Summer School 2016

The role of IPM in mitigating pest development under climate change–modelling approaches

Rationale

Climate change, by inducing variability of temperature, rainfall and atmospheric CO2 concentration levels, is likely to impact many agricultural production situations worldwide. In addition to direct impact on crop yield, climate change will also affect biocenosis dynamics. In particular, pests (pathogens, animal pests and weeds) and beneficial dynamics will also be affected, thereby leading to new injury profiles and associated quantitative and qualitative damage to crop production. Given the complexity of the crop-soil-atmosphere-pest-beneficial system, modelling is a key scientific approach to help design more resilient cropping systems to biotic stress, with limited reliance on pesticides.

Objectives

- Present up-to-date knowledge on climate change and its impact on pest dynamics
- Present the conceptual and methodological principles of various modelling approaches
- Illustrate how modelling can be used to help design IPM strategies for future climate scenarios
- Give hands-on experience in a class modelling project that will test IPM strategies under climate change

Lecturers

- Camilla Moonen (SSSA, ENDURE, Local organisation)
- Jean-Noël Aubertot (INRA, ENDURE)
- François Brun (ACTA, ENDURE)
- Daniel Wallach (INRA, AgMIP)
- Til Feike (JKI, ENDURE)
- Mark Szalai (SZIE, ENDURE)
- Jay Ram Lamichhane (INRA, ENDURE)
- Katia Laval (Guest lecturer, Paris University)
- Marcello Donatelli (Guest lecturer, CREA, AgMIP)

Ressources for participants

- Data (climate and pests)
- models: small models from appendices from ZeBook (http://www.modelia.org/moodle/course/view.php?id=61) presented as sheet (2 pages) + adding a few
- Access to the UNISIM, IPSIM, PESTOBSERVER and XPEST platforms

Program

Day 1.

Start	**Duration (min)**	**Climate Change, crops, pests and models**	**Who**
8h30	10	Welcome and introduction to the Summer School	Camilla Moonen
8h40	50	Introduction: presentation of the program, pedagogical objectives, lecturers and participants	Jean-Noël Aubertot
9h30	60	Global warming: certainties and uncertainties. Part 1	Katia Laval
10h30	30	Coffee break	All
11h00	30	Global warming: certainties and uncertainties. Part 2	Katia Laval
11h30	30	Impact of Climate Change on crops	Til Feike
12h00	30	AgMIP and the role of model ensembles in modelling	Daniel Wallach
12h30	60	Lunch	All
13h30	30	Why modelling? Conceptual modelling	Jean-Noël Aubertot
14h00	30	Introduction to system models	Daniel Wallach
14h30	30	Which models for which objectives of IPM in the context of Climate Change?	Jean-Noël Aubertot
15h00	60	Effects of Climate Change on pest development and spread. Implications for IPM	Jay Ram Lamichhane
16h00	30	Coffee break	All
16h30	30	General discussion on the effects of Climate Change on pest dynamic and mitigation	All
17h00	90	Phenology model of insect (carrot Weevil). Description and practical work with R to help design IPM strategies for future climate	François Brun
18h30	0	End of day	

Day 2.

Start	Duration (min)	Methods for modelling + starting projects	Who
8h30	90	Projects: definition of objectives	All
10h00	30	Model evaluation	Daniel Wallach
10h30	30	Coffee break	
11h00	90	Sensitivity and uncertainty analyses	Mark Szalai
12h30	60	Lunch	All
13h30	30	How to get weather and pest data?	François Brun
14h00	30	Dimensional analysis	Jean-Noël Aubertot
14h30	60	Parameter estimation. Part 1	Daniel Wallach
15h30	30	Coffee break	
16h00	60	Parameter estimation. Part 2	Daniel Wallach
17h00	90	Projects: conceptual modelling, planned work, short presentation to all	All
18h30	0	End of day	

Day 3.

Start	Duration (min)	Modelling applications for IPM under CC + Projects + Volterra	Who
8h30	45	Impact of climate change on *septoria tritici* (Septolis). Toward IPM strategies for future climate	Daniel Wallach
9h15	45	Weed modelling example using lattice	Mark Szalai
10h00	30	The qualitative modelling IPSIM platform to predict injury profiles. Application to disease management under future climate	Jean-Noël Aubertot
10h30	30	Coffee break	All
10h30	45	How to use lattice models, spatial and temporal models to help design IPM strategies for future climate	Mark Szalai
11h15	75	Projects: group work	All
12h30	60	Lunch	
13h30	90	Projects: group work	All
15h00	150	Visit of the Etruscan city of Volterra	All
17h30	120	Free time in Volterra	All
19h30	150	Social dinner	All

Day 4.

Start	Duration (min)	Crop and pest interactions + Projects.	Who
8h30	30	Integrating pests into crop models	Til Feike
9h00	60	Integrating pests into crop models	Marcello Donatelli
10h00	30	The XPEST modelling platform to design online damage models	Jean-Noël Aubertot
10h30	30	Coffee break	
11h00	60	2nd model example. SEIR model of disease (brown rust). Description of the Zadoks model, large scale simulation and practical work with R to help design IPM strategies for future climate	François Brun
12h00	30	Integration and extensibility: practical aspects in software design and development	Marcello Donatelli
12h30	60	Lunch	
13h30	120	Projects: group work	All
15h30	30	Coffee break	
16h00	150	Projects: group work	All
18h30	0	End of day	

Day 5.

Start	Duration (min)	Project presentations and summer school wrap-up session	Who
8h30	105	Presentation of results of the modelling projects	All
10h15	15	Coffee break	All
10h30	60	Presentation of results of the modelling projects	All
11h30	30	Wrap-up session of the summer school	All
12h00	45	Lunch	All
12h45	0	Departure from Volterra and arrival at Pisa Airport 14.15	All

Day 1.

Welcome and introduction to the Summer School
Camillla Moonen
This session will welcome participants and lecturers and provide the background and context of the summer school.

Presentation of the program, pedagogical objectives, lecturers and participants
Jean-Noël Aubertot
The general objective of this session is to present an overview of the summer school and its pedagogical objectives. Each lecturer will introduce him/herself in terms of background and area of expertise. Each participants will also introduce himself/herself and will present his/her expectations with regard to the summer school.

Global warming: certainties and uncertainties, parts 1 and 2
Katia Laval
The increase of greenhouse gas concentrations in the atmosphere induces a global warming of the earth. Following the AR5 report, the consequences of this warming are studied by analyzing the results of simulations performed with general circulation models. Those results are compared with observations recorded since decades.
The evolution of temperatures, precipitations, and some extreme events will be described, as well as the uncertainties related to inherent approximations in global models. I will also mention the difficulties arising from natural variability of the climate and model resolution to detect climate changes.

Impact of Climate Change on crops
Til Feike
Climate change (CC) is a major concern for sustainable crop production and challenge for future global food security. This presentation aims at acquainting the ENDURE SC participants with the current state of knowledge, the applied methods, as well as the limitations and uncertainties related to evaluating the impact of CC on crop production. CC is expected to exert negative as well as positive effects on crops, depending on the production region and crop types. While temperate regions are generally expected to benefit from global warming, crop production in tropical and Mediterranean regions is most likely going to suffer from the consequences of CC. Increasing CO_2-levels act positive while increasing occurrence of extreme events (e.g. heat and drought) acts negative. For the impact assessment of CC, crop models are indispensable tools. The presentation will also introduce the limitations and uncertainties of the approach. Finally, the crucial aspect of evaluating adaptation options and examples of empirical evidence of the relation between climate (change) and crop yields will be presented.

AgMIP and the role of model ensembles in modelling

Daniel Wallach

Description of AgMIP (Agricultural Intercomparison and Improvement Project), its objectives and organization. The importance of model intercomparison projects in providing new information about model uncertainty, in providing better predictors and as a vector of collaboration between modeling groups in multiple disciplines (crops, climate, economics, pests and diseases). A brief review of some of the AgMIP projects, with emphasis on the multi-model estimation of the effect of climate change on crop production at field or regional level.

Why modelling? Conceptual modelling

Jean-Noël Aubertot

Modelling is a common approach used in all scientific fields. First of all, this lecture will present the various objectives of modelling activities. It will then focus on the essential role of conceptual modelling when conducting a modelling project. A method to help design conceptual models will be presented.

Introduction to system models

Daniel Wallach

Definition of a system, of a model, of a mathematical model, of a mathematical system model. Some examples of simple mathematical system models. The components of a mathematical system model – state variables, explanatory variables, parameters. The role and importance of each component. The difference between an empirical model and a systems model. Advantages and disadvantages of each.

Which models for which objectives of IPM in the context of Climate Change?

Jean-Noël Aubertot

This presentation will address the main objectives of models for IPM. In addition, the main modeling methods used in the field of crop protection will be briefly presented. The new modeling objectives due to Climate Change will be highlighted.

Effects of Climate Change on pest development and spread. Implications for IPM

Jay Ram Lamichhane

Climate change is increasingly perceived as one of the major constraints that limit agricultural productivity. Climate change causes crop losses either directly or indirectly. Direct effects regard damages due to flooding, storms or elevated levels of temperatures or drought events while indirect effects are exercised via altered distribution levels of crop pests (animal pests, pathogens and weeds) including pest range shifts. On the other hand, climate change is likely to have beneficial effects on growth and development of certain crops which also means higher amount of available plant biomass favorable for certain pests to develop (biotrophic pathogens in particular). The real impact of climate change at global level however is still uncertain and likely variable from one region to another. Overall, it is difficult to predict effects of climate change, especially when long-term datasets from the past are lacking, thereby hindering potential development and testing of predictive models for the future. However, our knowledge about plant-pest interactions, population genetics of pests and crops, and recent examples of overwhelming establishment of new pests in a given region provides insights into how climate change may affect pest incidence and severity. This presentation attempts to: i) provide examples of pest populations which have been established across regions previously considered detrimental for their survival and associated yield losses; ii) highlight that climate change also has positive effects on crop production across certain geographic areas, and iii) discuss how climate change will impact the development and adoption of integrated pest management (IPM) practices.

General discussion on the effects of Climate Change on pest dynamic and mitigation

All. Chairman: Daniel Wallach

The aim of this general discussion will be to share reflexions and experiences among participants and lecturers on Climate Change on pest dynamic and mitigation

Phenology model of insect (carrot Weevil). Description and practical work with R to help design IPM strategies for future climate

François Brun

A very common variable used in agronomy and in crop protection is thermal time. Phenology models predict timing of events base on thermal time. For crop protection, it is often used to calculate the development of pests such as insects, whose development depends on the temperature of their environment.

In this practical work, we will consider Carrot Weevil (*Listronotus oregonensis*) that develops only when temperature is above a development threshold of 7.0 °C. We will write the code in the R programming language using loops, conditions and functions of this simple model. Thus, participants will learn to build a simple model based on differential equations and to run simulations for future climate scenarios.

Day 2.

Projects: definition of objectives

All. Chairman: Jean-Noël Aubertot. Secretary: Jay-Ram Lamichhane

The objective of this session is to define the objectives of group projects that will be conducted until the last day of the summer school. Participants will be invited to propose objectives for modelling projects focusing on mitigation of pest development under climate change. Lecturers will ensure that the proposed objectives are feasible within the given timeframe. *Ad hoc* datasets or online resources will be provided. Participants will be free to use different modeling tools: the R language, or one of the UNISIM, IPSIM or XPEST modeling platforms. Participants will prepare short presentations to describe the objectives of their projects, the method foreseen and the expected results. These presentations will be given at the end of the day.

Model evaluation

Daniel Wallach

The difference between evaluation (how well a model performs) and validation (whether the model is a true representation of reality). Evaluating model goodness-of-fit. Mean squared error of prediction (MSEP) – a criterion of model predictive accuracy. The difference between predictive accuracy and goodness-of-fit. Estimating MSEP. A second approach to evaluation, based on model uncertainty. Estimating MSEP based on model uncertainty. Comparison of the two approaches to model evaluation.

Sensitivity and uncertainty analyses

Mark Szalai

Simulation models often use literature values as parameters, or input variable values. However, in many cases, other values can be considered for the model. Moreover, one can remark that "…most simulation models will be complex, with many parameters, state-variables and non linear relations. Under the best circumstances, such models have many degrees of freedom and, with judicious fiddling, can be made to produce virtually any desired behaviour…" (Hornberger and Spear, 1981). Hence, the simulations are using distributions of inputs instead of fixed, say, most likely values, and this results in variability, often referred as uncertainty, of the output.

To identify the source of the output uncertainty, different sensitivity analysis measures can be used. Many modellers use simple screening technique such as OAT (one factor at a time), which can be criticised as the majority of the input space remain uncovered. Global sensitivity analysis tools can study the entire input space to identify the key input factors according to their account for the variance of the model output. However, the systematic cover of the input space (brute force method) can cost too much in processor time. Therefore, randomised sampling of the input space is often considered. Totally random sequences for more than 7-10 dimensions, i.e. models with more than 7-10 input factors, can cause high discrepancy. Thus, quasi-random, low-discrepancy sequences, e.g. Sobol-sequence should be used for the analysis. This approach also works well with empirical distribution of input factors. The following proposal will be presented: generating quasi random sequences and using them to run models with several input factors; then calculate one or two sensitivity indices.

How to get weather and pest data?

François Brun

Modelling projects require datasets on past and future climate scenarios. In addition, long term observations on pests (animal pests, weeds and plant pathogens) are needed. The general objectives of this presentation is to give access to online resources with regard to weather and pest data. To this end, a number of useful databases and possibilities to retrieve relevant weather and pest data useful for simulation studies will be highlighted during the presentation.

Dimensional analysis

Jean-Noël Aubertot

Dimensional analysis is a method for comparing the dimensions of the physical quantities occurring in each term of an equation to better understand it and to check potential errors. In addition, it can be used to find relationships between quantities involved in a problem without having to solve the problem completely. After presenting the conceptual bases and a simple method to conduct dimensional analyses, participants will have to roll up their sleeves to solve several problems. Mastering dimensional analysis is a powerful way to limit errors when designing new models and to increase the understanding of existing simulation models.

Parameter estimation

Daniel Wallach

Parameter estimation, parts 1 and 2

Introduction to parameter estimation. A standard statistical approach to parameter estimation – ordinary least squares (OLS). The assumptions behind OLS. How to know if the assumptions are satisfied, and what to do if that isn't the case, with particular emphasis on the case of system models. The R function for OLS. A different approach to parameter estimation – a Bayesian approach.
The second part will be a hands-on exercise, where R is used to calculate the OLS parameters for a simple problem.

Projects: conceptual modelling, planned work, short presentation to all

All. Chairman: Til Feike

After reflexion conducted in groups at the beginning of the day, this session aims at sharing the objectives of the modelling projects, along with the foreseen method and the expected results.

Day 3.

Impact of climate change on *septoria tritici* (Septolis). Toward IPM strategies for future climate

Daniel Wallach

Description of SeptoLIS, a commercial mathematical system model for Septoria blight. Uses of the model, for current guidelines for treatment and for evaluating the effect of climate change. The parameter estimation problem for this model and the available data. Applying a Bayesian approach to parameter estimation for this problem. Set-up of the calculation and analysis of the results.

Weed modelling example using lattice

Mark Szalai

To simplify complex spatial arrangement of the modelled system, a lattice model can be a helpful tool. Competition of plant species can also be modelled with lattice models, an introductory example will be covered using cellular automata. The cell update rules depend on the state of the neighbouring cells. Then, step by step, more specific agricultural situation, i.e. clear crop-weed relationship and weed management measures will be added. Moreover, models for weed life cycle will be introduced.
Specific lattice modelling issues, such as the type of neighbourhood (Moore or von Neumann), updating rules, lattice size, edge effect - toroidal arrangement, will be covered.

The qualitative modelling IPSIM platform to predict injury profiles. Application to disease management under future climate

Jean-Noël Aubertot

The limitation of damage caused by pests (plant pathogens, weeds, and animal pests) in any agricultural crop requires integrated management strategies. Although significant efforts have been made to i) develop, and to a lesser extent ii) combine genetic, biological, cultural, physical and chemical control methods in Integrated Pest Management (IPM) strategies (vertical integration), there is a need for tools to help manage Injury Profiles (horizontal integration). A given cropping system, in a given production situation will exhibit a unique injury profile, defined as a dynamic vector of the main injuries affecting the crop. This presentation will describe IPSIM (Injury Profile SIMulator), a modelling framework to predict injury profiles as a function of cropping practices, abiotic and biotic environment. The conceptual bases of IPSIM, an aggregative hierarchical framework and a method to help specify IPSIM for a given crop will be presented. IPSIM can be used as a tool to help design ex-ante IPM strategies at the field scale under various climate change scenarios.

How to use lattice models, spatial and temporal models to help design IPM strategies for future climate

Mark Szalai

Many agricultural regions can be modelled with lattice models as crops are often "clear" patches in the landscape, and the cells of the lattice can be the patches of habitats and non-habitats for the considered organisms. This approach can also save processor time compared to run models on real (georeferenced) landscapes which can be particularly important in model development phase.

The example of the maize pest, western corn rootworm (*Diabrotica virgifera virgifera*) will be used. Here the landscape can be simplified to a cellular automaton like structure with categorical states of the cells while the pest population dynamics can be modelled with simple equations of population build up and dispersion. Moreover, implementation of pest control measures and crop rotation strategies will be covered. Both the update of the cells and the population dynamics part can be used as an example for practical.

Day 4.

Integrating pests into crop models

Til Feike

Process-based crop models are an important and powerful tool in agronomic research. They simulate plant growth and development within the soil-plant-atmosphere continuum and hence help describing and understanding processes and cause-effect relationships observed in the field. A crop model validated for a specific region can be used for various purposes, including optimisation of crop management or climate change impact assessment. A major limitation of most commonly used crop models is the non-consideration of biotic stress. By overcoming this limitation, the potential applications of crop models, especially for simulating crop production under practical on-farm conditions, would strongly be usefull. The presentation will introduce the rationale, challenges and a general conceptual approach of integrating pests into existing crop models. For crop modelers, the specific pest itself and its development is less in the focus, but the actual damage to various crop compartments and respective growth processes caused by the different pests is critical. This information needs to be obtained and integrated into the models via coupling variables. As an example, an ex-post approach of pest integration in the DSSAT CERES-maize model will be presented.

Integrating pests into crop models

Marcello Donatelli

The simulation of crop performance under climate change scenarios includes, as one of the assumptions, the likely lack of adaptation of crops to the new environmental conditions. Climate impacting on crops is no longer "known variability", but it might include extremes and new patterns of temperatures and rainfall, which increase the risk of relying on observations even to estimate future trends of crop responses. Process-based crop models need to be verified in terms of assumptions accepted in the formalization of processes, often implemented as simplifications of responses. Plant diseases models are no different; moreover, site and weather-specific interactions with crops may substantially change under new scenarios. Applied modelling of crop diseases and pests has been dominated by short term, tactical questions, such as the development of support capabilities to schedule scouting or pesticide applications, i.e., decision support systems. These modelling activities are often based on specific pest-crop systems, in specific environments, and based on multi seasonal observations, that allowed the building of robust empirical relationships using weather variables and crop phenology. Process-based modelling, combined with the careful design of scenarios to analyse impacts, provides an avenue to address questions related to changing climate. Shared modelling structures among a network of scientists from different fields appear to be a most appealing and efficient way to scientifically address these challenges. A framework to model and couple disease and crop models is presented, and its implementation will be presented.

The XPEST modelling platform to design online damage models

Jean-Noël Aubertot

Yield losses caused by pests (plant pathogens, weeds, and animal pests) are responsible for major limitations of agricultural productions. For instance, without any control, it has been estimated that pests were responsible for 77, 50 and 75% yield loss worldwide on rice, wheat and potato respectively (Oerke, 2006). In order to design IPM strategies to control pests, it is of primary importance to quantify and rank yield losses. The purpose of the X-PEST platform is to help researchers to develop models aimed at representing yield losses caused by an injury profile in a given production situation. X-PEST combines a simple representation of photosynthesis along with the partitioning of the created assimilates in various organs to 4 major damage mechanisms: assimilate sapping, light stealer, assimilate rate reducing, biomass reduction. The platform is composed of 3 sections: the documentation section, the modeling forge, and the simulation center. Participants will be given access to the online platform to design their own yield loss models.

SEIR model of disease (brown rust). Description of the Zadoks model, large scale simulation and practical work with R to help design IPM strategies for future climate

François Brun

The model that will be presented is a classical SEIR model proposed by Zadoks (1971) to simulate epidemics of diseases of crops. It is a Susceptible-Exposed-Infectious-Removed (SEIR) model. This simple epidemiological model is based on the concepts of "latent period", "infectious period", and "multiplication factor". The crop is considered to consist of a large but finite number of infectious sites. The physical dimensions of an infectious site roughly coincide with the reproductive unit of the parasite studied. Different pathosystems (with different infectious site definitions) can be considered with this model. The practical work will consist in defining the general structure of an algorithm to run this model and to write the corresponding code in R. Then, we will use it to simulate future climate impact on leaf rust (*Puccinia triticina*) epidemics on wheat crops (*Triticum aestivum*). IPM strategies can be tested in this context.

Integration and extensibility: practical aspects in software design and development

Marcello Donatelli

The demand of model tools to perform integrated evaluation of agro-ecological systems has further increased in the last decade. The major obstacle has been the fragmented availability of modelling resources, partly due to the difficulty of having a clear base for communication across domains, and also because of technical bottlenecks. Since many years, model frameworks have represented a substantial step forward with respect to monolithic implementations of biophysical models. The separation of algorithms from data, the reusability of services such as I/O procedures and integration services, the target of isolating a modeling solution in a discrete unit have brought a solid advantage in the development of simulation systems. However, the diffusion of such frameworks beyond the groups developing them, as model development environment, can be considered modest. The reusability of models has also proved to be modest; a model unit for a given framework is not used in other frameworks.

A framework flexible enough to meet the requirements of simulation systems in different domains would likely imply a substantial infrastructure and in any case would have a steep learning curve. Developers in the operational arena, but even in research, have de facto reacted by developing their own framework. Interoperability across frameworks is consequently of interest to avoid duplication, to exploit expertise in other domains, and to test the predictive power of different approaches to model systems. Model units reuse may imply several technical and conceptual challenges. This talk will introduce to main requirements and challenges to build an integrated system via the case of the platform BioMA.

Day 5.

Presentation of results of the modelling projects

All, Chairman: Jean-Noël Aubertot

This session will aim at presenting the results obtained by the modelling projects conducted during the summer school. Participants will be invited to ask questions and to comment the results presented by the different groups.

Wrap-up session of the summer school

All, Chairman: Camilla Moonen

This session will aim at sharing feedbacks from the summer school participants and to identify benefits and improvement points for future editions.