Lobell<sup>3</sup>, Mark Howden<sup>4</sup>, Sonja Vermeulen<sup>5</sup>

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The projected yields of crops under a range of agricultural and climatic scenarios are needed to assess food security prospects. Here we compare the meta-analysis of yield impact studies conducted for AR4 to that conducted for AR5. The former summarised climate change impacts and adaptive potential as a function of temperature; the latter added quantification of uncertainty, the timing of impacts, and the quantitative effectiveness of adaptation. The analysis focusses on mean yields. Whilst less is known about interannual variability in yields, the available data indicate that increases in yield variability are likely. Uncertainty analyses for a small number of crop-climate studies are presented in order to illustrate key points emerging from the meta-analysis.

We also present a novel framework for analysing how climate models might be used to inform adaptation. The framework categorises adaptive actions according to whether they are aimed at coping with existing climate variability, or carrying out more systemic or transformational changes. Climate information is used to assess when particular actions might be needed, rather than focussing on a given lead time and asking what the range of impacts and appropriate associated responses might be. The results demonstrate the potential for robust knowledge and actions in the face of uncertainty.

We conclude with two recommendations: full treatments of uncertainty, which go beyond impacts models and include relationships between climate and its impacts; and more multi-variable impacts studies, where e.g. nitrogen, water use and crop quality are assessed alongside yield.

# Error and uncertainty of wheat multimodel ensemble projections

Pierre Martre<sup>1</sup>, Daniel Wallach<sup>2</sup>, Senthil Asseng<sup>3</sup>, Frank Ewert<sup>4</sup>, Claas Nendel<sup>5</sup>, James Jones<sup>3</sup>, Kenneth Boote<sup>3</sup>, Reimund Rötter<sup>6</sup>, Alex Ruane<sup>7</sup>, Peter Thorburn<sup>8</sup>, Cynthia Rosenzweig<sup>7</sup>, Davide Cammarano<sup>3</sup>, Jerry Hatfield<sup>9</sup>, Pramod Aggarwal<sup>10</sup>, Carlos Angulo<sup>11</sup>, Bruno Basso<sup>12</sup>, Patrick Bertuzzi<sup>2</sup>, Christian Biernath<sup>13</sup>, Nadine Brisson<sup>2</sup>, Andrew Challinor<sup>14</sup>, Jordi Doltra<sup>15</sup>, Sebastian Gayler<sup>16</sup>, Richie Goldberg<sup>7</sup>, Robert Grant<sup>17</sup>, Lee Heng<sup>18</sup>, Josh Hooker<sup>19</sup>, Leslie Hunt<sup>20</sup>, Joachim Ingwersen<sup>21</sup>, Roberto Izaurralde<sup>22</sup>, Kurt Kersebaum<sup>5</sup>, Christoph Müller<sup>23</sup>, Soora Kumar<sup>24</sup>, Garry O'Leary<sup>25</sup>, Jørgen Olesen<sup>26</sup>, Tom Osborne<sup>27</sup>, Taru Palosuo<sup>6</sup>, Eckart Priesack<sup>13</sup>, Dominique Ripoche<sup>2</sup>, Mikhail Semenov<sup>28</sup>, Iurii Shcherbak<sup>12</sup>, Pasquale Steduto<sup>29</sup>, Claudio Stöckle<sup>30</sup>, Pierre Strattonovitch<sup>28</sup>, Thilo Streck<sup>21</sup>, Iwan Supit<sup>31</sup>, Fulu Tao<sup>6,32</sup>, Maria Travasso<sup>33</sup>, Katharina Waha<sup>23</sup>, Jeffrey White<sup>34</sup>, Joost Wolf<sup>35</sup>

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Projections of climate change impacts on crop performances are inherently uncertain. However, multimodel uncertainty analysis of crop responses is rare because systematic and objective comparisons among process-based crop simulation models are difficult. Here we report on the largest ensemble study to date, of 27 wheat models tested using both crop and climate observed data in four contrasting locations for their accuracy in simulating multiple crop growth, N economy and yield variables. The relative error averaged over models was 24-38% for the different end-of-season variables. There was little relation between error of a model for grain yield and grain protein concentration and error for in-season variables. Thus, most models did not arrive at accurate simulations of grain yield and grain protein concentration by accurately simulating preceding growth dynamics. Ensemble simulations, taking either the mean (e-mean) or median (e-median) of simulated values, gave better estimates than any individual model when all variables were considered. The error of e-mean and e-median declined with an increasing number of ensemble members, with little decrease beyond 10 models. Simulated climate change impacts vary across models owing to differences in model structures and parameter values. When simulating impacts assuming a mid-century A2 emissions scenario for climate projects from 16 downscaled general circulation models (GCMs) and 26 wheat models, a greater proportion of the uncertainty in climate change impact projections was due to variations among crop models than to variations among downscaled GCMs. Uncertainties in simulated impacts increased with CO<sub>2</sub> concentrations and associated warming. These impact uncertainties can be reduced by improving temperature and CO<sub>2</sub> relationships in models and better quantified through use of multi-model ensembles.

# Examining wheat yield sensitivity to temperature and precipitation changes for a large ensemble of crop models using impact response surfaces

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Impact response surfaces (IRs) depict the response of an impact variable to changes in two explanatory variables as a plotted surface. Here, IRs of spring and winter wheat yields were constructed from a 25-member ensemble of process-based crop simulation models. Twenty-one models were calibrated by different groups using a common set of calibration data, with calibrations applied independently to the same models in three cases. The sensitivity of modelled yield to changes in temperature and precipitation was tested by systematically modifying values of 1981-2010 baseline weather data to span the range of

changes projected for the late 21st century at three locations in Europe: Finland (northern, mainly temperature-limited), Spain (southern, mainly precipitation-limited) and Germany (central, high current suitability). Only a baseline CO<sub>2</sub> level was considered and simplified assumptions made about soils and management with an aim to distinguish differences in model response attributable to climate.

The patterns of responses depicted in the IRS plots can be used to compare model behaviour under a range of climates, evaluate model robustness, locate thresholds, and identify possible model deficiencies while searching for their causes. Preliminary results indicate that while simulated absolute yield levels vary considerably between models, inter-annual relative yield variability for baseline conditions is remarkably consistent across models, especially for spring wheat. Results are sensitive to calibration method, as the same models calibrated by different groups exhibited contrasting behaviour. Further work will examine other responses (e.g. CO<sub>2</sub> and adaptation options) and combine IRSs with probabilistic climate to evaluate risks of yield shortfall.

# The AgMIP Coordinated Climate-Crop Modeling Project (C3MP)

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Initial results will be presented from the Agricultural Model Intercomparison and Improvement Project (AgMIP) Coordinated Climate-Crop Modeling Project (C3MP), an activity underway that mobilizes the international community of crop modelers in a coordinated climate impacts experiment via the Agricultural Model Intercomparison and Improvement Project (AgMIP). Crop modelers were invited to run a set of common climate experiments through sites where their models are already calibrated and then submit results to enable coordinated analysis for high-impact publications and data products. Of particular interest is the sensitivity of regional agricultural production to changes in precipitation, temperature, and carbon dioxide concentrations, which in many cases is more robust across crop models and locations than are the absolute yields. By coordinating an investigation into these fundamental sensitivities, C3MP enables an investigation of projected climate impacts across a range of global climate models, regional downscaling approaches, and crop model configurations. More than 1000 simulation sets have already been contributed across 51 countries, with 14 crops investigated and 19 crop models utilized. Coverage will increase in crops, models, farming systems, and locations as more and more crop modelers conduct the experiments. By analyzing carbon, temperature, and water sensitivities with today's climate as the origin, C3MP results will also facilitate the identification of key vulnerabilities and urgent interventions. This presentation will describe the C3MP process and show preliminary climate impact results from this community effort. A comparison between results driven by local meteorological observations and those driven by a global gridded historical climate product (AgMERRA) also elucidates the current challenges in providing climate data as a basis for impacts assessments.

# Investigating the variability uncertainty of soil input data resolution - A multi-model regional study case in Germany

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The spatial variability of soil properties is an important driver of (field and regional) observed yield variability. Consequently, the choice of spatial resolution of soil input data might influence the accuracy of crop models to reproduce observed yield variability. We used four crop models (SIMPLACE<LINTUL-SLIM>, DSSAT-CSM, EPIC and DAISY) differing in model structure and detail for soil water dynamics, uptake and drought effects on plants to simulate winter wheat yields in two (agro-climatically and geo-morphologically) contrasting regions of the federal state of North-Rhine-Westphalia (Germany) for the period from 1995 to 2008. Three spatial resolutions of soil input data were taken into consideration, corresponding to the following map scales: 1:50 000, 1:300 000 and 1:1 000 000. The model results were evaluated in form of frequency distributions, depicted by bean-plots. Soil data aggregation had very small influence on the shape and range of frequency distributions of simulated yield and simulated total growing season evapotranspiration for all models. The small influence of spatial resolution of soil input data might be related to: a) the high precipitation amount in the region which partly masked differences in soil characteristics for water holding capacity, b) the loss of variability in hydraulic soil properties due to the methods applied to calculate water retention properties of the used soil profiles, and c) the method of data aggregation. Our results support conclusions from other studies about the importance of considering a multi-model approach when carrying out regional yield assessments.

## **Symposium session 1.2:**

### **Impact and adaptation assessment studies at field and farm level**

# Simulating historical adaptations of barley production across Finland

Taru Palosuo<sup>1</sup>, Reimund Rötter<sup>1</sup>, Fulu Tao<sup>1</sup>, Tapio Salo<sup>1</sup>, Pirjo Peltonen-Sainio<sup>1</sup>

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Agriculture and crop production are rapidly changing mainly due to more dynamic socio-economic and technological developments but also due to changes in climate and other environmental factors. Process-based crop simulation models, widely used for projecting future crop production, should be able to reflect effects of various yield-determining and -limiting factors to enable assessment of different adaptation measures. Tests on how well crop models can reproduce historical adaptations are, however, rarely done.

We studied barley yield trends in Finland from 1970 to 2010 and simulated the time series using the WOFOST model, which has been successfully calibrated and applied for current Finnish barley cultivars. Simulations were compared with comprehensive databases on barley yield and management observed at experimental stations and reported by farmers. Simulations were performed for different study sites representing different agro-ecological zones in Finland.

The results showed the contributions of individual yield factors that have affected the trends of Finnish barley production such as changes in cultivar use, weather events, date of sowing, fertiliser use, liming and drainage. We also identified yield factors that were not captured with the applied modelling approach.

Our analysis revealed limitations of the modelling approach to simulate the yields under sub-optimal management. Estimation of actual farmers' yields applying crop models is still difficult as many yield-limiting factors, such as pests and diseases, are excluded from the models. Improvement of process-based models and modelling approaches will be essential for more reliably estimating effects of future adaptations on crop production.

# Improving yield predictions by crop rotation modelling? a multi-model comparison

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Crop rotations belong to the most fundamental practices in agriculture. In general, the choice of crops within the sequence strongly depends upon expected profit of the farmer as well as on the prevailing climate and soil type. In practice, the choice of crops is mainly constrained by governmental regulations, preference of the grower, technology available, farm/market demand and last but not least the preceding crop.

Modern predictions of agricultural yields are commonly conducted by modelling each crop separately year-by-year. Simulating the continuous sequence of crops and thus, taking into account carry-over effects of previous crops and cultivation may improve yield predictions.

Here, we show first results of a multi model comparison. Modelling teams capable of simulating continuous crop production were provided with five agricultural datasets collected along a European gradient from France to Denmark. The datasets reflected typical crop rotations of European agriculture. The selection of crops consisted of wheat, barley, rye, sugar beet, potato and maize plus catch crops such as pea, oats, radish and mustard. Simulation results were provided as single year calculations as well as continuous runs. Thus, we will present inter-model comparisons as well as the contrasts between simulating a crop rotation continuously and simulating it year-by-year.

# Using seasonal forecasts for predicting durum wheat yield over the Mediterranean Basin

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Uncertainty about the weather in the forthcoming growing season leads farmers to lose some productivity by making decisions on their own experience of the climate or by adopting conservative strategies aimed at reducing the risks (Jones et al., 2000). The increasing skills of producing seasonal forecasts may represent a great opportunity to overcome this limitation.

This study aimed at assessing the utility of different seasonal forecasting methodologies (i.e. analogues, dynamic models, empiric models) in predicting durum wheat phenology and yield at 10 different sites across the Mediterranean Basin.

To assess the value of forecasts, the approach described by Semenov and Doblaz-Reyes (2007) was adopted. The crop model, SiriusQuality, was used to compute wheat phenology and yield over a 10-years period. First, the model was run with a set of observed weather data to calculate the reference yield distributions. Then, yield predictions using seasonal forecasts were produced at a monthly time-step, starting from 6 months before harvest, by feeding the model with observed weather data from the beginning of the growing season until a specific date and then with synthetic data from the forecasting methodologies until the end of the growing season.

The results indicate that durum wheat phenology and yield can be accurately predicted under Mediterranean conditions well before crop maturity, although some differences between the sites and the forecasting methodologies were revealed. Useful information can be thus provided for helping farmers to reduce negative impacts or take advantage from favorable conditions.

# Modeling climate change impact and assessing adaptation strategies for rice based farming systems in Sri Lanka

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The rising temperature in combination with changing precipitation affect crop production and food security in tropics that demands developing viable adaptation measures. This study investigated productivity changes of rice based farming systems in a region where climate change vulnerability is higher and possible adaptation measures in line with AgMIP. -Sri Lanka project.

Commonly cultivated rice varieties by the farmers in the selected study region where detailed agronomic and production information is available, were calibrated and validated for both DSSAT and APSIM models using experimental data obtained from the Rice Research and Development Institute of Sri Lanka. Rice yield was simulated for 104 farmer fields where irrigated farming was practiced using Department of Agriculture recommendations for two growing seasons (major [October-February] and minor [April-September]) for the years (2012-2013), baseline period (1980-2010), mid-century (2040-2069) for five GCMs (CCS<sub>4</sub>, GFDL, HaD, MIROC, MPI) of RCP-8.5 scenario and for 99-climate sensitivities (C3MP).

Both models reported a good agreement between observed and simulated yields for farmer locations in both seasons (RMSE <1300 kg/ha). Compared to historical period, a significant yield reduction ranging from 14% to 42%, was reported for tested five GCMs and was also in consistent with C3MP. However, HaD which reported the higher temperature rise simulated the highest yield losses due to shortening of crop duration. Among the adaptation strategies explored, alteration of N fertilization and delay planting reduce yield losses, especially in the minor-season where rainfall is relatively less and warmer.

# Simulating seasonal nitrous oxide emissions from maize and wheat crops grown in two different cropping systems in Atlantic Europe

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Optimal nitrogen (N) management in cropping systems is essential for the agricultural systems that are most extensive in each particular region in order to mitigate climate change impacts. This implies the necessity to build tools that help to understand and quantify differences in nitrous oxide (N<sub>2</sub>O) emissions among different N management options to select those characterized by high N use efficiency and low losses. In a previous study it was concluded that deficiencies in the simulation of greenhouse gases emissions with the FASSET model may be due to an inability to model soil organic matter decomposition. This presentation aims to evaluate FASSET with a new algorithm for modelling decomposition of added organic materials to simulate N<sub>2</sub>O emissions in maize and wheat crops grown with different N sources. These crops were grown in two characteristic cropping systems of Atlantic Europe, forage maize in a conventional dairy system in Galicia (Spain) and wheat in an organic crop rotation in Jutland (Denmark). Field trials with maize were performed from 2008 to 2010 and included plots with N mineral fertilizer, cattle slurry, pig slurry and non-fertilized. Organic wheat was grown in 2008 and 2009 and included treatments with pig slurry, digested manure and unmanured. Good estimations of crop dry matter yield were obtained after a proper model calibration of each crop. The source of N input did not produce differences in cumulative seasonal N<sub>2</sub>O emissions. The ability of the model to reproduce seasonal N<sub>2</sub>O is discussed in relation to the environmental factors and crop management.



## **Symposium session 2.1:**

**How to improve modelling of crop growth and development processes including the tightening of links to experimenters?**

# A scheme to evaluate suitability of experimental data for model testing and improvement

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Agroecosystem models are increasingly applied to support decision-making and to assess the impact of changes in management and/or environmental conditions such as climate change. The validity of models used for decision support has to be proven comparing modelling results to corresponding field observations. In general, calibration of a model integrating different processes should be done using balanced data with different observed state and flux variables covering as many of the processes and states of the model as possible at resolutions that allow process parameters in the model to be adjusted and model assumptions to be tested.

Since agricultural datasets were usually not recorded for modelling purposes, its level of detail and quality of records vary enormously. In addition to crops' state variables observations of boundary conditions for growth (like weather and soil variables) are important to test the consistency of simulations. We present a quantitative classification scheme for evaluating the consistency and quality of experimental agricultural data in order to define minimum requirements for data sets for testing model assumptions as well as useful observations for calibration and validation. Variables under consideration are weighted according to their importance and quality considering the variance of the state variables and measurement methods. The objective is to provide a scheme of data evaluation and labelling to select appropriate data according to modeller's requirements and offer guidelines for experimentalists to design their experiments, encouraging them to consider aspects beyond their primary research question which allows a broader use for systems analysis and modelling.

# Causes for uncertainty in simulating wheat response to temperature

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Demand for wheat as food continues to increase with the global population, but it is uncertain whether wheat yield increase can meet the extra demand under future climate change. Crop modelling has been increasingly used to assess the impact of future climate change on wheat yield. However, different wheat models disagree, particularly in simulated wheat yield under warming conditions. Here we compared the simulated responses of wheat yield to temperature change from 28 crop models against those derived from observed data from various temperature treatments in the Hot Serial Cereal (HSC) Experiment at Maricopa. We analysed whether the uncertainty in simulated yield responses to temperature change can be traced back to the differences in the temperature response functions used for modelling key physiological processes in the crop models. We further investigated whether better model calibration and improvement in process-level temperature responses can lead to increased certainty in simulating wheat yield.

# Exploring synergies in field, regional and global yield impact studies

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Field, regional and global crop modelling studies each have their own aims, and their own advantages and disadvantages. For example, global assessments are important for policy and planning, but at these scales, data availability tends to be poorer, and full treatments of uncertainty are more difficult to perform.

To overcome these limitations we propose integrated use of modelling at a range of scales. We present two regional studies, one for wheat in India and another for maize in France, and suggest how this work might inform global modelling efforts. The wheat study finds significant crop model uncertainty due to temperature-driven processes, particularly crop development. This study can be used to identify processes that need particular attention in global studies. The maize study demonstrates the value of high resolution land use data, and long time series of yield data, in skilfully simulating crop production. The same result likely holds at the global scale.

We also use some examples from the literature to illustrate potential synergies between regional and global studies. Regional test cases with known climatic constraints like high VPD (models using canopy versus air temperature), specific drought patterns (Australia), or changes in irrigation patterns (France) can be used to investigate why models differ from observed data and can help to identify important processes that global crop models should include.

We conclude with two recommendations for future research: coordinated cycles of model improvement and multi-model projection; and use of systematic intercomparison of impacts studies to synthesise knowledge.

# A new approach to crop growth modelling: a process-based model based on the optimality hypothesis

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Global agriculture will, in the future, be faced with two main challenges: climate change and an increase in global food demand driven by an increase in population and changes in consumption habits. To be able to predict both the impacts of changes in climate on crop yields and the changes in agricultural practices necessary to respond to such impacts we currently need to improve our understanding of crop responses to climate and the predictive capability of our models. Ideally, what we would have at our disposal is a modelling tool which, given certain climatic conditions and agricultural practices, can predict the growth pattern and final yield of any of the major crops across the globe. We present a simple, process-based crop growth model based on the assumption that plants allocate above- and below-ground biomass to maintain overall carbon optimality and that, to maintain this optimality, the reproductive stage begins at peak nitrogen uptake or maximum carbon gain in the canopy. The model includes responses to available light, water, temperature and carbon dioxide concentration as well as nitrogen fertilisation and irrigation. The model is data constrained at two sites, the Yaqui Valley, Mexico for wheat and the Southern Great Plains flux site for maize and soybean, using a robust combination of space-based vegetation data (including data from the MODIS and Landsat ETM+ instruments), as well as ground-based biomass and yield measurements. We show interactions between impacts of changes in climate and agricultural practices.

# Modeling crop adaption to atm. CO<sub>2</sub> enrichment based on protein turnover and use of mobile nitrogen

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Crop models are frequently used for extrapolation of crop biomass production and yield quality under elevated atm. CO<sub>2</sub> concentration ([CO<sub>2</sub>]). Due to multiple interactions of elevated [CO<sub>2</sub>] with other environmental factors the characteristics of crop acclimation vary strongly in range and comprise higher biomass production, lower tissue nitrogen concentrations, altered yield quality, and increased water and nitrogen use efficiencies. The lower tissue nitrogen concentrations are widely seen as a key factor in plant adaption. Therefore, various hypotheses exist to explain the decreased tissue nitrogen concentrations but the mechanisms in terms of [CO<sub>2</sub>] enrichment are still not clear. Also how to model crop adaption is not sufficiently solved, yet. Therefore, we developed a model to test the 'down regulation of photosynthesis' hypothesis. Based on the GECROS model that was embedded into the Expert-N model environment (XN-G) we developed a new canopy model that accounts for the dynamic turnover of photosynthetic active nitrogen in the leaf (XN-GN). Mobile nitrogen derived from protein degradation is then available for redistribution within the plant. In this way the plant can then optionally use the re-mobilized nitrogen either for growth or for the synthesis of new photosynthetic active nitrogen. Both the original and the new model were tested against data of spring wheat grown in a Mini-FACE system. The sensitivities of both models to [CO<sub>2</sub>] enrichment were analyzed. Using the new model [CO<sub>2</sub>] enrichment altered the depth distribution of protein, increased the root:shoot-ratio and the biomass production.



## **Symposium session 2.2:**

**Impact and adaptation assessment  
studies at regional and continental/global**

# AgMIP's Global Gridded Crop Model Intercomparison

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In 2012 AgMIP led a Global Gridded Crop Model (GGCM) Intercomparison fast-track project in coordination with the PIK-led Inter-Sectoral Impacts Model Intercomparison Project (ISI-MIP). In this fast-track, 7 GGCMs and updated the state of knowledge on climate change vulnerabilities and impacts culminating in 4 papers in the PNAS special issue published in 2014. These results indicate the potential of GGCM simulations and the need to further improve understanding of mechanisms, assumptions, and uncertainties of model design and execution, which are now addressed in a 3-stage coordinated model intercomparison project at continental and global scale: 1) Historical simulation and model evaluation, 2) Analysis of model sensitivity to CTWN (carbon, temperature, water, and nitrogen), and 3) Coordinated regional and global climate assessment.

We summarize the findings of the ISI/Ag-MIP fast-track assessment and identify further research needs for global gridded crop modeling. We present preliminary results from stage 1 of the GGCMi on historical simulation and model evaluation. In this stage, models are being run using various observation and reanalysis-based historical weather products so that they can be evaluated over the historical period globally and in various key interest regions. For model evaluation and harmonization of management assumptions, we cooperate with several other major data partners. The project currently includes 20 modeling groups from 11 countries and a broad variety of model types: gridded field-scale models, extended land surface scheme and dynamic global vegetation models, and empirical-process model hybrids explicitly developed for the global scale.

# Assessing climate change impacts and adaptation measures on crop yield at European level

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JRC has started to assess climate change impacts on agricultural yields and production and to explore adaptation measures at European level, in response to the need of the European Commission to prepare for CAP policy measures beyond 2020. The crop growth models WOFOST and CropSyst currently implemented within the BioMA modelling platform have been run with different realizations of the SRES A1B climate scenarios for the 2030 horizon after post-processing of the climate datasets in order to provide meaningful input for the crop models. Among them, the equally valid HadCM3Q0-HadRM3Q0 and ECHAM5-HIRHAM5 realizations differ considerably in quantity and spatial distribution of projected precipitation over Europe. Model simulations, performed at a 25km grid covering EU27/28 for 9 of the most grown crops in EU28, have been executed without any adaptation considered and with selected adaptation measures at farm level included. The resulting changes in projected crop yields, as produced in the frame of the projects AVEMAC, PESETA 2, and ULYSSES, will be presented. The crop growth model results have been also included in following agro-economic analyses to explore the impact on commodity prices and at farm level.

# Integrated climate change impact and adaptation assessment for the agricultural sector in Austria

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An integrated modelling framework (IMF) has been developed and applied to assess climate change impacts and adaptation measures in Austrian agriculture. The IMF couples three models: the CropRota model is employed to derive typical crop rotations which serve as input into the bio-physical process model EPIC. EPIC is applied to simulate – inter alia – crop yields and environmental outcomes for alternative climates and management practices at 1km-grid-resolution. The bottom-up economic land use optimisation model PASMA uses outputs from EPIC at NUTS-3 level and calculates gross margins. Scenario analysis is applied to evaluate the effects of three adaptation and policy scenarios. We analyse four contrasting regional climate model (RCM) simulations until 2050 to account for climate change related uncertainty. Impacts from the RCM simulations show increasing agricultural productivity on national average. Changes in average gross margins range from 0% to +5% between the baseline and three scenarios until 2040 at national level. The impacts are more pronounced at regional scale and range between -5% and +7% among Austrian NUTS-3 regions between the baseline and the three scenarios until 2040. Adaptation measures such as winter cover cropping, reduced tillage, and irrigation are cost-effective in reducing yield losses, increasing revenues, or in improving environmental effects under climate change. Future research should account for extreme weather events to analyse whether average productivity gains at aggregated level suffice to cover costs from expected higher climate variability. This work serves as a case study within the FACCE MACSUR project.

# Representing the links among climate change forcing, crop production and livestock, and economic results in an agricultural area of the Mediterranean with irrigated and rain-fed farming activities

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This paper presents a comprehensive and integrated methodology analysis, by means of climatological, agronomic, livestock and economic evaluations, to represent the production and economic dynamics of an agricultural Mediterranean district under the effects of climate change are to be assessed. The district includes an irrigated lowland served by a water user association and a hilly land area where rainfed farming is practiced. The paper first describes how a regional atmospheric model has been used for downscaling climate change scenarios to evaluate the atmospheric forcing over the Mediterranean basin. Secondly, the paper illustrates how two crop models, EPIC and DSSAT, were used to estimate the impact of climatic variables on irrigation requirements and yields of irrigated crops and rainfed cereals and and pastures . Finally, it shows how these production results were used to specify the expectations on factors requirements and production yields that guide the programming on farms. For this purpose, farmers expectations are represented as probability distributions of the levels that the production variables may take. The ranges of these probability distributions were divided into states of nature whose representative values and probabilities are incorporated into a model of Discrete Stochastic Programming. This model simulates the decisions and the economic performance of the farm types that operate in the area. The analysis focuses on comparing the production of fodder in the irrigated dairy farms types operating in the plains, and the grazing schemes in the dairy sheep farms of the rainfed hilly sub-areas.

# Yield gap analysis of cereals in Europe supported by local knowledge

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The increasing demand for food requires a sustainable intensification of crop production in underperforming areas. Many global and local studies have addressed yield gaps, i.e. the difference between potential or water-limited yields and actual yields. Global studies generally rely on generic models combined with a grid-based approach. Although using a consistent method, it has been shown they are not suitable for local yield gap assessment. Local studies generally exploit knowledge of location-specific conditions and management, but are less comparable across locations due to different methods. To overcome these inconsistencies, the Global Yield Gap Atlas (GYGA, [www.yieldgap.org](http://www.yieldgap.org)) proposes a consistent bottom-up approach to estimate yield gaps. This paper outlines the implementation of GYGA for estimating yield gaps of cereals across Europe. For each country, climate zones are identified which represent the major growing areas. Within these climate zones, weather stations are selected with  $\geq 15$  years of daily data. For dominant soil types within a buffer zone around the weather stations, the potential and water-limited yields are simulated with a crop model, using local knowledge on management. Actual yields are derived from sub-national statistics. Yield gaps are scaled up from buffer zones to climate zones and countries. We will present the first results for Germany and Poland. Furthermore we will address these methodological issues: (i) location specific observed weather versus derived grid-based weather, (ii) upscaling from weather station buffer zones to climate zones and countries, (iii) value of additional local validation and calibration, and (iv) benefits of collaborating with country agronomists.

# **CropM Workshop:**

## **1st set Progress and Highlights**

# Water balance and yield estimates for field crop rotations - present versus future conditions based on transient scenarios

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Main aim of submitted study was to compare selected parameters of water balance and expected yields estimated by Hermes crop model for present and future climatic conditions. Eight locations representing various agroclimatic conditions within Czech Republic were selected using clustering method. The crop rotation including winter rape, winter wheat, spring barley, silage maize was simulated continuously for the period 1981-2080. The period 1981-2010 was represented by measured meteorological data and period 2011-2080 was represented by transient synthetic weather series from weather generator MaRfi. Generated data were based on five circulation models in combination with medium climatic sensitivity. Five climate models from the ensemble of 18 CMIP3 global circulation models were picked in a way that preserves the whole range of uncertainty of 18-member ensemble. Moreover, a control run was carried out for the period 2011-2080 without any changes in statistical characteristics of meteorological parameters or long-term trends. Crop model HERMES was calibrated and validated using experimental data from 2001-2013 period and was run in fully automated mode. Two types of crop management were considered: i) best-practice scenario aimed at preserving the soil organic content and ii) biomass-intensive when most biomass was removed. The influence of soil water holding capacity and increasing atmospheric CO<sub>2</sub> was considered as well. For each location 1200 (1 control + 5 climate models x 10 realizations from MaRfi x 2 types of crop management x 5 initializations of crop rotation x 2 soils) realizations were simulated by Hermes. Finally, for the period 1981-2080 yields, reference and actual evapotranspiration, level of drought stress and other parameters were analyzed continuously and also divided into individual decades.

# Effects of climate input data aggregation on modelling regional crop yields

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Crop models can be sensitive to climate input data aggregation and this response may differ among models. This should be considered when applying field-scale models for assessment of climate change impacts on larger spatial scales or when coupling models across scales.

In order to evaluate these effects systematically, an ensemble of ten crop models was run with climate input data on different spatial aggregations ranging from 1, 10, 25, 50 and 100 km horizontal resolution for the state of North Rhine-Westphalia, Germany. Models were minimally calibrated to typical sowing and harvest dates, and crop yields observed in the region, subsequently simulating potential, water-limited and nitrogen-limited production of winter wheat and silage maize for 1982-2011. Outputs were analysed for 19 variables (yield, evapotranspiration, soil organic carbon, etc.). In this study the sensitivity of the individual models and the model ensemble in response to input data aggregation is assessed for crop yield.

Results show that the mean yield of the region calculated from climate time series of 1 km horizontal resolution changes only little when using climate input data of higher aggregation levels for most models. However, yield frequency distributions change with

aggregation, resembling observed data better with increasing resolution. With few exceptions, these results apply to the two crops and three production situations (potential, water-, nitrogen-limited) and across models including the model ensemble, regardless of differences among models in simulated yield levels and spatial yield patterns. Results of this study improve the confidence of using crop models at varying scales.

# Responses of crop's water use efficiency to weather data aggregation: a crop model ensemble study

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Climate effects on cropping systems can be simulated and assessed at different spatial resolutions to provide information for decision making at regional and larger spatial scales. Low resolution simulation needs less effort in computation and data management, but important details could be lost during the process of data aggregation. This aggregation effect could be propagated with the simulated results of the crop model. This paper aims to study the aggregation effects of weather data on the simulations of evapotranspiration (ET) and water use efficiency (WUE) using different crop models. Using ten process-based crop models, we simulated a 30-year continuous cropping system for two crops (winter wheat and silage maize) under water-limited conditions with 1 km resolution weather data. We aggregated the weather data to resolutions of 10, 25, 50, and 100 km and repeated the simulations. The WUE was calculated as the ratio of grain yield to ET and annual mean of the results were mapped.

For each model, the aggregation only slightly changed the result means and spatial patterns, while the spatial variations were lost with the coarsening of the resolution. The temporal trends of the aggregated ET and WUE were consistent among models, but the

absolute values and spatial patterns differed. This indicates that the uncertainties sourced from aggregation of the weather data are less considerable than the differences among the crop models. If the spatial details are needed for local management decision, a high resolution is desired to adequately capture the spatial heterogeneity in the region.

# Delivering local-scale CMIP5-based climate scenarios for impact assessments in Europe.

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Local-scale climate scenarios are required as input to impact models for assessment of climate change impacts. These scenarios incorporate changes in climatic variability as well as extreme events which are particularly important when used in conjunctions with process-based non-linear impact models. ELPIS is a repository of climate scenarios for Europe, which is based on the LARS-WG weather generator and future projections from 18 global climate models (GCMs) from the CMIP5 multi-model ensembles used in the latest IPCC AR5. In ELPIS, the site parameters for climatic variables for the baseline period, 1981-2010, were estimated by LARS-WG from the European Crop Growth Monitoring System daily weather interpolated from observed sites over 25 km grid in Europe. Using changes in climate projected by GCMs, LARS-WG perturbed site distributions for the baseline climate to generate local-scale daily climate scenarios for the future under RCP4.5 and RCP8.5 recommended concentration pathways. The ability of LARS-WG to reproduce daily weather for the baseline period 1980–2010 was assessed using statistical tests and baseline site parameters were validated against independent dataset of from the ECA&D archive. ELPIS represents a unique resource for impact assessments of climate change in Europe.



# **CropM Workshop:**

## **2nd set Progress and Highlights**

# Assessing climate impacts on wheat yield and water use in Finland using a super-ensemble-based probabilistic approach

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Ensemble-based probabilistic projection is an effective approach to deal with the uncertainties in climate change impacts and in assessing adaptation options. First, we adapted a large area crop model, MCWLA-Wheat, to winter wheat and spring wheat in Finland. Then the Bayesian probability inversion and a Markov chain Monte Carlo (MCMC) technique were applied to the MCWLA-Wheat to analyze uncertainties in parameter estimations, and to optimize parameters, based on 10 years of phenological and yields observation data in a district. Ensemble hindcasts showed that the MCWLA-Wheat simulated the inter-annual variability of Finland wheat historical yield series fairly well. Finally, a super-ensemble-based probabilistic projection system was developed and applied to project the probabilistic impacts of climate change on wheat productivity and water use in Finland. The system used 6 climate scenarios and multiple sets of crop model parameters. We present the spatiotemporal change pattern of wheat productivity and water use due to climate change/variability during 2020s, 2050s and 2080s, respectively. The results show that generally climate change will increase wheat yields in Finland with relative high probability. However, in some parts of southern Finland wheat production will face increasing risk of high temperatures and drought stress. Our study parameterized explicitly the effects of high temperature and drought stress on wheat yields, accounted for a wide range of wheat cultivars with contrasting phenological and thermal characteristics, presented new findings on probabilistic impacts of climate change and variability on wheat yields and water use in Finland.

# Breeding forage grasses: simulation modelling as a tool to identify important cultivar characteristics for winter survival and yield under future climate conditions in Norway

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Grass-based dairy and livestock production constitute the most important agricultural sectors in Norway in economic terms. Climate change may have considerable impact on the survival and productivity of grasslands. New cultivars will be needed that are better adapted to the changed climate conditions than current cultivars. Breeding for a new grass cultivar usually takes 15-20 years. It is difficult to predict which trait combinations will be important in the future, especially under climate change conditions. However, it is important to define breeding targets and investigate the underlying genetic and physiological mechanisms of important traits. Process-based simulation models represent a powerful tool to assist in the breeding process. Here we show an example with preliminary results from a study where the process based grassland model BASGRA is used to evaluate the effect of modified plant characteristics on grass winter survival and yield under projected climate change conditions. Grass simulations were carried out for three locations in Norway: Apelsvoll (60° 42'N; 10° 42'E), Sola (58° 53'N; 5° 38'E) and Tromsø (69° 41'N; 18° 55'E), and the three periods 1961-1990 (baseline), 2046-2065, and 2080-2099. Daily weather data were generated with the LARS-WG tool incorporating projections from different General Circulation Models (GCMs) under the greenhouse gas emission scenario A1B. For each climate projection, grass performance was simulated for a current cultivar, and then for cultivars with altered traits. The results indicate that a high maximum frost tolerance will be important for winter survival in perennial forage grasses also under future climate conditions. Delayed reproductive development in spring will have limited effect on the total seasonal yield.

# Adaptation Strategies to Climate Change for summer crops on Andalusia: evaluation for extreme maximum temperatures.

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Increase of mean, maximum and extreme temperatures may threaten summer crops in southern Iberian Peninsula. The objective of this work is to evaluate a set of agricultural adaptation strategies to cope with climate change impacts, with focus on the consequences of extreme events on the adaptations proposed. The evaluation of impacts and of a set of possible adaptation strategies is done using irrigated maize as a reference crop. The study was conducted in five locations in Andalusia, where the CERES-Maize crop model under DSSAT v4.5. platform was applied. Two types of observed climate were used: station data from Agroclimatic Information Network of Andalusia (RIA) and gridded data from ERA-Interim re-analysis. The simulated climate was obtained from the ensemble of Regional Climate Models from ENSEMBLES European Project with a bias correction in temperature and precipitation. Crop experimental data were provided by the Andalusian Network of Agricultural Trials (RAEA). Crop model calibration was site-specific, considering real soils and observed cultivars and practices for potential yield, in order to reduce the uncertainty linked to the climate models. Once evaluated the impacts, three sets of adaptation strategies were proposed: 1) earlier sowing dates looking for cooler temperatures, 2) changes in the cultivar looking for increasing the grain filling rate and duration, and 3) the combination of both strategies.

New phenological dates from adaptation simulations were then compared to the projections of extreme events of maximum temperature. Concurrence of these events with vulnerable phenological stages is discussed.

# An economist's wish list for crop modeling

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Both economic and crop models may need improvements to deal with issues of food production and food security under climatic change. A dialog between economists and crop scientists may ensure that we meet on common grounds.

While crop scientists state how yields are affected by management in experiments under varying climate, the economist would rather like to know how yields are affected by climate and weather under farmers' decisions of management --- in turn decisions are functions of climate and weather.

Management of a farm will always be different from management of an experiment. While experiments follow certain protocols to ensure comparability, the farmer can be rewarded with higher profits due to lower costs and correspondingly lower yields by following other procedures. Moreover, management decisions like choice of cultivar and timing and intensity of treatments are largely exogenous in crop modeling. Economists on their hand do not in general know these decisions and need models which simulate farmers' choices.

Modeling of endogenous management decisions is definitely within the economic realm. The economist can do this for representative farmers by optimizing management using a menu of crop models. These need be re-calibrated with respect to the effects of management to make model outcomes consistent with observed yields. The re-calibration should be smooth in temporal and spatial dimensions. Such exercises presume relatively simple though robust crop models.



## **Posters:**

### **Field and farm level studies**

# Multifractal analysis of chosen meteorological time series to assess climate impact in field level

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Multifractal analysis of the physical quantities describing the elements of the soil-plant-atmosphere system could be an efficient way to assess the climate change impact on the crop production. When using the long stage non-stationary time series of meteorological quantities in crop yield models it is important to know their multifractal structure. In this study the Multifractal Detrended Fluctuation Analysis (MFDFA) was used for time series of the air temperature, wind velocity and relative air humidity (at the height of 2 m above the active surface) as well as the soil temperature (at 10 cm depth in the soil). The 12 years' field data for the analysis were gathered at agro-meteorological station in Felin, near Lublin, Poland at hourly interval. The empirical singularity spectra for studied meteorological quantities were obtained indicating their multifractal structure (the shapes of all the spectra were similar to the wide inverted parabolas). The richness of the studied multifractals was evaluated by the width of their spectrum, indicating their considerable differences in dynamics and development. The log-log plots of the cumulative distributions of all the studied absolute and normalized meteorological parameters tended to linear functions for high values of the response indicating that these distributions were consistent with the power law asymptotic behaviour.

# Assessment of soil organic C response to climate change in rainfed wheat-maize cropping systems under contrasting tillage using DSSAT

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Climate change adaptation for agricultural systems requires resilience to both high intensity rainfall and extended drought periods. The increase of soil organic carbon (SOC) in the surface soil horizons associated to repeated no tillage practices, can contribute to improving soil structure and water absorption capacity.

In the present study we assessed the effect of tillage management practices on SOC and crop yields in a rainfed durum wheat-maize rotation system (Agugliano, Italy) under temperate sub-Mediterranean conditions and a silty clay soil.

The differential impact of no tillage (NT) management compared to conventional tillage (CT), both characterized by non-limiting nitrogen (N) fertilizer applications were evaluated under current and future climate scenarios by combining long-term field experiment outcomes with simulation approaches.

DSSAT 4.5 was used to simulate crop yields and long term SOC dynamics following the calibration based on observed values in a long term experiment (1994–2008) run in central Italy (De Sanctis et al., 2012, Eur J Agron).

Climate scenarios were generated using the regional model RAMS, bias calibrated with local observed conditions, considering a present (2000-2010) and near future (2020-2030) climatic conditions.

NT management under non-limiting N conditions significantly contributed to increase SOC content in rainfed cereal systems through the greater soil cover offered by weeds in the 9-10 months intercropping period between wheat harvest (July) and maize seeding (end-April). Crop yield was significantly lower under NT than under CT and the simulated CO<sub>2</sub> effect was greater than that expected from changed temperature and precipitation regimes in the near future.

# Field experiment in Lubelskie region to validate crop growth models in temperate climate

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To validate crop growth models in different climate zones under climate change high quality agrometeorological data are essential. They should also include a broad set of parameters describing the system soil-plant-atmosphere system. Here, we present a field experiment to validate crop growth models in temperate climate under climate change. It was set-up in the Stany Nowe (N50°49'17.0555", E22°16'28.51", height 243m a.s.l.) in Lubelskie province in Poland. The experiment was conducted on a typical for Lubelskie highland arable land, cultivated with winter wheat. The TDR moisture, temperature and salinity (electrical conductivity) sensors were installed at four levels - 5, 15, 30 and 50 cm of the soil profile. The basic physico-chemical properties of the soil samples gathered from the field, among others nitrogen and also other macroelements content, were measured. The dynamic chambers for measuring emission of carbon dioxide from soils and its assimilation by plants were developed and tested. Carbon dioxide fluxes have been measured by EGM-4 PP Systems sensor during fixed stages of the plant growing season. A system measuring atmospheric parameters at 2 meters above the active surface contains following sensors: temperature humidity, wind speed, wind direction, precipitation, albedo and the radiation balance. The measurements of plant parameters, such as plant height, temperature of the leaves, leaf area index with hourly interval once every two weeks and head weight, weight of 1000 grains, dry mass, nitrogen and other macroelements content in yield and total yield at the end of growing season were also carried out.

# Maize production and nitrogen dynamics under current and warmer climate in Denmark: simulations with the DAISY model

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Maize cropping systems in North Europe are expanding and there is still lack of knowledge on the agronomic and environmental consequences. Accumulating evidence of climate change also sets a need to investigate responses towards more climate resilient maize systems.

The ability of the DAISY model to satisfactorily simulate maize production, water and N dynamics was tested in Denmark under current and warmer climate. Data from field experiments on loamy and coarse sand involving maize monoculture and intercropped with catch crops were used. The main objectives were to (i) calibrate and evaluate DAISY model for soil hydrology, maize growth and soil organic matter turnover, and (ii) provide model-based estimates of the changes in the system in response to temperature increase of 2 C and [CO<sub>2</sub>] increase to 532 ppm by 2050.

The model performed well in simulating maize dry matter and N uptake, but it underestimated net N mineralization during autumn. Successfully established catch crops decreased N leaching, but also reduced yields at low fertilizer rates, especially on coarse sand. The warmer climate simulations demonstrated higher maize net photosynthesis and increased yields on loamy sand. On coarse sand, however, expected yield increase was hampered due to significant water and N stress, implying on higher irrigation and fertilization requirements on coarse sand under warmer climate.

Although some segments of DAISY need to be improved, this study offers insight of maize intercropping production systems and accompanied N leaching in Denmark under current and warmer climate.

# Effects of tillage, fertilizer and residue management on crop growth dynamics in winter wheat at Foulum, Denmark

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In crop modelling efforts, several parameters need to be adjusted. More detailed measurements for different treatments could help us to calibrate our models with higher certainty. A crop rotation experiment had already been established in 2002 on loamy sand at Research Centre Foulum (Denmark). The experiment was a split-plot in four replications with two factors: crop rotation as main plot and tillage as subplots. Four tillage practices (direct sowing, stubble cultivation with two different depths and ploughing) were applied for each rotation system. In 2013, three rotation systems (R2, R3 and R4), were fields under winter wheat. Whereas straw was removed in the R3 rotation, it was retained in the other two rotation systems (R2 and R4). For this year additional treatments were included in R2 and R4 with total N rates of 50, 150 and 250 kg N/ha. From April 2013, aboveground biomass samples were collected biweekly and analyzed for leaf area, biomass accumulation and nitrogen (N) uptake. Winter wheat growth was monitored frequently by recording growth stages and making Ratio Vegetation Index (RVI) measurements. Nitrogen leaching, soil mineral N and water content were also measured. Preliminary results show that winter wheat yields increased dramatically in response to N fertilizer from 0 to 100 kg N/ha, thereafter there was no response to fertilization until the treatment with 200 kg N/ha when yields actually began to decrease. There was no significant difference between yields of plots with removed and retained straw (R3 and R4).

**Posters:**

**Regional and global studies**

# Statistical identification of Nature-states within the state-contingent framework

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It is the main objective of this work to contribute towards understanding the economic impacts of an environmental change, which in our understanding influence crop productivity and thus grain yields. Our focus lies on winter wheat and maize production in regions of Saxony-Anhalt. What could be considered novel in the poster is the use of statistical methods to identify biophysical states of Nature.

Broadly, field observations of winter wheat and maize yields in the districts of Saxony-Anhalt are clustered using a classical k-means algorithm. Running a multivariate adaptive regression splines model then allows us to gain insight into the structure and dynamic in the data, while simultaneously experimenting with data partition. The dependent variables in the models, of climatic and atmospheric nature, have been constructed from publicly accessible meteorological data. Analysis of the regression results serves as a guide towards constructing biophysical states of Nature in the state-contingent sense.

In a second step, we assign the yields as reported by farmers to the identified states of Nature and express them in economic terms, as the outcome resulting from farmers committing a certain amount of inputs under a stable technology, within a state contingent production framework. Our results suggest a farmer's ability to adapt to uncertainty by ex ante reallocating inputs between possible states of Nature and thereby substituting state-contingent outputs. This finding suggests the usefulness of the state-contingent framework and validates the synergies arising from the integration of economic and biophysical data.

# Comparing the performance of different irrigation strategies for producing grain maize in Europe

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Analysis of the spatial distribution of water demand for irrigation is a prerequisite to devise an appropriate water management strategies, which could stabilize crop production. Implemented irrigation strategies in agriculture should therefore minimize the water use and increase the overall water use efficiency. In order to assess the effect of irrigation on crop yield, the experiment was conducted on grain maize, well known as a crop sensitive to water deficit and drought. The spatial distribution of water deficit and maize yield deficit across Europe has been simulated with the WOFOST model and compared between current and expected climatic conditions in 2030s. In our study, the priority has been given to future projections of the A1B emission scenario given by two contrasting regional climate model runs (in terms of projected air temperature change) within the ENSEMBLES project. The effectiveness of three irrigation strategies was compared, which could potentially be applied to offset the adverse climate change impact on grain maize yield in Europe: full, deficit and supplemental irrigation. These irrigation strategies differ in timing of water application and in the total volume of water spent during the growing season. The three strategies triggered a different number of irrigation events during the growing season. Deficit strategy resulted in a lower number of triggered events than the full strategy. The results show that similar yields can be achieved using deficit irrigation strategy, when compared to full irrigation, thereby saving at least 30% of irrigation water in the current and future climate conditions.

# Climate change impacts on natural pasturelands of Italian Apennines

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As well as the entire Mediterranean area, the Italian Apennines have been affected by increasing temperatures, rainfall extreme events and decreases in annual precipitation due to climate change. Moreover, permanent grasslands, species-diverse ecosystems characterizing the marginal areas of the Apennines landscape, are acknowledged as very sensitive and vulnerable to climate variation. Building on these premises, statistical classification models coupled with data integration by GIS techniques, were used to territorially assess future climate change impacts on pastoral communities on the Italian Apennines chain. Specifically, a machine learning approach (Random Forest - RF), firstly calibrated for the present period and then applied to future conditions, as projected by HadCM3 General Circulation Model (GCM), was used to simulate potential expansion/reduction and/or altitudinal shifts of the Apennine pasturelands in two time slices, centred on 2050 and 2080, under A2 and B2 SRES scenarios. RF classification model proved to be robust and very efficient to predict lands suited to pastures with regards to present period (classification error: 12%). Furthermore, according to RF simulations, a slight reduction (<15%) of areas potentially suitable for pastoral resource is expected under the future climatic conditions, as depicted by the GCM and SRES scenarios. Despite a moderate reduction of areas potentially suited to pasturelands, troubling impacts on floristic composition might be expected in the future (e.g. expansion of more xeric and thermophilous species and decline of high-altitude pastoral typologies). This might threaten the typical and unique herbaceous biodiversity characterizing the Apennine pasturelands.

# Modelling observed relationships between crop yields and climate towards resilient future

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Despite ongoing improvements in crop production technology, changes in climate regulate global crop production. Overdependence on major species threatens food security thus future sustainability demands crops resilient to climate variability. Quantification of crop-climate relationships is important in assessing future climate impacts on crop production. Two detailed cases analyse relationships between yield and climate across crop models, spatial scales and geographical locations (a) global food crops: GLAM-maize-Sri Lanka, DSSAT-rice-Sri Lanka (b) underutilised crops: AquaCrop-Bambara-groundnut-Africa, APSIM-foxtail-millet-Sri Lanka. Each 'use-case' provides an example explaining observed yield trends with predictions for baseline, mid-century RCP8.5 scenario from GCMs (CCSM4, GFDL-ESM2M, HadGEM2, MIROC5, MPI-ESM) and climate sensitivities (C3MP).

GLAM-maize-Sri Lanka (University of Reading) gave significant correlations for detrended maize yield to seasonal mean temperature and total rainfall (only for some districts) and GLAM yield predictions correlated well with observed values. GCMs projected a decrease in yield caused by shorter crop growing seasons due to higher temperatures and lower precipitation.

AquaCrop-Bambara-groundnut-Africa (Crops for the Future Research Centre) tested bambara groundnut (underutilised African legume) for genotypic suitability under baseline, future scenarios and 99-climate sensitivities across geographical locations in southern Africa, to synthesise farmer decisions. Landraces originating from various semi-arid Africa locations exhibit diverse adaptations and sensitivities to climate.

Observed crop-climate correlations within yield simulating models generated advice on suitable adaptation strategies under future climate. Productivity simulations for contrasting African and Sri Lankan locations demonstrated that interrogation methods can identify genetically distinct materials for climate resilience to predict optimal selections of parental germplasm suited to different geographical locations.

# Simulating current and future crop productivity in Ukraine using SWAT

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Ukraine is one of the most important players in global agricultural markets due to large tracts of fertile black soils and temperate climate conditions. However, current crop yields are less than half compared to similar areas in other countries, mainly due to low applications of intermediate inputs, suggesting ample potential to increase crop productivity. Moreover, frequently occurring droughts in the region result in high annual yield volatility. We use the Soil and Water Assessment Tool (SWAT) to simulate biophysical yield potentials and to quantify yield gaps for the entire country at district level and for the five major crops in terms of area used (wheat, sunflower, maize, barley and soybean). We calibrate and validate the SWAT models for all crops with a district-level dataset of all commercial farms in Ukraine that contain crop-specific productivity, input applications and farm management indicators for each year since 2001. In a next step, we will use the calibrated models to forecast future yield potentials under climate change by using downscaled climate scenarios. The results will allow quantifying the potential future contribution of Ukraine to global crop production. Moreover, we will be able to suggest adaptation measures for agricultural entrepreneurs, plant breeders and policy makers on how to adapt crop production to changing environmental circumstances.

# The agro-meteorological model for yields of winter triticale

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Winter triticale is a relatively new species grown since the 80s of the XX century. This cereal is well adapted to the environmental conditions of Poland.

The cultivation area of winter triticale increases progressively. It is cultivated presently, at more than 1 million hectares. It can be expected, that in subsequent years the importance of this crop will grow. What is important in the context of adaptation to climate change.

The meteorological- statistical model predicting the yield of winter triticale has been processed according to the methodology developed in IUNG. The yield data obtained from the Main Statistical Office (GUS) from 1988-1998 were collected and used to develop a model. Meteorological data from one the weather station was assigned to each, chosen voivodeships .

The developed meteorological- statistical model consists of 7 sub-indices that take into account the dependencies between the weather factors and yield. Each developed algorithm is characterized by important stages of growth and development of winter triticale. The model allows to evaluate the impact of weather on the crop, during the growing season in 7 terms.

The assessment of the suitability of the model for forecasting yields was performed. The model predictions were compared with the quotations of GUS in 1999-2011. The Model allows to estimate the yield of the whole country with a standard error of 4.1%. The model gives ability for forecasting the winter triticale crop in Poland in particular year and can be used in climate change impact study.

# Modelling climate change impacts on thermophilic crops production in central and southern Europe

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The agriculture in all its segments is directly affected by extreme weather events and their effects, especially negative, cannot be ignored. However, an increase in the length of the growing season, together with a warmer climate, may increase the potential for growing thermophilic vegetables in open fields in lowland and increase the potential number of harvests in large areas from Europe. To develop strategies on climate change adaptation for different varieties of thermophile crops for future climate change in different regions in order to increase productivity, while reducing the water footprint of agriculture per unit product is one the main task in climate smart agriculture. This research presents an assessment of the potential climate change impacts on various types of thermophilic crops in central and southern Europe. In this context, the main objectives of the research will focus on assessing crop water use efficiency and pests and diseases incidence under current and future climate scenarios for different cropping systems, especially thermophilic species (maize, sunflower, vegetables), for different agricultural sites that are vulnerable to extreme climatic events. Firstly a comprehensive analysis to determine perspective areas for growing thermophilic crops in the study regions based on projected climatic data provided by regional climate models. Secondly, applying crop models to evaluate adaptation options to reduce impacts and take advantage of new sequences technologies based on future climate changes. Third, the effect of climate change on the main pest and diseases in thermophilic crops is based on the sustainable approaches for vegetables protection.

# Probabilistic assessment of agroclimatic effects on winter rapeseed yield in Denmark

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Statistical models could be suitable tools for predicting future impacts under climate variations. Usefulness of such models could vary depending on the generality of the relations used in the model. In this study, data from different locations in Denmark for standard management for a 20-year period from 1992 to 2011 was gathered. Biweekly averages over climatic variables along with soil type, sowing and maturity dates and previous crops were considered as explanatory variables. The non-climatic variables were added to address some of the yield variations that could not be assigned to climatic variability. The LASSO, a shrinkage and selection method for regression was used to select the climatic variables that best explained crop yield responses. Since this analysis was meant for prediction of yield response to climate change, hold-one-out cross validation method, with each year as a “fold”, was implemented in feature selection process. Results show that the statistical model, without any prior knowledge about the crop physiology and the processes, shows the positive effect of temperature around the sowing and flowering that highly complies with our knowledge about the growth of oilseed rape. The negative effect of rain is another significant result of this analysis which could be interpreted as the higher risk of disease. Results imply that coarse sandy soils have a highly negative effect on yield. Later sowing also significantly reduces yield of oilseed rape in Denmark. This statistical approach can be a basis for modelling climate change projection on winter rape yield in Denmark.

# Dry rot of potato tubers – *Fusarium* species data collection

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Dry rot is a disease caused by fungi belonging to genus *Fusarium* (*Ascomycota*). Even up to 60% of potato tubers can rot in storage due to dry rot. Moreover, crop losses caused by poor sprouting of the infected seed tubers can reach 25% (Wharton & Kirk, 2007). Dominating species responsible for dry rot vary in world's regions, most likely depending on the climate and climate changes can affect composition of *Fusarium* spp. populations. The goal of this study is to expand limited knowledge about potato dry rot in Poland, *Fusarium* populations were sampled in three localizations in Poland in 2012 and further sampling is in progress in 2013. Sequences of the short noncoding ribosomal internal transcribed spacer (ITS) regions and translation elongation factor 1- $\alpha$  (TEF) gene amplified in PCR will be aligned with records of identified species in GenBank database.

Using the DNA isolated from pure fungal cultures 45 *Fusarium* isolates were so far identified by TEF gene sequencing. The most frequently occurring species in the potato dry rot samples was *F. oxysporum* (26 isolates). As additional markers genes engaged in mycotoxin production were applied. Since only some of *Fusarium* species are capable of synthesizing particular toxins (Batur-Cieśniewska & Suchorzyńska, 2011), these markers will be a good tool for characterizing the obtained fungal cultures and double-checking the accuracy of species identification.

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# Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa

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Multiple cropping systems provide more harvest security for farmers, allow for crop intensification and furthermore influence ground cover, soil erosion, albedo, soil chemical properties, pest infestation and the carbon sequestration potential. We identify the traditional sequential cropping systems in ten sub-Saharan African countries from a survey dataset of more than 8600 households. We find that at least one sequential cropping system is traditionally used in 35 % of all administrative units in the dataset, mainly including maize or groundnuts. We compare six different management scenarios and test their susceptibility as adaptation measure to climate change using the dynamic global vegetation model for managed land LPJmL. Aggregated mean crop yields in sub-Saharan Africa decrease by 6 % to 24 % due to climate change depending on the climate scenario and the management strategy. As an exception, some traditional sequential cropping systems in Kenya and South Africa gain by at least 25 %. The crop yield decrease is typically weakest in sequential cropping systems and if farmers adapt the sowing date to changing climatic conditions. Crop calorific yields in single cropping systems only reach 40-55 % of crop calorific yields obtained in sequential cropping systems at the end of the 21<sup>st</sup> century. The farmers' choice of adequate crops, cropping systems and sowing dates can be an important adaptation strategy to climate change and these management options should be considered in climate change impact studies on agriculture.

# Climate change impact assessment for four key crops in the Flemish Region, Belgium

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We assessed the impact of changes in climate and CO<sub>2</sub> concentration ([CO<sub>2</sub>]) towards 2050 on four key crops (winter wheat, maize, potato and sugar beet) in the Flemish Region, Belgium with process-based crop models. Scenarios of future local-scale climate data were constructed for the coastal and inland area of the Flemish Region by downscaling climate signals from two ensembles of global (from the Coupled Model Intercomparison Project (CMIP3)) and regional climate models (from the EU-ENSEMBLES project (ENS)) by the stochastic weather generator LARS-WG. All models projected temperature increases but the CMIP3-based scenarios were generally more pronounced than the ENS-based scenarios. Precipitation changes tended towards more wetter winter and drier summers. The climate projections were used as input in the AquaCrop and Sirius models. Even though impacts vary among crops, environment and projected climatic changes, there are clear trends. For mean crop production, positive effects can dominate over negative ones. Elevated [CO<sub>2</sub>] benefits productivity of C3 crops and counteracts potential negative effects of supra-optimal temperatures and droughts. Maize benefits less from elevated [CO<sub>2</sub>] than the C3 crops and suffers from drought stress under the projected climatic changes. Management adaptation (including shifted sowing and late-maturing cultivars) shows additionally potential to augment the mean production level of spring-sown crops. Yet, both climatic changes and adapted management affect the soil water balance negatively (more droughts and higher crop vulnerability) and decrease interannual yield stability, mostly for spring-sown crops. Only for winter wheat, the soil water balance and interannual yield stability are less affected.

# Climatic conditions yielding of maize in Poland in the period 1971-2010

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Until recently, the deficiency of heat was the limiting factor the maize yield in Poland. Improvement of thermal conditions resulted in the maize is grown not only in southern but also in the northern Poland. Increased of cultivation area meant that maize has become one of the most important crops. Higher temperature favorable for maize has occurred with a greater climate variability. This results in more frequent droughts, which can be a limiting factor in the maize yield. Assessment of weather parameters determining the yield, is possible after analyzing the meteorological conditions using models describing the impact of weather on the yield. Statistical models describe a function of regression relationship between weather conditions and yields.

Aim of the study was the evaluation of influence climate conditions on the maize yield in Poland, in the years 1971-2010. The research was based on the statistical-empirical models for maize yield developed in IUNG-PIB.

In the analysis, the years in which maize yields were lower or higher than the average multiannual were defined. In addition, spatial diversities of weather indices were characterized the in years with large declines in crop yields, and the factors having the greatest influence on the resulting weather indicators.

The conducted analysis shows that the years of unfavorable weather conditions for maize yielding in period 1971 - 2010 were: 1974, 1980, 1994 and 2006. The most beneficial were 1997 and 2007. The weather condition in that years allowed to obtain higher yields compare to average multiannual.



**Posters:**

**Uncertainty, scaling**

# A Comparison of Optimal Nitrogen Fertilisation Strategies Using Current and Future Stochastically Generated Climatic Conditions

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In the context of nitrogen (N) management, since 2002, the Belgian Government transposed the European Nitrate Directive 91/676/EEC in the Belgian law, with the aim to maintain the productivity of Belgian's farmers while reducing the environmental impacts associated to excessive N management. The current Belgian's farmer practice consists to fertilise 180kgN.ha<sup>-1</sup>, split in three equal doses, applied respectively at tillering, stem extension and flag leaf stages.

A feasible approach to cope with climatic uncertainty in crop modelling is to quantify the risk associated to historical climate records, which, however, are often not numerous. Therefore, the main purpose of this research is to use a high number of stochastically generated climatic conditions to supply weather inputs and perform probabilistic risk assessment on the corresponding finely discretised yield distributions.

In particular, this research aims to determine the optimal N strategies under current and future climatic conditions. Different N protocols, that consist to maintain 60kgN.ha<sup>-1</sup> at tiller and stem extension while applying increasing level of N at flag leaf, were evaluated and intercompared. Actual and, as an anticipation to climatic changes, hypothetic future climatic conditions corresponding to IPCC's A1B scenario were derived. Finally, in front of the European environmental requirements, two types of farmer's behaviour were analysed with the objective to find the N strategy that respectively maximises the expected yields or that optimises the revenue while limiting the potentially leachable soil N after harvest.

The LARS-WG and STICS models were respectively used to generate the synthetic time-series and simulate yield elaboration.

# Responses of soil N<sub>2</sub>O emissions and nitrate leaching on climate input data aggregation: a biogeochemistry model ensemble study

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Numerical simulation models are increasingly used to estimate greenhouse gas emissions at site to regional and national scales and are outlined as the most advanced methodology for national emission inventory in the framework of UNFCCC reporting. Process-based models incorporate the major processes of the carbon and nitrogen cycle of terrestrial ecosystems systems and are thus considered to be widely applicable at various spatial and temporal scales. The definition of the spatial scale of simulation is determined by the simulation objectives. GHG emission reporting requests spatially and temporally aggregated information whereas for the assessment of mitigation options on hot spots and hot moments of soil N<sub>2</sub>O emissions a high spatial simulation resolution is required.

Low resolution simulations require less effort but important details could be lost during data aggregation. Furthermore, low resolution simulations are associated with a high level of uncertainty from different sources. Both aggregation effect and uncertainty will be propagated with the simulations. This paper aims to study the aggregation effects of climate input data on the simulations of soil N<sub>2</sub>O emissions and nitrate leaching by

comparing different biogeochemistry models. Using process-based models we simulated a 30-year continuous cropping system for two crops under water- and nutrient-limited conditions with 1 km spatial resolution. We aggregated the climate data to 10, 25, 50, and 100 km and repeated the simulations. In a first step, the soil input data was kept homogenous. We calculated the N<sub>2</sub>O emissions and nitrate leaching on all scales. First results will be presented and discussed.

# Impact of soil properties regionalization methods on regional wheat yield in southeastern Norway

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Soil factors including texture and water holding capacity can have a large impact on crop productivity. The handling of these factors is therefore critical in estimations of regional crop yield potential. The goal of this study was to determine the regional spring wheat yield potential and inter-annual yield variability for Akershus and Østfold Counties in southeastern Norway, using different descriptions of the regional soil characteristics. This region is characterized by highly variable soils. Four soil profile extrapolations were made, where the whole region was represented by 77, 15, 5 and 1 profile respectively. In the extrapolations, soil physical properties including texture, organic matter and water holding capacity were taken into account. Spring wheat growth and yield were simulated with the CSM-CERES-wheat model in DSSAT v4.5 for each of the soil profiles. For the wheat simulations, daily weather data, which represented two periods (1961-90 and 2046-65) and the location, Ås (59 41'N; 10 47'E), Akershus County, were generated using the LARS-WG tool. The weather data for the future period were an average of 15 global climate models and represented the greenhouse gas emission scenario A1B from the Intergovernmental Panel on Climate Change. Crop management represented common regional practices. Three cultivars, Bjarne, Demonstrant and Zebra were included and calibrated against field trials to determine if the soil extrapolation effect on the regional grain yield varied among cultivars. Preliminary results show large variations in average yield and inter-annual yield variability among the soil extrapolations for some of the combinations of weather data and cultivars.

# Impact of soil properties regionalization procedures on regional timothy dry matter yield and variability in southeastern Norway

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Soil physical properties and their interactions with the weather and other environmental variables can have large impact on crop growth and productivity. Spatially heterogeneous soil characteristics are an important contributing factor to the intra-regional crop yield variability in many agricultural regions. Crop models designed for field scale simulations together with different regionalization techniques can be used to assess regional crop yield potential. The goal of this study was to determine the regional timothy yield and its inter-annual variability in Akershus and Østfold County in southeastern Norway, using different extrapolations of soil profiles to describe the regional soil characteristics. Timothy (cv Grindstad) was simulated with the BASGRA model using four soil extrapolations, with 77, 15, 5 and 1 soil profile, respectively to represent the region. Daily weather data that were input to the simulations represented Ås, Akershus County and two periods (1961-1990 and 2046-65), and were generated using the LARS-WG tool. For the future period, an average of 15 Global Climate Models and the greenhouse gas emission scenario A1B from the Intergovernmental Panel on Climate Change were used. For each period, timothy was simulated for 30 years of independent weather data to obtain a representative variation in the simulated yields. Simulated crop management represented normal practices for the region. Preliminary results show large differences in regional yield potential and variability among the soil extrapolations. These results can be useful when assessing the appropriate level of soil description in further analyses of the regional timothy yield potential in southeastern Norway.

# Crop-Climate Ensemble scenarios to narrow uncertainty in the evaluation of climate change impacts on agricultural production

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It is unanimously agreed upon that climate variability and change have great impacts on natural systems particularly rainfed agriculture. However, the rate and the sign of the impacts are still full of discrepancies due to cascades of uncertainties. The sources of uncertainty include *i)* lack of accurate crop-soil management information, *ii)* crop model sensitivity, *iii)* divergence of climate models on rainfall distribution, *iv)* linear bias propagation between climate/crop models. The objective of this research is to narrow the rate of uncertainty in the evaluation of climate change impacts on millet and maize growth and production through a wide range of consistent and practical scenarios. The latter include the use of multi-model and statistical climate change envelop on precipitation and temperatures, crop management practices such as different seedling densities, several fertilization levels, early/late sowing dates and soil types at 64 well-distributed experimental stations over West Africa as a case study. The outputs of the ensemble scenarios simulations exhibit a strong convergence of rates and signs in the estimation of the impacts of climate variability and change over the study area. At stations where warming rate is below 2degrees rainfall and optimum crop management practices help compensate loss in production. However when warming rate is much more above 2degrees loss in production is higher. These results suggest a unified evaluation of impacts on rainfed and non photoperiodic millet and maize cultivars grown in the Western Sudan-Sahel of West Africa.

# Sensitivity assessment of the use of aquacrop model in Embu Kenya

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Sensitivity using Aquacrop (Ver. 4 of 2012) simulations in three locations in Kenya were assessed to identify biomass and grain yield variations between three locations using three maize varieties grown between 2000 and 2001 seasons. Historical meteorological data (rainfall, min and max temperatures and solar radiation for Embu RRC 1980-2010) were used to calculate ETO in the ETO calculator of Aquacrop model. Simulations were then run with this historical data and the simulated yields compared to observed yields. Simulated biomass and yields of H511 and Katumani were consistently lower than observed while they varied in the H513 variety.

Biomass and grain yields were optimal at medium plant populations while increasing fertility increased biomass yields consistently. Grain yields however tended to zero as the fertility stress was made severe. Early planting had a clear advantage over subsequent planting dates. Increasing temperatures by 1, 3 and 5 degrees centigrade with both 10% rainfall increment and 10% rainfall reduction increased biomass and grain yields to an optimum at 3 degrees before reducing it at 5 degrees.

The model can be appropriately used to test sensitivities of planting dates which reflect dwindling moisture regime as the crop grows, temperature changes and any rainfall scenarios that are likely to occur in this area. Sensitivity to fertility stresses are also clear but adjustments have to be made to the model to accept actual nutrient amounts.

# Measuring the impact of climate and yield data errors on regional scale crop models

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Projections of future food production and food security are in part underpinned by an understanding of the relationship between climate and crop productivity. Our knowledge of crop physiology comes from controlled experiments at the field scale. However, climate models have skill at the regional scale, where our inability to perform controlled experiments leads to a greater reliance on modelling studies. Regional scale crop models have been developed as principled frameworks for upscaling field scale knowledge to the regional scale. These models aim to capture the key crop-climate processes; an aim which is contingent on the quality of the available crop yield observations and climate data. Importantly, what constitutes 'quality' here is not necessarily a matter of high temporal/spatial resolution, but of whether the model-significant statistics of the input data (such as monthly mean temperature or cumulative seasonal precipitation) accurately reflect reality.

Both yield observations and climate model output have known systematic errors, but the effects of these errors on regional scale crop models is not well understood. Here we present work which investigates how such errors impact regional scale crop models by (1) introducing errors to rainfall, temperature and yield observations at various temporal scales, and then (2) measuring the impact that these errors have on the skill of hindcasts made by the GLAM crop model. We find that errors in inter-annual variability of seasonal precipitation and temperature significantly impact crop model skill, and that errors in yield observations can account for increases of more than 140% in model RMSE.



**Posters:**

**Model improvements**

# BioSTAR, a New Biomass and Yield Modeling Software

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BioSTAR (**B**iomass **S**imulation **T**ool for **A**gricultural **R**esources) is a new crop model which has been developed for the assessment of agricultural biomass potentials. BioSTAR is kept simple and can thus be used by scientists as well as non-scientific users, e.g. staff in planning offices or farmers. BioSTAR is written in Java and uses an MS Access database connection for data storage. This enables fast editing and organization of the data sources needed to run a crop simulation. The number of sites which can be processed as a batch is only limited by the maximum size of a MS database (2 GB). The model simulates single or multiple year crop growth with total biomass production, evapotranspiration, soil water budget and nitrogen budget. BioSTAR's main growth engine is carbon based, but an RUE and two transpiration based growth engines were added at a later point. Up to date (11/2013), the model has been tested for several cereals, canola, maize, sorghum, sunflower and sugar beet. A Comparison of simulated and observed biomass yields has rendered good results with errors (RMSE) ranging from below 10% (winter wheat, n= 102) to 18.6 % (sunflower, n=8). Simulations can be made with limited soil data (soil type or texture class) and limited climate data. To date the model has been used for yield predictions in northern Germany, but comparisons with output data of the model AquaCrop have shown good performance in arid and semi-arid climates.

# Using a dynamic multi-scale model that links from Arabidopsis gene networks to phenology and carbon metabolism

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Plant models are commonly used for predicting crop growth and development. In contrast, modelling is more recently adopted in fundamental biology for understanding genotype X environment interaction. This has been facilitated by advances in molecular and systems biology, where events at intracellular to multicellular scales are linked to the genetic and genomic levels. Using a modular approach in the laboratory model species *Arabidopsis thaliana*, we have developed a multi-scale model by integrating four existing modules without re-calibration: 1) an ODE gene-circuit module of the photoperiod pathway; 2) a photothermal module that predicts flowering time (both at whole-plant level); 3) a process-based module of rosette-level photosynthesis, sugar/starch metabolism and sugar partitioning; and 4) a functional-structural module describing source-sink relations among organs and rosette structure for light interception. Our Framework Model therefore simulates growth at the single organ and whole-plant levels by incorporating the effects of endogenous control, environmental signalling and plant architecture. Using hourly input data of CO<sub>2</sub> concentration, temperature and light intensity, our model accurately predicted individual leaf biomass and population-level net ecosystem production for three *Arabidopsis* varieties with a median nRMSE of 17.4%. Model performance for different photoperiod conditions was improved when new biological understanding on the timing of starch degradation was incorporated, demonstrating the advantage of using a model species. In conclusion, our results demonstrate that models from crop science, systems biology and ecology can readily be synergised using our modelling platform, to improve biological understanding of this model species and potentially transferred to crops.

# **Institutionalization of agricultural knowledge Management System for Marginalized Rural Farming Community**

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Agricultural technology has led to a process of marginalization. A weak agricultural economy producing insufficient food is frequently associated with a weak or nonexistent democracy and can lead to migration, social unrest, an unhealthy as well as unproductive labor force, and mismanagement or abuse of environmental resources. The key framework for addressing these problems is Agricultural Knowledge Management System (AKMS), consisting of the organizations, sources of knowledge, methods of communication, and behaviors involved in the agricultural process. As farmers make critical decisions throughout the year, a typical household will rely on its' own accumulated experience and the support of local organizations. Thus, farmers were in need of a permanent solution to overcome these barriers to production. By applying a participatory approach called Knowledge Brokering (linking rural farmers with the national and international researchers) the farmers' community could develop a self-driven system to manage all those crucial issues. Designing ICT-enabled knowledge flows between these actors in any specific case requires careful consideration of the types of ICTs that are accessible by each group and the technological and conceptual packaging of information so that it can flow effectively. Effective ICT deployment explicitly considers the appropriate interfaces between the digital and non-digital worlds, so that those without access to ICTs can still benefit from an improved local information environment. These farmers need local support groups that will act as brokers between the available knowledge system and the individual needs of farming households.

# **RDAISY: a comprehensive modelling framework for automated calibration, sensitivity and uncertainty analysis of the DAISY model**

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The development of process-based models has provided methods to explain how changing climate affects crop productivity and hydrological and nitrogen dynamics. These models often contain a large set of parameters and are therefore often considered as over-parameterized. Additionally, some of the parameters whose values are uncertain might be a major source of uncertainty on the model predictions. Consequently, the estimation of the uncertain parameters from experimental data is an important step and model performances depend for a large part on the accuracy of the parameter estimates. In general, finding an accurate estimate for all the parameters is very time consuming and reduction of the parameter space is therefore required. Several approaches for addressing model calibration, parameter uncertainty and sensitivity analysis have been proposed and have recently been implemented into various R packages. To our knowledge, no prior attempts have been made to automate the calibration, sensitivity and uncertainty analysis of the DAISY crop growth model. In this work, we therefore present a comprehensive modelling environment for DAISY implemented in R. It includes automated calibration, sensitivity, and uncertainty analysis. The approach adopted here makes use of a number of pre-existent R packages (FME, hydromad). Our motivation is that such framework can reduce programming efforts necessary for model calibration and routine time for visualization and data manipulation by taking advantage of R's extensive statistical, mathematical, and visualization packages. To demonstrate how the RDAISY package works, a case study from the exercises provided with DAISY was used and can easily be reproduced.

# AgroC – Development and first evaluation of a model for carbon fluxes in agroecosystems

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Agroecosystems are highly sensitive to climate change. To predict and describe the processes, interactions and feedbacks in the plant-soil-system a model accounting for both compartments at an appropriate level of complexity is required.

To describe the processes of crop development, crop growth, water flux, heat transport, and carbon cycling three process models were coupled and adjusted to each other: the one-dimensional soil water, heat and CO<sub>2</sub> transport model SOILCO<sub>2</sub>, the carbon turnover model RothC, and the plant growth model SUCROS. Thereby, the main focus was on the full description of the CO<sub>2</sub> flux into the atmosphere via plant and soil processes and finally on simulating the net ecosystem exchange. Additionally, the model was modified to work at the temporal resolution between 0.5 and 24 hours.

For a first model evaluation a winter wheat data set obtained within the TERENO Rur catchment (North Rhine-Westphalia, Germany) during 2009 was used. For model initialisation soil carbon fractions were available. Plant specific parameters and soil properties were taken from literature. Measured soil water contents, soil temperatures, crop measurements, autotrophic, and heterotrophic chamber-based respiration measurements were used for validation and calibration.

The coupled agroecosystem model AgroC described the crop development and heat transport well. Minor adjustments had to be made for carbon cycling, and to adapt the model to site specific conditions the soil hydraulic coefficients for soil water transport had to be determined by inverse modelling.

# **BioMA – An operational crop modelling platform to simulate the impact of climate change and adaptation measures on production**

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BioMA (Biophysical Models Applications) is a software platform developed at the Joint Research Centre and continuously refined in partnership with CRA-CIN and the University of Milan. BioMA serves analyzing, parameterizing, running and spatializing the output results of biophysical models. The BioMA platform currently comes with a library of crop models: CropSyst, WOFOST, WARM, STICS or CANEGRO and many other modules dedicated to the modelling of soil water balance, biotic and abiotic stresses, climate indices or agro-management practices. A set of tools are included in BioMA to facilitate crop modelling activities: data viewing, calibration, and model programming. A key aspect of the framework is its modularity, which allows the implementation of new components and their coupling with already existing models as well as the connection with various databases. The object-oriented breakdown of previous monolithic models eases model testing, improvement, and tailoring for various applications. BioMA is also a platform of interest for model intercomparison: Input and output data handling is transparent for all crop models implemented in BioMA so that models or even single algorithms can be compared with limited effort. A BioMA-based WOFOST implementation will become the new crop model engine within the operational MARS Crop Yield Forecasting System at JRC for operational crop monitoring and yield forecasting along the growing season over Europe. BioMA is also used to assess the impact of climate change and adaptation measures in various projects and study area: Basal in Cuba, E-Agri in Morocco and China, CAPRESE and ULYSSES in Europe.

# Bayesian method for predicting and modelling winter wheat biomass

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The objectives of this paper are threefold. The first objective is to propose to use an Improved Particle Filtering (IPF) based on minimizing Kullback-Leibler divergence for crop models' predictions. The performances of the proposed technique are compared with those of the conventional Particle Filtering (PF) for improving nonlinear crop model predictions. The main novelty of this task is to develop a Bayesian algorithm for nonlinear and non-Gaussian state and parameter estimation with better proposal distribution. The second objective is to investigate the effects of practical challenges on the performances of state estimation algorithms PF and IPF. Such practical challenges include (i) the effect of measurement noise on the estimation performances and (ii) the number of states and parameters to be estimated. The third objective is to use the state estimation techniques PF and IPF for updating prediction of nonlinear crop model in order to predict winter wheat biomass. PF and IPF are applied at a dynamic crop model with the aim to predict a state variable, namely the winter wheat biomass, and to estimate several model parameters. Furthermore, the effect of measurement noise (e.g., different signal-to-noise ratios) on the performances of PF and IPF is investigated. The results of the comparative studies show that the IPF provides a significant improvement over the PF because, unlike the PF which depends on the choice of sampling distribution used to estimate the posterior distribution, the IPF yields an optimum choice of the sampling distribution, which also accounts for the observed data.

# Can a global dynamic vegetation model be used for both grassland and crop modeling at the local scale?

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We report on the use of a dynamic vegetation model, CARAIB, within two modeling exercises in the framework of MACSUR. CARAIB is a physically-based, mechanistic model that calculates the carbon assimilation of the vegetation as a function of the soil and climatic conditions.

Within MACSUR, it was used in the model intercomparison exercises for grassland and crop modeling, in the LiveM 2.4 and CropM WP4 tasks, respectively. For grassland modeling, blind model runs at 11 locations were performed for various time ranges (few years). For crop modeling, a sensitivity analysis for building impact response surfaces (IRS) was performed, based on a bench of model runs at different levels of perturbation in the temperature and precipitation input data over 30 years. For grassland modeling, specific management functions accounting for the cutting or grazing of the grass were added to the model, in the framework of the MACSUR intercomparison. Initially developed for modeling the carbon dynamics of the natural vegetation, CARAIB was already adapted for crop modeling but further modifications regarding the management, i.e., yearly-dependent sowing dates, were introduced.

For grassland modeling, simulation results will be further intercompared with other modeling groups. For crop modeling, building the IRS over 30 years permitted to assess the sensitivity of the model to temperature and precipitation changes. So far, the participation of CARAIB in the intercomparison exercises within MACSUR resulted in further improvements of the model by introducing new functionalities.

# Describing Differences in Wheat Cultivars: Model Parameterisation

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Crop models have an important role in crop system management and as research tools, through the predictions they produce concerning crop growth and development over time. For accurate predictions they require calibration. However, there is no set methodology for this. Calibration is often done manually, and there has been little work on employing the automated fitting procedures that are available. In this work, a comparison of parameter estimation methods was made for a wheat model using a dataset including two UK and two French sites, with 16 wheat cultivars grown over two years under two contrasting nitrogen treatments. The work explored the use of manual tuning and algorithms in parameter estimation, with the aim of establishing whether wheat cultivar differences can be effectively resolved using these methods.

# IC-FAR: Linking Long Term Observatories with Crop Systems Modeling For a better understanding of Climate Change Impact, and Adaptation Strategies for Italian Cropping Systems

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IC-FAR is a new project (2013-2016) funded by the Italian ministry of Research University and Education. IC-FAR aims to use datasets from Italian long term experiments to assess the reliability of the available cropping system models over a wide range of Mediterranean environments and cropping systems. The selected models will be used for scenario and uncertainty analyses for Italian cropping systems vs near-future climate change. The field datasets will be made available from the main long-term field experiments running on in seven sites in Italy: Turin, Padua, Bologna, Ancona, Pisa, Perugia, Foggia. The Project's activity is integrated with other European projects such as MACSUR, AgMIP, ANAEE, ESFRI and GRA networks.

The project is structured in 5 workpackages: WP1 will build the common long-term experiment database and a common protocol for data sharing and management which does not exist in Italy so far. WP2 will calibrate, validate and compare the performances of different cropping system models for a wide range of Italian environments. WP3 will perform an uncertainty analysis and design adaptation strategies to future climate change scenarios. WP4 is designed to network with international projects, training and dissemination.

IC-FAR is the first attempt in Italy to connect and coordinate the long-term field experiments with research teams specialized in model development and testing. IC-FAR has the potential to provide new insights on the future of Italian cropping systems and represents a first step towards an integration of available data and to enhance their access to the scientific community.

# Modeling short term grass leys with CATIMO - focus on the nutritive value

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Crop growth models are useful in quantifying the complex interactions between the underlying biochemical growth processes and the environmental factors. In addition, crop growth models allow the estimation of the potential consequences of predicted climate change on grass production and, consequently, to ruminant production that contributes significantly to agriculture in the Northern areas of Europe. Perennial grass models must also cover the second cut because it represents up to 50 % of the annual dry matter (DM) yield. In addition to DM production, it is crucial to simulate the nutritive value of forages because it plays a key role in milk and beef production. Recently, the model CATIMO (Canadian Timothy Model) was modified to simulate the summer regrowth of timothy (Jing et al. 2012) and its nutritive value (Jing et al. 2013) under northern latitudes. This presentation will give a short summary of the work published in these two papers main focus being in estimation of the nutritive value.

# Designing new cereal cultivars as an adaptation measure using crop model ensembles

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To date, crop models have been little used for characterising the types of cultivars suited to a changed climate, though simulations of altered management (e.g. sowing) are often reported. However, in neither case are model uncertainties evaluated at the same time.

Ensemble modelling can provide information on uncertainty in model outputs. Here, a probabilistic approach using multi-model ensembles is presented for evaluating the effectiveness of new crop cultivars under climate change. It comprises a unique combination of crop ensemble modelling with three other methodological elements illustrated for wheat: (i) ideotyping of wheat cultivars for future climates based on an agroclimatic indicator approach used for identifying shifts in risks to be avoided, (ii) impact response surface (IRS) analysis of current and new wheat cultivars under different CO<sub>2</sub> concentrations, and (iii) overlay of resultant IRSs for different time periods with joint probabilities of projected temperature and precipitation to evaluate changing risk.

This novel approach applies a subset of results from a systematic climate sensitivity analysis based on a large ensemble of over twenty wheat models (IRS1), and on agroclimatic indicator analyses with recently refined critical thresholds that suggest severe impacts of future climate change on yields of current wheat cultivars in Europe.

Applying the approach for different soil conditions and projected 2050s climate shows the potential of new cultivars with adjusted management to reduce risks of future climate-

induced crop stress. Results also underline the need for crop model improvements, new experimental data and co-innovation with stakeholders, to better evaluate adaptation options.



# Conference Agenda

## 10 February (Monday)

Arrival of participants

1800- Registration

1900-2100h **Evening Reception:** with scientific and socio-cultural programme

Welcome speeches by:

1. BIOFORSK Research Director (*Nils Vagstad*): Challenges for crop production and food security in a changing climate
2. FACCE MACSUR Hub Coordinators (*Richard Tiffin*): Why Malthus is not the answer to Food Insecurity: Lessons from a not-so-dismal scientist

## 11 February (Tuesday)

830h- Registration available

**900- 1030h** *Opening session (Chair: Frank Ewert)*

900 – 915h Welcome addresses

The Research Council of Norway (*Kristin Danielsen*): FACCE JPI: The importance of knowledge hub for meeting grand challenges

CropM co-ordination (*Reimund Rötter*): Climate change and food security: The role of CropM

915 – 1030h Keynotes

Keynote 1: State-of-the-art and future perspectives of crop modelling for climate risk assessment (*J.R. Porter*)

Keynote 2: Critical Challenges for Integrated Modelling of Climate Change and Agriculture: Addressing the Lamppost Problem (*G. C. Nelson*)

*1030-1100h Refreshments*

1100-1300h *Parallel Session 1*

1.1 Uncertainties in model-based agricultural impact assessments (including entire modelling chain, i.e. from climate via impact to economic /trade modelling) (*Chair: Alex Ruane; Rapporteur: Margarita Ruiz-Ramos*)

*Andy Challinor et al.*: How have uncertainties in projected yields changed between AR4 and AR5?

*Pierre Martre et al.*: Error and uncertainty of wheat multimodel ensemble projections

*Nina Pirttioja et al.*: Examining wheat yield sensitivity to temperature and precipitation changes for a large ensemble of crop models using impact response surfaces

*Alex Ruane*: The AgMIP Coordinated Climate-Crop Modeling Project (C3MP)

*Carlos Angulo et al.*: Investigating the variability uncertainty of soil input data resolution - A multi-model regional study case in Germany

1.2 Impact and adaptation assessment studies at field and farm level (*Chair: K. Christian Kersebaum; Rapporteur: Thomas Gaiser*)

*Taru Palosuo et al.*: Simulating historical adaptations of barley production across Finland

*Chris Kollas et al.*: Improving yield predictions by crop rotation modelling? a multi-model comparison

*Roberto Ferrise et al.*: Using seasonal forecasts for predicting durum wheat yield over the Mediterranean Basin

*Asha Sanjeevani Karunaratne: et al.* Modeling climate change impact and assessing adaptation strategies for rice based farming systems in Sri Lanka

*Jordi Doltra et al.*: Simulating seasonal nitrous oxide emissions from maize and wheat crops grown in two different cropping systems in Atlantic Europe

*1300-1400h*

*Lunch break*

1400-1600h

**Parallel Session 2**

2.1 How to improve modelling of crop growth and development processes including the tightening of links to experimenters? (Chair: Jorgen E. Olesen; Rapporteur: Senthold Asseng)

*Kurt Christian Kersebaum et al.:* A scheme to evaluate suitability of experimental data for model testing and improvement

*Enli Wang et al.:* Causes for uncertainty in simulating wheat response to temperature

*Ann-Kristin Koehler et al.:* Exploring synergies in field, regional and global yield impact studies

*Silvia Caldararu et al.:* A new approach to crop growth modelling: a process-based model based on the optimality hypothesis

*Christian Biernath et al.:* Modeling crop adaption to atmospheric CO<sub>2</sub> enrichment based on protein turnover and use of mobile nitrogen

2.2 Impact and adaptation assessment studies at regional and continental/global  
(Chair: Martin K. van Ittersum; Rapporteur: Andy Challinor)

*Christoph Mueller et al.:* AgMIP's Global Gridded Crop Model Intercomparison

*Stefan Niemeyer et al.:* Assessing climate change impacts and adaptation measures on crop yield at European level

*Hermine Mitter et al.:* Integrated climate change impact and adaptation assessment for the agricultural sector in Austria

*Luca Giraldo et al.:* Representing the links among climate change forcing, crop production and livestock, and economic results in an agricultural area of the Mediterranean with irrigated and rain-fed farming activities

*René Schils et al.:* Yield gap analysis of cereals in Europe supported by local knowledge

1600-1700h

**Reporting back from the sessions and plenary discussion**  
(Chairs: Frank Ewert and Reimund Rötter)

1700-1830h

**POSTER tour**

1930h

*Conference Dinner at Clarion Hotel Royal Christiana*

## 12 February (Wednesday)

- 830-1215h**      ***CropM workshop: Session on Progress and Highlights***  
(Chair: Reimund Rötter; Rapporteur: Taru Palosuo)
- 830-915h      CropM activities – an overview (*CropM Co-ordinators and WP leaders*)
- 915-1030h      First set of short presentations on results of concrete exercises of CropM
- Petr Hlavinka et al.*: Water balance and yield estimates for field crop rotations - present versus future conditions based on transient scenarios
- Holger Hoffmann et al.*: Effects of climate input data aggregation on modelling regional crop yields
- Gang Zhao et al.*: Responses of crop's water use efficiency to weather data aggregation: a crop model ensemble study
- Mikhail Semenov*: Delivering local-scale CMIP5-based climate scenarios for impact assessments in Europe
- 1030-1100h      *Refreshments*
- 1100-1215h      Second set of short presentations on results of concrete exercises of CropM
- Fulu Tao et al.*: Assessing climate impacts on wheat yield and water use in Finland using a super-ensemble-based probabilistic approach
- Mats Höglind et al.*: Breeding forage grasses: simulation modelling as a tool to identify important cultivar characteristics for winter survival and yield under future climate conditions in Norway
- Clara Gabaldon-Leal et al.*: Adaptation Strategies to Climate Change for summer crops on Andalusia: evaluation for extreme maximum temperatures
- Øyvind Hoveid*: An economist's wish list for crop modeling
- 1215-1300 h      *Lunch*
- 1300-1400h      Break-outs for CropM group work (to exchange about specific ongoing studies)(opportunity to tour POSTERS for others)

**1400-1530h**

***Break-out Session on Challenges for Crop Modelling – what steps to take next?***

Dealing with lessons learned from previous conference day (e.g. 4 break-out group sessions)

- 1) Crop rotation modelling and assessing impacts of indirect climate interference with plant growth and production  
(Chair: Marco Bindi; Rapporteur: Chris Kollas)
- 2) Is it possible to improve crop models without new modelling approaches and experiments?  
(Chair: John R. Porter; Rapporteur: Enli Wang)
- 3) Ensemble model simulations, uncertainty analysis  
(Chair: Mikhail Semenov; Rapporteur: Mike Rivington)
- 4) Scaling methods and integration with economic models  
(Chair: Sander Janssen; Rapporteur: Pier Paolo Roggero)

**1530-1545h**

***Refreshments***

**1545-1630h**

***Final Plenary (Chairs: Frank Ewert and Reimund Rötter):***

Reporting back from the sessions and discussion

Wrap-up and closing (with concluding remarks by *M. Banse*)