Chapter 13

AgMIP Training in Multiple Crop Models and Tools

Kenneth J. Boote[1], Cheryl H. Porter[2], John Hargreaves[3], Gerrit Hoogenboom[4], Peter Thorburn[5], and Carolyn Mutter[6]

[1] *University of Florida, Gainesville, FL, USA*

[2] *University of Florida, Gainesville, FL, USA*

[3] *Agricultural Productivity Flagship, CSIRO, Brisbane, Australia*

[4] *Washington State University, Prosser, WA, USA*

[5] *Agricultural Productivity Flagship, CSIRO, Toowoomba, Australia*

[6] *Columbia University, New York, NY, USA*

Introduction

The Agricultural Model Intercomparison and Improvement Project (AgMIP) has the goal of using multiple crop models to evaluate climate impacts on agricultural production and food security in developed and developing countries. There are several major limitations that must be overcome to achieve this goal, including the need to train AgMIP regional research team (RRT) crop modelers to use models other than the ones they are currently familiar with, plus the need to harmonize and interconvert the disparate input file formats used for the various models. Two activities were followed to address these shortcomings among AgMIP RRTs to enable them to use multiple models to evaluate climate impacts on crop production and food security. We designed and conducted courses in which participants trained on two different sets of crop models, with emphasis on the model of least experience. In a second activity, the AgMIP IT group created templates for inputting data on soils, management, weather, and crops into AgMIP harmonized databases, and developed translation tools for converting the harmonized data into files that are ready for multiple crop model (hereafter termed *multi-model*) simulations. The strategies for creating and conducting the multi-model course and developing entry and translation tools are reviewed in this chapter.

Participants came to the multi-model training course with data that they had already tested and simulated with their favored model; an iterative process commonly referred to as model "calibration". Following lectures on the general principles of crop growth and soil–water balance common to both models, the participants used the IT tools to convert the files into the alternate model, and worked with the experts of those models to step through a calibration process with the new model. This provided each crop modeling team with a second simulation of production associated with the same farmer field survey data.

The course was clearly valued by the participants, as it was a mid-project achievement that allowed them to complete the multi-model simulations as part of the integrated assessment that they were doing in their regional research teams (see Part 2, Chapters 1–12 in this volume). The designation and use of trainers and AgMIP resource persons was very valuable, as they mentored and assisted small working groups, the number of which exceeded the number of instructors available. Furthermore, the course was a good test-bed for the IT tools, providing evaluation that led to improvements in the conversion tools for creating model-ready files.

History of Crop Modeling Courses

Training in crop modeling has followed several pathways. A common pathway over the past 30–40 years has been one-on-one training during graduate or post-doctoral programs, or during targeted visits with crop modeling experts. A second pathway has been structured training courses in which a number of trainees come to a location and follow a five to eight day course of lectures, hands-on training, and exercises. The first of these types of one-week training courses was conducted in 1981 by the Department of Theoretical Production Ecology, Wageningen Agricultural University, the Netherlands. The senior author was privileged to attend that course. That course was connected to the 1982 book edited by Penning de Vries and van Laar (1982).

University of Florida crop modelers (J. W. Jones, K. J. Boote, and G. Wilkerson) conducted their first crop modeling course at the University of Florida in 1985, with a similar one-week format. After that initial start, a larger group of crop modelers associated with the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project proceeded to conduct six to ten day crop modeling courses at various sites in the US and around the world, beginning with Taiwan in 1986 and the International Center for Research in the Semi-Arid Tropics (ICRISAT) in 1987. Crop modeling courses with the Decision Support System for Agrotechnology Transfer (DSSAT) software have continued since on a nearly annual or biannual basis (Hoogenboom *et al.*, 2010; Jones *et al.*, 2003). The course was offered 20 times in the USA since 1985, and international courses were taught

Table 1. History and locations of DSSAT training courses since 1985.

Country	Year of training course
United States	1985, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2002, 2004, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Taiwan	1986
India	1987, 2010, 2011, 2012
Senegal	1989, 2014
Venezuela	1989
Republic of South Africa	1990, 1995
Hungary	1991, 1992
Canada	1997
Egypt	1998, 1999
Togo	1998
Thailand	2003, 2004, 2007, 2013, 2014
Tanzania	2004
Ghana	2005
Argentina	2006, 2007
People's Republic of China	2006
Kenya	2007
Namibia	2007
Malaysia	2009
Spain	2009
Barbados	2012

in Taiwan, India, Senegal, Venezuela, Republic of South Africa, Hungary, Canada, Togo, Ghana, Egypt, Tanzania, Argentina, the People's Republic of China, Kenya, Namibia, Malaysia, Barbados, Spain, and Thailand (Table 1). The number of participants ranged from 10–60 people, usually 20–30 at a time. The book edited by Tsuji, Hoogenboom, and Thornton (1998) serves as the textbook for the DSSAT crop modeling courses. More than 1000 students have been trained over this period.

The Dutch crop modelers conducted similar training courses on a regular basis, especially during the Dutch government-funded project, Simulation and Systems Analysis for Rice Production (SARP) in Asia during the mid-1980s to the mid-1990s (ten Berge, 1993). In that project, the Center for Agrobiological Research and Wageningen Agricultural University linked with the International Rice Research Institute and 16 national agricultural research centers in Asia, to conduct systems analysis and simulation modeling, mostly on rice, by using the SUCROS model (Penning de Vries *et al.*, 1989). Training courses were conducted at Wageningen and at international sites, following the template of the Penning de Vries and van Laar (1982) book, along with training in use of SUCROS and use of the Continuous Systems Modeling Program (CSMP) language.

Other models and modeling groups such as the Agricultural Production Systems Simulator (APSIM; Keating *et al.*, 2003), EPIC (Izaurralde *et al.*, 2006; Williams *et al.*, 1989), and CropSyst (Stöckle *et al.*, 2003) hold somewhat shorter in-house training sessions for one to ten people at a time, generally at their research sites. The CropSyst group uses web-based training approaches. APSIM conducts two-day training sessions several times per year in Australia, mostly on operational aspects of the model software. Many Australian international agricultural research projects include five-day APSIM workshops in-country for 15–20 persons as required. These courses are tailored for the regions (i.e., Africa and Asia) in which the project members operate, and usually consist of three days of hands-on activities with science theory and understanding of the dynamics of the processes producing the simulation results, followed by two days of small-group activities using simulations to explore local issues and strengthen simulation skills. A half-day of instruction on soil sampling is sometimes conducted. Other APSIM international training activities include participatory crop modeling training that targets agricultural researchers proficient in the use of APSIM for adding value to on-farm research and extension focusing on climate change adaptation and crop production. The first international APSIM course was held in 1997 at the ICRISAT center as part of a joint project entitled "Collaboration on Agricultural Resource Modeling and Applications in Semi-Arid Tropics".

Approaches Followed in Crop Modeling Courses

The approaches in the DSSAT and Dutch-SARP crop model training courses followed a template that included some lectures interspersed with hands-on use of the software and model interfaces, along with exercises. The lectures covered principles of crop phenology, crop carbon (dry matter) balance, crop soil–water balance, soil–plant N balance, model calibration, model sensitivity analyses, etc. The hands-on training with the software included exercises to demonstrate data entry, proper creation of weather, soils, and management files, model calibration, model simulation, and data analyses. Trainees were encouraged to come with their own data and to develop a special topic or exercise with their data. If they did not have data, students were given topics in which they were to create model-ready files to conduct multi-year simulations of various treatments or crop sequences. Results were then analyzed to evaluate how various treatments affected crop yields, irrigation requirements, seasonal evapotranspiration, soil C dynamics, fertilizer N response, N leaching, economic returns, and optimal economic decisions, etc.

The Dutch government-funded SARP project, particularly in its later phases, discovered that sustained follow-through was very important. Project organizers established and funded a program for field-oriented scientists from Asia for one-year of formal training that involved about half-time on field data collection and half-time on crop modeling (ten Berge, 1993). The African Network for Soil Biology and Fertility (AfNet) Project (Bationo *et al.*, 2012) established a similar program in Africa. In this multi-year-funded project, African scientists participated in an introductory crop modeling workshop, followed by field data collection on a topic that could be further analyzed by crop model simulations, followed by a workshop with the models and their data, and then a third workshop to present their final results that ended up as written papers being published in a book (Bationo *et al.*, 2012). A similar approach is followed by Australian projects that make use of the APSIM systems modeling as an analysis tool.

APSIM workshops are conducted in Australian projects in which simulation is required as an analysis tool for components of the project (Keating *et al.*, 2003). Most experiences are published in project reports by the project sponsors (e.g., Australian Center for International Agricultural Research, Australian Agency for International Development, ICRISAT, and Rockefeller Foundation).

Reasons for Multi-model Course Taught by AgMIP Scientists

The AgMIP project has a strong focus on multi-model simulations to evaluate impacts of climate scenarios on agricultural production, similar to the use of multiple global climate models for prediction of future climate (Rosenzweig *et al.*, 2013). The concept of multi-model use is that the ensemble of several models may be a better predictor than any given single model, as already learned by the AgMIP wheat teams (Asseng *et al.*, 2013), the AgMIP maize teams (Bassu *et al.*, 2014), the AgMIP rice teams, and AgMIP sugarcane modelers. As a result, projects using AgMIP protocols require the application of at least two crop models. This goal can be achieved by bringing together scientists with expertise in different models to analyze datasets from the region of interest. However, in many regions, especially in developing countries, there are few scientists proficient in crop modeling and RRTs may have scientists proficient with just one model. Thus, there is a need to encourage these crop modelers to learn to use more than one crop model, as well as to collaborate with others in multi-model activities.

Specifically, participating scientists in the regional teams funded by the UK Department of Foreign International Development (DFID) wished to use multiple crop models (DSSAT and APSIM at minimum) to simulate yields relative to farm survey data collected by socio-economists as a way to evaluate climate impact on farm-to-farm variability in production, and subsequently to conduct integrated production–economic assessment. Therefore, AgMIP leaders developed training courses for the regional team participants in which multi-model training/use were emphasized. In the AgMIP Handbook protocol (see Part 1, Appendix 1 in this volume and Rosenzweig *et al.*, 2014) of the DFID-funded regional integrated assessment projects, economists use the simulated farm-to-farm variability and simulated climate change ratio (*R*, the yield under 30-year future climate divided by yield under 30-year current climate for each farm). The value of R is multiplied by the present farm survey yield as part of an integrated assessment of winners and losers among the farmers as affected by climate change and technological adaptation. The value of R for a given field may differ among crop models, thus representing a range of uncertainty regarding the potential effect of climate change on crop production.

Other reasons for multi-model courses are that participants want to learn about crop models other than the model they currently use. Participants are interested in seeing how other models take different approaches to address soil processes, crop management, and cultivars. The crop modelers can translate their experiences from one model to the next, because the concepts are often similar even if the coefficients and model structure may be different. Although the crop models and the software interfaces may differ among different modeling groups, the basic principles are similar relative to use of weather, soils, and management data. Likewise, crop growth and yield measurements are similar in use and purpose, despite different variable naming and different graphical and text comparisons of simulated versus observed values.

Finally, modelers understand that all models need further calibration and development to improve their simulation of biophysical field conditions. Learning about how different models simulate response to the biophysical environment provides rich stimulus for considering how to further improve model processes themselves. Differently parameterized models typically yield different results for the same input data — deciphering why this happens is an important learning experience for modelers, who must be able to assess and interpret outputs — all of which yield information (or limitations) as to how models simulate agricultural systems, and why they sometimes "fail".

An important reason for the AgMIP multi-model course was to introduce and teach the crop modelers how to use the newly developed IT tools (see also Part 1, Chapter 6 in this volume) for data entry and conversion. The alternative would have been for students to learn both the DSSAT- or APSIM-specific tools for defining crop management in the models based on the farm survey data, but this would not have accomplished the objective of having the same data entered once with templates into the AgMIP-harmonized format and being translatable into the files ready to run for both models. For that reason, the IT tools were a strong focus for at least three days of the training course. AgMIP is motivated to help create tools that encourage the use of multi-model approaches by easing the ability to move among models, an activity that requires close collaboration with the model developers themselves (see also Part 1, Chapter 6 in this volume).

Planning and Preparations for the Multi-model Training Course

Potential participants were surveyed to learn of their prior experience in crop modeling with their currently used model and to designate which model they wanted to learn more about. An important requirement was that participants have prior experience with at least one crop model, as this course was not designed to be a beginners' course.

Prior to the training course, an email was sent to participants requesting that they: (1) come with their own portable laptop computer, (2) identify and come with sentinel site experimental data following AgMIP sentinel site data standards (Kersebaum *et al.*, 2014) that had a minimum amount and quality of measurements of crop life-cycle phenology, final biomass, final yields, modest growth analyses, along with site-specific weather, soils and crop management inputs in order to simulate crop growth, for which they were already running their current model and for which they would calibrate cultivar coefficients with a new model; (3) come with the farm survey yield data (as well as associated management and soils data), which they would enter during the course; and (4) come with 30 years of historical "baseline" weather data for the farm survey region, including weather for the actual farm survey years.

The 30-year current baseline weather data were to be modified by their climate scientist colleagues to produce a given defined climate scenario by using the delta method. During the course they followed-up with crop simulations of the individual farm sites in order to calculate the climate change ratios to provide to their economist collaborators, by following protocols of the AgMIP Handbook (see Part 1, Appendix 1 in this volume and Rosenzweig *et al.*, 2014).

Instructors and Train-the-Trainers

An important goal of AgMIP is capacity-building and development of regional crop modeling capability, to include facilitating individuals with the potential to become future instructors and trainers of other crop modelers. Prior to the multi-model training course, the instructors (K. J. Boote, C. H. Porter, J. Hargreaves, and G. Hoogenboom) and P. Thorburn engaged AgMIP coordination in a process of candidate selection, with selectees demonstrating good crop modeling skills, good leadership, and good teaching and mentoring potential, with appropriate regional and gender representation (five developing countries and two women). The selectees included D. S. MacCarthy (Ghana), D. M. Kadiyala (India), D. Fatondji (Niger), N. Subash (India), G. Baigorria (US), P. Masikati (Zimbabwi), B. Singh (India), and A. Wajid (Pakistan). During the training course, these individuals took an active role to mentor and assist their colleagues on particular models and/or crop expertise that they had. The instructors provided additional guidance and advice to these designated individuals, with the expectation that they would return to their region or university and help train other crop modelers in their current team, university, or region.

Fig. 1. Initiation of multi-model training course activities in the learning systems unit at the ICRISAT, Andra Pradesh, India.

Conducting the Course and the Course Syllabus

The course was conducted at two locations using the same curricula and overall plan: During March 18–22, 2013 at Hotel Annapurna, Kathmandu, Nepal (about ten students attended), and during March 25–29, 2013 at the ICRISAT center, Andhra Pradesh, India (about 40 students attended, see Part 2, Appendix 1 in this volume for the ICRISAT Workshop report). To the extent possible, trainers-in-training attended both events. This allowed for close interaction and advancement of their own capabilities in the first, smaller event — and provided immediate opportunity to utilize their skills as trainers in the second, larger event. The photo (Fig. 1) shows the initiation of the second course, held at the Learning Systems Unit at ICRISAT. Course activities for the AgMIP Multiple Crop Model Training Program are described in the syllabus (Annex 1 at the end of this chapter). In addition, participants were provided with the *Guide for Regional Integrated Assessments: Handbook of Methods and Procedures, Version 4.0*, specifically Appendix 2, *Crop Model Simulations for Integrated Assessments: User's Guide*, available in the AgMIP Handbook (see Part 1, Appendix 1 in this volume and Rosenzweig *et al.*, 2014). The latter contain the AgMIP protocols for using the IT tools for entering farm survey yield data in template files, creating the data overlay files to provide assumptions for information missing from survey management and soils, and conducting the crop model simulations to produce results to pass on to the economists for the integrated biophysical and socio-economic assessment.

systems unit at the ICRISAT.

e curricula and overall
ıandu, Nepal (about ten
ℸRISAT center, Andhra
.dix 1 in this volume for
ɜrs-in-training attended
ɑent of their own capa-
ɜ opportunity to utilize
Fig. 1) shows the initi-
ıit at ICRISAT. Course
ıgram are described in
ion, participants were
ts: Handbook of Meth-
rop Model Simulations
ıgMIP Handbook (see
2014). The latter con-
ing farm survey yield
ıvide assumptions for
d conducting the crop
nists for the integrated

During the first day of the course, we introduced the integrated assessment goals, and then gave an overview of DSSAT and APSIM crop models, specifically how phenological development, growth and yield, soil–water dynamics, and genetic coefficients are formulated in each model. Principles of genetic coefficient calibration were introduced. Initially, all participants were together in the same room learning about both models. Late in the afternoon of the first day, participants installed their newly chosen models, and learned the procedures for inputting new crop, soil, management, and weather data for the purpose of estimating genetic coefficients from the sentinel site experiment data.

On day 2 of the course, after one plenary lecture on soils and crop management aspects, we separated into two parallel sessions, with one group learning DSSAT and the other learning APSIM. During the rest of this day, students worked with their new crop model, and entered soil, weather, management, and crop observation data, which they used to estimate the model-specific genetic coefficients for their cultivar from their sentinel site experiment data. As necessary, small-group model-specific lectures were conducted to address model-specific issues related to genetic coefficient calibration.

On day 3, the students completed their calibration of genetic coefficients for their new crop model, created visuals, and presented their results per team in a plenary session near mid-day. After each presentation, we discussed what had been done and gave recommendations for improvement.

In the afternoon of day 3, the AgMIP IT tools — survey data template, data overlay files, and QuadUI (the desktop application for data translation) — for entering farm survey data were introduced and explained (see also Part 1, Chapter 6 in this volume). The participants then began to enter their farm survey yield and management information into the AgMIP template spreadsheets.

On day 4, there was a plenary lecture on the goals of AgMIP integrated assessment for analyzing farm production as well as methods for analyzing farm survey data and simulated production. We discussed proper use of AgMIP tools to complete entry of field survey data as well as creation of Data Overlay for Multi-model Export (DOME) files for input of missing initialization and management information. We assisted the participants in use of the AgMIP tools to convert field survey data into model-ready files. We advised on the need to verify their inputs (management, soils, initial conditions, and cultivar) and assisted in getting the crop models to run with their data.

We assisted in analyzing simulated results and in computing the mean and plotting the cumulative probability of exceedance for the observed farm survey yields and model-simulated yields on the same graph. Figure 2 illustrates the probability of exceedance of a given yield level for farmer survey yields, compared with the yields simulated by DSSAT and APSIM for peanut fields near Nioro, Senegal in

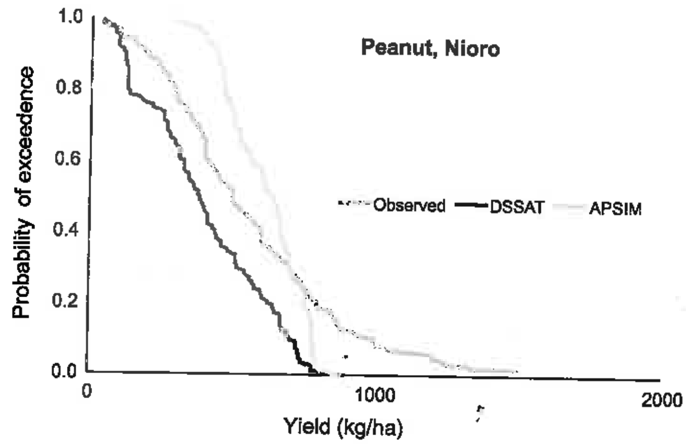

Fig. 2. Probability of exceedance of a given yield level among farmer survey fields, DSSAT simulations, and APSIM simulations for peanut fields near Nioro, Senegal in 2007 (courtesy of CIWARA team in Part 2, Chapter 2 in this volume).

2007 (courtesy of AgMIP's Western Africa team, CIWARA; see also Part 2, Chapter 2 in this volume). The farmer survey fields generally have greater yield variation, possibly because failures from pest, disease, and weed problems in farmer fields mean that the models do not simulate, as well as insufficient variation of soils (water/productivity) assigned to the model simulations. We discussed the need to evaluate the simulated and observed distributions and to understand the causes for model failure to predict accurately the mean as well as the high or low tails of the cumulative probability of exceedance. In some cases, these were caused by simple errors in setting up of the models and these were resolved. In some cases, soil initial-condition assumptions related to soil water and soil organic carbon pools had major effects on the distributions obtained.

Although the economists had requested that no external bias adjustments be made (because they only needed the value of climate change ratio (R) to be predicted to transform the observed yield in each farm), there were often serious bias-influencing input issues relative to initial soil water, initial soil mineral N, soil organic C pools, and residue assumptions that were made (because such information was missing from the farm survey data). Consistent rules for bias-adjusting corrections were suggested to facilitate realistic yield levels and distributions for the region that would be believed by stakeholders. At the same time students were cautioned that corrections needed to be limited to broad classes of problems for multiple farms, and in no case were adjustments allowed to be made on a "farm-by-farm" basis in absence of data. The reason for this caution was that at least one group had previously micro-calibrated inputs for every single field (without true evidence of input variation) to exactly mimic the observed yield for each and every survey field.

ιT — APSIM

2000

ıer survey fields, DSSAT simu-
in 2007 (courtesy of CIWARA

A; see also Part 2, Chap-
ve greater yield variation,
ɪroblems in farmer fields
ficient variation of soils
Ve discussed the need to
ınderstand the causes for
e high or low tails of the
e were caused by simple
n some cases, soil initial-
carbon pools had major

ɔias adjustments be made
io (R) to be predicted to
serious bias-influencing
N, soil organic C pools,
ıformation was missing
usting corrections were
ions for the region that
ents were cautioned that
ems for multiple farms,
a "farm-by-farm" basis
at least one group had
vithout true evidence of
ı and every survey field.

On day 5, there was a plenary lecture on seasonal analyses with multiple weather years that was presented as a way to analyze the risk of weather variability. Then the student-modelers moved on to conduct multi-year simulations using the seasonal strategy tools that provide consistent rules of auto-sowing to be set up, since the "single year" farmer survey sowing dates were potentially inappropriate for future climate conditions. Multi-year simulations were run for both baseline "current" weather and at least one future climate change scenario. Participants were shown how to use the IT tools to place the simulated yields (current and future) into the AgMIP crop model output (ACMO) harmonized format, ready for use by the agricultural economists (see also Part 1, Chapter 6 in this volume). Mean 30-year yield per farm was computed for the baseline and for future climate, for use in computing the value of R for each farm. The students prepared presentations of their results that were reported in a joint session that facilitated discussion and recommendations. The course ended with participant feedback of what worked and what did not work.

Experiences during the Course: What Worked and What Did Not

Some of the participants were not as experienced with crop modeling as presumed when setting up these workshops. All participants should have had a full basic training course prior to coming to this multi-model course. Because of time limitations and the need to use two crop models along with new IT Tools, this multi-model course intentionally did not include the basic lectures or hands-on training exercises typical of beginners' crop modeling courses. That created some frustration and lack of effective learning for some participants who came with insufficient required experience.

The number of participants also made a difference. There were ten students in Nepal and 40 at ICRISAT, and the latter number stretched the training capacity of the four instructors despite help from the eight designated "train-the-trainers" in the role of instructor–advisors. There was a relative deficiency in APSIM instructor support, although five of the trainers had some APSIM experience. Train-the-trainers provided expertise to solve many issues along the way, considering that there were only four primary lecturers and that many IT tool issues came up along with the typical crop model issues. The train-the-trainers also provided expertise on alternate crops. Because of several different crops and different country teams (six teams at ICRISAT), students evolved into many small working groups, which is another reason that multiple instructors and trainers with expertise in different models and crops were needed.

The installation and setup of the DSSAT and APSIM models worked well on the individual students' laptop computers, with a few exceptions due to international language operating systems and Macintosh computers. There were some difficulties with the use of the new IT tools. The rice models required additional management inputs to characterize paddy management (puddling, bund height, flooding depth, percolation rate, etc.), which had not yet been programmed into the data translators for DSSAT or APSIM. By the time of the second one-week course held at ICRISAT, these problems were mostly solved.

Mid-week, we had separate break-out sessions of 20–30 minutes in which instructors met separately with each modeling team, to look in detail at the model input files for simulations, to verify correct entry and use of sentinel site data for calibrating cultivar coefficients, and to set up model assumptions for farm survey fields relative to irrigation, initial soil water, initial nitrate and ammonium, and soil organic C pools (if the latter were to be used). In these sessions, the DSSAT modelers worked with DSSAT instructors and APSIM modelers worked with the APSIM instructor. This double-check was very important and valuable to all, despite not being listed as a course topic. While inspecting the model input files, we discovered many issues such as not setting initial conditions for soil water, crop residue, nitrate and ammonium, and failure to simulate rice as paddy. Some teams "micro-calibrated" to each farmer field and this was strongly discouraged. Some did the climate scenarios incorrectly. These were issues that were not apparent in the preliminary written reports of the teams, and therefore required the re-doing and re-running of their original simulations. Hands-on-evaluation of model *input files* by model experts *must* be a part of all training courses that have viable simulations as an output.

The IT tools were successfully used for template entry, and conversion of survey data to DSSAT ready-to-run files worked for maize, millet, and wheat. Conversion to files ready to run for the DSSAT CSM-CERES-rice did not work initially because of limitations related to paddy water management (puddling, percolation rate, bund height, and water height). These were solved during the multi-model training courses. The tools to convert to APSIM-ready files worked only for maize. The course was successful in being a "beta" test-bed in which to identify issues that the AgMIP IT team needed to resolve for wheat, sorghum, and millet model files; these issues were resolved by the end of the two weeks. The APSIM-rice issues were solved later.

A shortcoming of this course was that no one successfully parameterized the soil carbon modules, whether the DSSAT CSM-CENTURY's stable soil carbon pool (SOM3) or the APSIM's fraction inert soil carbon pool. The CENTURY soil carbon option was generally not used despite encouragement to use it, and it was never used for the rice models. So, a conclusion here is that the correct setting of soil carbon pools is a major difficulty in the crop models, and that this may limit the ability to accurately predict production of non-legumes under degraded soil conditions.

Another short-coming is that there was insufficient time to discuss the effects of climate change scenarios, and specifically the climate change ratio. The five-day course was too short. We also lacked time for sufficient discussion and evaluation of the probability of exceedance distributions (and means) for simulated and observed farm survey yields, despite having a final report-back on those topics on the last day. The report-back on genetic coefficient calibration early in the week worked well.

Feedback at end-of-day and at start of every morning was valuable for purposes of discovering how far individual groups had progressed and to solve any problems that may have arisen. The majority of the project-funded teams managed to calibrate genetic coefficients for both crop models, and accomplished their farm survey simulations for at least DSSAT. Deficiencies in the APSIM data translator prevented completion of APSIM simulations for rice, wheat, and millet crops. The teams learned enough that they could return to their countries and complete the simulations later, after the data translation issues were solved.

Conclusions and Next Steps

The AgMIP Multiple Model Course was clearly needed and valued by the crop modeling participants, as it allowed them to complete the multi-model simulations for the integrated assessment that they were doing in their RRTs. The course generally went smoothly, especially in Nepal, where the number of students was small (about ten) and the crops fewer. At the ICRISAT center in India, the facilities were good, but the auditorium setting and the number of students (40 or more) with diverse regions and more crops simulated, made the course more difficult to handle. More of the participants at ICRISAT were beginners to crop modeling. Future courses with multi-model agendas will need to ensure better beginners' training or vetting of the participants. The use of trainers and AgMIP resource persons was very valuable, as they assisted with the many small working groups that exceeded the number of instructors available.

The IT tools generally worked as planned, although mid-course improvements in the conversion tools were needed in order to create model-ready files for DSSAT CSM-CERES-rice, and for nearly all APSIM crops with the exception of maize. In that sense, the course provided a useful opportunity to test, refine, and improve the IT tools.

The need for continued training in crop modeling is highlighted by this course. Distance-training modules can be designed, but will require coordination with DSSAT and APSIM modeler groups who have the training materials. The use of the IT tools for multi-model use and translation of data formats from one model to the other could be set up as a distance-training module within AgMIP. Another approach is to encourage the new train-the-trainers to lead crop model training courses in their own regions and institutions.

The participants in the multi-model training were requested to identify specific actions planned after this course to include: (1) How will the multiple-model capability be used in research that is under way? (2) Who would go back and host training sessions and with what institution? (3) What opportunities exist for leveraging multi-model capabilities in related work that falls outside of the AgMIP area? (4) What opportunities exist for introducing materials of multiple-crop-model methods into institutional practice guides or university course curricula?

In conclusion, the AgMIP Multiple Crop Model Course successfully met its objective of training crop modelers on two different models; this in turn allowed the regional project teams to meet their integrated assessment goals. The experience with this course also provided ideas for improvements in future multi-model training courses.

Annex I

ICRISAT Science with a human face

AgMIP

AgMIP Multiple Crop Model Training Program

25–29 March 2013

ICRISAT

Andhra Pradesh, India

Program

Day/Date/ Time	Session	Facilitator
Day 1 Monday 25 March	**Overview:** Overview of DSSAT and APSIM crop models, specifically how phenological development, growth and yield, and soil water dynamics are modeled, and overview of the genetic coefficients needed for each model.	
0800-0830	Registration	
0830-0900	**Plenary Session** — Welcome	G Dileepkumar
	Introductions — each participant	All
	About AgMIP Project	Peter Craufurd
0900-0940	Course objectives, overview of program	Ken Boote
	A broad overview and discussing APSIM, DSSAT including AgMIP Integrated Assessment perspective	
0940-1000	Group Photo, Tea/Coffee break	
1000-1100	Overview of DSSAT growth and phenology	Ken Boote
1100-1200	Overview of APSIM growth and phenology	John Hargreaves
1200-1300	Lunch	
1300-1400	Principles of genetic coefficient calibration	Ken Boote

(Continued)

› would go back and host
:tunities exist for leverag-
de of the AgMIP area? (4)
iple-crop-model methods
cula?
ırse successfully met its
lels; this in turn allowed
ent goals. The experience
ure multi-model training

rogram

	Facilitator
ically how mics are h model.	
	G Dileepkumar
	All
	Peter Craufurd
	Ken Boote
IIP	
	Ken Boote
	John Hargreaves
	Ken Boote

(*Continued*)

(*Continued*)

Day/Date/ Time	Session	Facilitator
1400-1430	Discussion — Issues with data and calibration	Instructors
1430-1445	Tea/Coffee Break	
1445-1700	**Parallel Sessions: DSSAT and APSIM Groups** Model installation and operation Example calibration of genetic coefficients Procedures for inputting new crop, soil, management, weather data. Entering new experiments for use in estimating GCs	
1700-1730	**Plenary Session:** Discussion of progress, issues	Instructors
1830	Welcome Dinner	
2030-2130	**Optional Session** for review and refinement of data, prior calibrations, methods	
Day 2 Tuesday 26 March	**Overview:** Consideration of soils and management; parallel DSSAT and APSIM sessions; exploration of soil, weather, management, and crop data; understanding model-specific genetic coefficients; feedback on progress and issues; optional evening session for review and practice.	
0830-0930	**Plenary Session:** Initializing soils and management for reliable simulations	Cheryl Porter
0930-1200	**Parallel Sessions: DSSAT and APSIM Groups** Work with participant's data (use AgMIP IT tools as available to convert files); review their prior simulations. Soil Weather Management Crop observations Verifying inputs and simulations	
1200-1300	Lunch	
1300-1700	**Continue Parallel Sessions: DSSAT and APSIM Groups** Model-specific genetic coefficient lectures Calibrate model for genetic coefficients	
1700-1730	**Plenary Session:** Discussion of progress and issues	
1930-2100	**Optional Session** for review, work, and practice	
Day 3 Wednesday 27 March	**Overview:** Continue parallel sessions, undertaking genetic coefficient calibrations; present findings in plenary; utilize AgMIP tools and procedures for integrated assessment; initiate field survey data analysis; optional evening session for review, work and practice.	
0830-1200	**Parallel Sessions: DSSAT and APSIM Groups** Participants complete estimation of genetic coefficients Prepare summary graphs, report	
1200-1300	Lunch	
1300-1400	**Plenary Session:** Presentation of genetic coefficient calibrations (5 minutes each)	
1400-1445	Discussion of calibrations, feedback, recommendations to teams for follow-up	Instructors
1445-1500	Tea/Coffee Break	
1500-1530	**Plenary Session:** Goals of AgMIP integrated assessment (creating economic inputs & results for DSS)	Ken Boote

(*Continued*)

(*Continued*)

Day/Date/ Time	Session	Facilitator
1530-1630	AgMIP tools and procedures for integrated assessment Use AgMIP Tools to complete entry of field survey data Create Overlay for "missing" initialization/management Convert field survey data into model-ready forms	Cheryl Porter
1630-1700	**Individual Study in Plenary:** Participants working on their field survey data	
1700-1730	Discussion	
1930-2100	**Optional Session** for review, work, and practice	
Day 4 Thursday 28 March	**Objectives:** AgMIP integrated assessments; analyzing farm production; using AgMIP tools to handle missing data; verify inputs and simulate productivity; analyze, bias correct, interpret, question reliability/believability of findings.	
0830-0900	**Plenary Session:** Methods for analyzing farm survey observed and simulated production	Ken Boote
0900-0915	Discussion	
0915-0930	Tea/Coffee Break	
0930-1200	**Parallel Sessions: DSSAT and APSIM Groups** Verify inputs (management, soils, IC, cultivar) & simulate Analyze simulated results, mean, cumulative probability Compute bias and determine if adjustments are needed Are results reliable? Believable?	
1200-1300	Lunch	
1300-1700	**Parallel Sessions: DSSAT and APSIM Groups** Verify inputs (management, soils, IC, cultivar) & simulate Analyze simulated results, mean, cumulative probability Compute bias and determine if adjustments are needed Are results reliable? Believable?	
1700-1800	**Plenary Session:** Discussion of problems and issues	
Day 5 Friday 29 March	**Objectives:** Seasonal analyses; multi year simulations, ACMO files, collaborative preparation of reports (for presentation by selected trainees); presentation; feedback on training.	
0830-0900	**Plenary Session:** Seasonal analyses with multiple weather years	G. Hoogenboom
0900-1030	**Parallel Sessions: DSSAT and APSIM Groups** Conduct multi-year simulations for integrated assessment	
1030-1045	Tea/Coffee Break	
1045-1200	Participants create ACMO files from survey year and Multi-year simulations (ready for economists)	C. Porter
1200-1300	Lunch	
1300-1500	Participants collaborate to prepare summary graphs and short report for presentation by selected trainees	
1500-1600	**Plenary Session:** Participants present reports (10 min each) Trainers will critique and discuss results	
1600-1630	**Participant Feedback**: what worked, what is needed, follow up actions	
1630	**End Training**	

References

Asseng, S., Ewert, F., Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane, A. C., Boote, K. J., Thorburn, P. J., Rötter, R. P., Cammarano, D., Brisson, N., Basso, B., Martre, P., Aggarwal, P. K., Angulo, C., Bertuzzi, P., Biernath, C., Challinor, A. J., Doltra, J., Gayler, S., Goldberg, R., Grant, R., Heng, L., Hooker, J., Hunt, L. A., Ingwersen, J., Izaurralde, R. C., Kersebaum, K. C., Müller, C., Naresh Kumar, S., Nendel, C., O'Leary, G., Olesen., J. E., Osborne, T. M., Palosuo, T., Priesack, E., Ripoche, D., Semenov, M. A., Shcherbak, I., Steduto, P., Stöckle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Travasso, M., Waha, K., Wallach, D., White, J. W., Williams, J. R., and Wolf, J. (2013). Uncertainties in simulating wheat yields under climate change, *Nat. Clim. Change*, **3**, 827–832.

Bassu, S., Brisson, N., Durand, J.-L., Boote, K. J., Lizaso, J., Jones, J. W., Rosenzweig, C., Ruane, A., Adam, M., Baron, C., Basso, B., Biernath, C., Boogaard, H., Conijn, S., Corbeels, M., Deryng, D., De Sanctis, G., Gayler, S., Grassini, P., Hatfield, J., Hoek, S., Izaurralde, C., Jongschaap, R., Kemanian, A. R., Kersebaum, K. C., Kumar, N. S., Makowski, D., Müller, C., Nendel, C., Priesack, E., Pravia, M. V., Kim, S.-H., Sau, F., Shcherbak, I., Tao, F., Teixeira, E., Timlin, D., and Waha, K. (2014). How do various maize crop models vary in their responses to climate change factors?, *Global Change Biol.*, **20**, 2301–2320.

Bationo, A., Tabo, R., Kihara, J., Hoogenboom, G., Traore, P. C. S., Boote, K. J., and Jones, J. W. (2012). "Building capacity for modeling in Africa", in Kihara, J., Fatondji, D., Jones, J. W., Hoogenboom, G., Tabo, R., and Bationo, A. (eds.), *Improving Soil Fertility Recommendations in Africa using the Decision Support System for Agrotechnology Transfers (DSSAT)*, Springer, Dordrecht, the Netherlands, pp. 1–7.

Hoogenboom, G., Jones, J. W., Wilkens, P. W., Porter, C. H., Boote, K. J., Hunt, L. A., Singh, U., Lisazo, J. L., White, J. W., Uryasev, O., Royce, F. S., Ogoshi, R., Gijsman, A. J., and Tsuji, G. Y. (2010). *Decision Support System for Agrotechnology Transfer Version 4.5* [CD-ROM], University of Hawaii, Honolulu, Hawaii.

Izaurralde, R. C., Williams, J. R., McGill, W. B., Rosenberg, N. J., and Jakas, M. C. (2006). Simulating soil C dynamics with EPIC: Model description and testing against long-term data, *Ecol. Model.*, **192**, 362–384.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J., and Ritchie, J. T. (2003). The DSSAT cropping system model, *Eur. J. Agron.*, **18**, 235–265.

Keating, B. A., Carberry, P. S., Hammer, G. L., Probert, M. E., Robertson, M. J., Holzworth, D., Huth, N. I., Hargreaves, J. N. G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J. P., Silburne, M., Wang, E., Brown, S., Bristow, K. L., Asseng, S., Chapman, S., McCown, R. L., Freebairn, D. M., and Smith, C. J. (2003). An overview of APSIM, a model designed for farming systems simulation, *Eur. J. Agron.*, **18**, 267–288.

Kersebaum, K. C., Boote, K. J., Jorgenson, J. S., Nendel, C., Bindi, M., Fruhauf, C., Gaiser, T., Hoogenboom, G., Kollas, C., Olesen, J. E., Rotter, R. P., Ruget, F., Thorburn, P., Trnka, M., and Wegehenkel, M. (2014). Analysis and classification of data sets for calibration and validation of agro-ecosystem models, *Environ. Model. Software*, submitted.

Penning de Vries, F. W. T., Jansen, D. M., ten Berge, H. F. M., and Bakema, A. (1989). *Simulation of ecophysiological processes of growth in several annual crops*, PUDOC, Wageningen, The Netherlands and International Rice Research Institute, Los Banos, p. 271.

Penning de Vries, F. W. T. and van Laar, H. H. (1982). *Simulation of plant growth and crop production*, PUDOC, Wageningen, the Netherlands.

Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane, A. C., Boote, K. J., Thorburn, P., Antle, J. M., Nelson, G. C., Porter, C., Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G., and Winter, J. M. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies, *Agric. Forest Meteorol.*, **170**, 166–172.

Rosenzweig, C., Jones, J. W., Hatfield, J., Antle, J., Ruane, A. C., Boote, K., Thorburn, P., Validivia, R. O., Porter, C., Janssen, S., and Mutter, C. (2014). *Guide for Regional Integrated Assessments: Handbook of Methods and Procedures Version 5.1*. Available at: http://www.agmip.org/regional-integrated-assessments-handbook. Accessed on 17 July 2014.

Stöckle, C. O., Donatelli, M., and Nelson, R. (2003). CropSyst, a cropping systems simulation model, *Eur. J. Agron.*, **18**, 289–307.

Ten Berge, H. F. M. (1993). "Building capacity for systems research at national agricultural research centers: SARP's experience", in *Systems approaches for agricultural development*, Penning de Vries, F. W. T., Teng, P., and Metselaar, K. (eds.), Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 515–538.

Tsuji, G. Y., Hoogenboom, G., and Thornton, P. K. (eds.) (1998). *Understanding options for agricultural production*, Kluwer Academic Publishers, Dordrecht, the Netherlands.

Williams, J. R., Jones, C. A., Kiniry, J. R., and Spanel, D. A. (1989). The EPIC crop growth model. *Trans. ASAE*, **32**(2), 497–511.