Crop simulation modelling training report

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Excellence in Agronomy (EiA) Initiative

The **EiA Initiative** aims to deliver agronomic gain for millions of smallholder farming households across 21 countries, with a particular emphasis on women and young farmers. It forms part of CGIAR's new research portfolio, delivering science and innovation to transform food, land, and water systems in a climate crisis.

Moving beyond conventional supply-driven scaling strategies, Excellence in Agronomy offers a new model for research and development (R&D) that sets out to leverage advances in diagnostics, data science, geospatial analysis, remote sensing, and behavioural sciences to develop widely applicable and locally relevant gender- and youth-responsive solutions at scale. It also assesses the effectiveness of the use case model, where research priorities are aligned with actual demand for agronomic solutions, and implemented through a co-creation process with demand partners, the science community, and other service providers.

EiA uses big data and advanced analytics to study the climate impacts, inclusivity, and sustainability of agronomic solutions. Demand partners are central to the model, connecting farmers and researchers, and increasing innovation, scalability, and return on investment in R&D, while better serving women and youth.

Sustainable Intensification of Mixed Farming Systems (MFS) Initiative

The **MFS Initiative** aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

Contents

Acronyms

ABC	The Alliance of Bioversity International and CIAT
APSIM	Agricultural Production System Simulator
APSRU	Agricultural Production Systems Research Unit
ARC	Agricultural Research Council
CIMMYT	International Maize and Wheat Improvement Center
CSM	Crop Simulation Model
CTAFS	Centre for Transformative Agricultural and Food Systems
DARS Malawi	Department of Agricultural Research Services Malawi
DSSAT	Decision Support System for Agrotechnology Transfer
EIA	Excellency in Agronomy
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization of the United Nations
GCC	Green canopy cover
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute
KU Leuven	Katholieke Universiteit Leuven
LAI	Leaf area index
SI-MFS	Sustainable Intensification of Mixed Farming Systems
URL	Uniform Resource Locator
ZSAS	Zimbabwe Sugar Association Experiment Station

Introduction

One of the major challenges to crop simulation modeling in Africa, especially for future crop performance projections and impact studies under varied conditions, is the unavailability of reliable experimental data for crop modeling studies. Several training programs have been done to introduce the Crop Simulation Model (CSM) in Africa, but only a few organizers have followed these up to see whether the models are being applied. We are in a situation where many have trained, but only a few apply the models.

From the participants' 'point of view, the low uptake and use could be due to the limited availability of data, inappropriate experimental designs for crop modeling, and inadequate knowledge about the capabilities of the different models and their suitability for field requirements. Lack of capacity among people trained in model development and application is the main gap in the uptake and adoption of crop modeling in research. In addition, there is a limited understanding of crop model inputs, requirements, lack of data for model calibration and validation, and a mismatch between the capabilities of crop models and expectations of what the models can do.

In this training workshop, we provided hands-on practical exercises on the use and application of crop models for decision support.

Workshop goal and objectives

The workshop aimed to provide practical exercises on the use and application of crop models for decision support.

Venue, format, and structure

The training workshop was held at the Bronte Hotel in Harare, Zimbabwe, from 19 – 13 January 2023. It used an interactive format which allowed discussions and hands-on sessions with experts on crop modeling. English was the language of instruction and participants attended physically.

Workshop trainers

The training was supervised by a panel of experts in various aspects of crop simulation modelling including:

1. Sue Walker – University of the Free state
2. Tafadzwa Mabhaudhi – International Water Management Institute
3. Karuturi Rao – International Crops Research Institute for Semi-Arid Tropics
4. Dirk Raes – Katholieke Universiteit Leuven
5. Diego Peqeuno – International Maize and Wheat Improvement Center
6. Siyabusa Mukuhlani – International Institute of Tropical Agriculture

Workshop participants

Diverse stakeholders in crop modeling and simulation attended the workshop. Around 40 junior scientists working in the Excellence in Agronomy (EiA) Initiative, the Sustainable Intensification of Mixed Farming Systems (SI-MFS) Initiative and the National Agricultural Research Systems (NARS) partners in Eastern, and Southern Africa participated in the workshop.

Day 1: Opening session

Introductions and opening remarks

Tafadzwa Mabhaudhi welcomed all participants to the workshop and urged everyone to participate throughout the training. He also called on participants to interact, share ideas, and engage throughout the workshop. Participants then introduced themselves and some gave their reasons for attending the training workshop. During this session, it was noted that some participants had taught themselves CSM and needed to interact with the experts to understand aspects of it better. Some participants indicated that they had joined online training sessions on CSM application, which was not effective, so they required face-to-face interactions. Several participants claimed to know about the Decision Support System for Agrotechnology Transfer (DSSAT). The attendees came from different backgrounds, including crop science, soil science, agro-meteorology, hydrology, climatology, and data science.

The host, Vimbayi Chimonyo, gave an overview of the training workshop. She highlighted that from the first survey sent out, it was noted that junior scientists, national staff, and various institutes in Africa needed to know the steps involved in CSM calibration and validation, and how to apply modeling to complex systems and scenarios. She explained the philosophy of CSM noting that it gives predictions of certain outcomes and not recommendations, which the expert in the field should provide. In addition, Chimonyo stated that expert trainers had been invited from across the world to help build capacity of the trainees so that they can train the next generation. She advised the trainees to interact with their trainers and said that Africa needs the capacity to create a knowledge base for crop modeling. She then described the structure and set-up of the training workshop and thanked everyone for participating.

The following topics were discussed on the first day.

- History of crop modeling
- Minimum data sets required for crop modeling
- Modelling calibration and validation
- Modelling confidence testing (statistics)
- Simulating phenological development
- Simulating basic growth processes

History of crop modelling focusing on southern Africa – Sue Walker

Sue Walker presented on the history of crop modeling focusing on Southern Africa. She mentioned that crop modeling has been developed and integrated into cropping systems to estimate economic yield under different management and climate scenarios. She also highlighted different models including empirical and statistical, mechanistic, static, and dynamic crop models, as well as deterministic and stochastic models. Internet and technological inventions have improved information access and enabled comparison and improvement of data quality and quantity.

Furthermore, she highlighted that the revolution of technology had led to advanced software and scientists need to keep up with the changes in technological transformation. Walker also highlighted the need for locally adapted models and noting that South Africa had developed models such as ACRU, BEWAB & swamp, CERES and CROPGRO.

She specified that many crops simulation projects had been carried out, but fewer statistical approaches have been used. She said that the next generation of models should use the latest technology such as machine learning and Big Data. However, she noted the need for advanced modeling training in Africa to increase the number of people with modeling skills.

Minimum data requirements for crop modelling – Vimbayi Chimonyo

Vimbayi Chimonyo presented the minimum data requirements for crop modeling. She highlighted that crop models help predict and depict farming systems' complexity. Crop models can be used for policymaking and to reduce risks and uncertainties. Furthermore, she mentioned that a minimum data set is relatively easy to collect under field conditions or in controlled environments. It provides reasonable answers and is also transferable across platforms. Since getting full data is difficult, taxing, time-consuming and costly, minimum data sets are used on parameters that can contribute to the important data sets. She mentioned that data could be classified into the following three levels:

- Level 1 data, which is used to adjust the model. Such data includes temperature, rainfall, and soil characteristics.
- Level 2 data, which is used to test or evaluate the model and requires data such as yield. Components/ phenology and growth process depending on research questions.
- Level 3 data, which is used for model development and requires parameters such as CO_2 enhancement, temperature responses, and changing coefficients.

She also indicated a need to bridge the gap between crop modellers and field scientists to allow the collection of standardized data and its free flow.

Modelling, calibration, and validation – Akinseye Folorunso

Akinseye Folorunso presented on modeling, validation, and calibration. He said that calibration is important to obtain or determine genetic coefficients for news crop cultivar, evaluate the model for a new region and evaluate hypothetical model improvements. He noted that calibration follows these steps.

- Step 1: Calibrate crop development using actual weather data, date, maturity date, leaf number per plant etc.
- Step 2: Calibrate dry matter accumulation by comparing observed and simulated data. Crop biomass and components, leaf area index (LAI), etc.
- Step 3: Calibrate yield and yield components. Grain yield and components

He went on to explain that model validation refers to the process of confirming that the model achieves its intended purpose and is carried out after model calibration. Model validation is important as it allows scalability and flexibility, enhances model accuracy, prevents the model from over- and under-predicting and helps expose more errors. Model Statistical Criteria frequently used include the Mean Bias Error, and the Normalized Root Mean Square Error.

Simulating basic growth processes – Dirk Raes

Dirk Raes gave a presentation on simulating the basic growth process. He lectured on growth engines and mentioned that the types of growth engines include:

- Water-driven growth engines which use AQUACROP
- Solar-driven growth engines which use DSSAT and Agricultural Production System Simulator (APSIM)
- Carbon-driven growth engines which are the Mechanistic and Explanatory Model

He went on to explain the Wageningen crop models and highlighted the importance of the ASTRO module. Regarding thermal time, he talked about the need to adjust the length/duration of development stages to the temperature regimes of the distinctive years. In addition, he talked about canopy development expressed as the LAI and green canopy cover (CC). Lastly, he talked about crop transpiration. He stated that the reference evapotranspiration was computed using the Food and

Agriculture Organization of the United Nations (FAO) Penman-Monteith equation from meteorological data.

Multi-modeling approaches – Karuturi Rao

In a brief presentation, Karuturi Rao differentiated between empirical/statistical models and dynamic/process-based models. He mentioned that the multi-modeling approach involves running the same system with several models, which brings a better understanding of the uncertainty, or involves integrating models simulating different systems or components of the system, which brings a better understanding of the dynamics of the whole system. He noted that multi-modeling approaches are commonly used in climate and industry simulations but not in simulating agricultural systems.

Moreover, he mentioned that the Integration of models coupled/linked with other tools like remote sensing should be considered more than the comparison of models in the future. He also highlighted the importance of understanding model limitations and questioned the necessity of having an ensemble of models versus improving existing ones.

Simulating phenological development – Nirman Shrestha

Nirman Shrestha gave a brief presentation on simulating phenological development. His presentation focused on how AquaCrop simulates phenological development. He explained that GCC is used to determine canopy cover instead of LAI because it is easy to use and observe. He also stated the importance of collecting canopy cover data at the same time every day to obtain uniform results. He also discussed how AquaCrop simulates GCC for non-limiting and water stress conditions. In addition, he lectured on how AquaCrop simulates the expansion of root zone for non-limiting and restrictive conditions. During the ensuing question and answer session, it was emphasized that canopy cover relates more to DSSAT and APSIM through biomass. The same session highlighted that readily available open-source software, such as Sigma Scan Software, can be used to determine canopy cover from pictures.

Group work

The participants were put into three groups for various practical exercises as follows:

DSSAT

The Decision Support System for Agrotechnology Transfer (DSSAT) is a crop simulation platform that homogenizes inputs and outputs to run several process-based models that share common modules. The DSSAT research tool for crop production analysis incorporates crop-soil-weather models and analysis tools, such as uncertainty and economic models. The DSSAT-CERES-Maize model is widely applicable to assess the effects of climate change on crop production, and it can also evaluate the best management options under changed climate scenarios. The group used DSAAT for various exercises throughout the workshop training.

AquaCrop

AquaCrop is a FAO crop model that simulates crop and soil response to water stress under various climatic, soil, crop and management conditions. It is a water-driven growth model with a simple structure that requires limited inputs. The model has different modules: the soil module contains the water balance, which makes the AquaCrop model different from other models; it separates the soil evaporation from crop transpiration-based Ritchie's' water balance approach. The plant module encompasses crop growth, development, and yield processes. The atmosphere module addresses thermal regime, rainfall, evaporative demand, and CO_2 concentration.

APSIM

The Agricultural Production System Simulator (APSIM) is a farming system model developed by the Agricultural Production Systems Research Unit (APSRU) to assess risk management in agricultural production. Within APSIM, a series of modules are grouped and categorized as crop, management, soil, and the environment.

Day 2: Data, databases, and climate modeling

Mabhaudhi led the day 1 recap focusing on 10 recap points, food for thought questions and participants giving feedback on activities from their respective groups on activities related to the different models. All groups had made little progress due to among other reasons had not downloaded the appropriate models.

Databases and climate modeling – Siyabusa Mkuhlani

Siyabusa Mkuhlani presented the data and databases available for use publicly. He talked about the rationale referring to Chimonyo's presentation on minimum data requirements. He also spoke about how data quality and quantity become a limitation in the data sets. A concern regarding the lack of sufficient data was raised, and it was agreed that organizations need to share data with their partners. Some sources of free external public or generic data sets were shared. However, it was noted that different data set sources have different precision and accuracy for different parameters. Therefore, it was considered better to compare sourced data from different sources for improved accuracy. It was also noted that there that in needs to advocate for more open-source data by involving more individuals, institutions and organizations.

After the presentation, participants were divided into groups to list additional data sets not included in the presentation, provide the URL of the sources, and describe how to access the data. Participants were asked to make PowerPoint presentations of their results and share them with Mkuhlani and Chimonyo.

Limitations of crop modeling approaches and alternate approaches –Anthony Whitbread

Anthony Whitbread, of the International Livestock Research Institute (ILRI), stated that crop models could be better, but they work. He presented on translating the model output into useful information. In response, it was agreed that there is need for expert interpretation and repackaging of information: whether crop modelers want farmers to understand and trust crop models and their output, whether crop modelers want farmers to understand and trust crop models and their output, or just want them to use the information provided and interpreted by experts.

Whitbread went on to state the limitations of crop modeling. It was highlighted that coupling in-season weather forecasts and seasonal and long-term climate forecasts can provide farmers with valuable information that, when interpreted by experts, can help them make informed decisions and reduce risk. One major limitation of modeling was identified as its inability to make recommendations. Therefor there is a need to have experts from different domains who can interpret model outputs to translate them into usable information. Participants were given an exercise to carry out in their model groups.

Day 3: Model sensitivity and yield gaps

Mabhaudhi led the recap session using the 10 points from Day 2 and the food for thought questions. Participants were then asked to give feedback and present the results of their exercises from Day 2. All groups made presentations based on their simulation outcomes from the exercises. However, they cited the need for more required data noting that they had spent much time searching for missing data and correcting the existing data.

Sensitivity analysis – Nirman Shrestha and Vimbayi Chimonyo

Nirman Shrestha and Vimbayi Chimonyo lead the section of sensitivity analysis. The main objectives were to:

- Understand what sensitivity analysis.
- Understand why it is carried out.
- Understand how sensitivity analysis is done

Sensitivity analysis was defined as the study of how the variation in the output of a model can be apportioned. It is carried out so that modellers determine how sensitive the model output is to changes in model inputs, and it shows the factors that interact mutually. They described the types of sensitivity analyses and how to use them. The participants were given the assignment to carry out sensitivity analysis on millet yield in their model groups.

Water and nitrogen-limited yield – João Vasco Silva

João Vasco Silva began his presentation by talking about grand challenges for crop production, including diverging agricultural production methods paradigms. He went on to talk about yield gap analysis and stated that crop models are the backbone of yield gap analysis. He stated that one can now estimate the maximum yield of a given place and compare it to what is given on the farm, but noted that limiting factors are often beyond the field level. He elaborated on the crop models for yield gap decomposition giving examples of wheat in Northeast Europe and sowing date and variety for rice in South East Asia. Silva also explained that crop models simplify reality and he encouraged participants to know models, their limitations and to challenge the models with empirical data.

Lastly, he encouraged participants to be creative and use models to generate and test hypotheses as part of simulation and experimentation cycles, as all models are prone to error, but some are useful. The participants were given practical exercises to carry out. They are using the experimental data from African Africa pearl millet crops.

Day 4: Soil, nitrogen, and water dynamics

The day started with a recap of Day 3 lectures using the 10 summary points of the day. All groups complained regarding the quality and quantity of data shared. Walker apologized for the inconvenience and explained that she was trying to get the accurate data sent in. However, Mabhaudhi stated that this was the real-life situation crop modellers were facing because of data shortage, so, it was a learning curve for the participants. AquaCrop and DSSAT presented their results, while APSIM could not as they had not finished their exercise due to poor quality and quantity data. They eventually downloaded additional data from public sources to make corrections to the existing files.

Modeling soil water dynamics – Dirk Raes

In a brief presentation, Dirk Raes lectured on the root zone as a reservoir. Regarding this, he mentioned that the rooting zone acts as a water reservoir. An increase in the rooting depth increases the reservoir size. He went on to talk about the time-depth grid and how water movement in a model considers a time-and-depth grid. Modelling soil water dynamics can be applied to irrigation scheduling. He then illustrated the required soil profile characteristics and how initial soil water should be described in each compartment. He also talked about how water movement is simulated using one-dimensional flow when modeling soil water dynamics and how the tipping bucket is the most common method used to depict water movement in soils. During the subsequent question and answer session, it was indicated that Aqua Crop has variables for saltwater dynamics. The participants were then given an exercise on modeling soil water dynamics to perform in their different groups.

Modelling soil carbon and nitrogen dynamics – Diego Pequeno

Diego Pequeno gave a presentation on modeling soil carbon and nitrogen dynamics. He highlighted that soil organic carbon could affect response to nitrogen and lectured on the DSSAT crop modeling ecosystem, explaining how the applications and support software are linked with databases. He emphasized the importance of considering the different attributes in the soil layers when modeling carbon and nitrogen dynamics. He said that initial soil conditions are important in understanding water and nutrient dynamics and described the processes simulated in the nitrogen module and nitrogen balance. In addition, Pequeno talked about CERES and CENTURY as DSSAT modules for soil organic matter highlighting their differences.

Lastly, he talked about the applications of the model, which include being applied to determine the optimum rate and timing for nitrogen application and to determine greenhouse gas emissions and carbon sequestration. The participants were then given a group work exercise on modeling soil carbon and nitrogen.

Day 5: Crop simulation models as decision support tools for climate impact and change

Wrap-up session

The wrap-up session was a combination of a question-and-answer session and a conversation on climate change impact assessment. Tafadzwa Mabhaudhi led the discussion during which climate change's impact on crops and humans was emphasized as a key variable. Modelling using Aqua Crop can help predict the effects of how various climate change parameters increase or decrease. It was also mentioned that modeling results could be used to carry out economic assessments of multiple projects to guide the choice of the most viable one. Trainees were encouraged to get more familiar with the models and carry out the climate change assessment using a combination of models, as this increases the accuracy of output.

The APSIM group managed to give a presentation of all their exercises as they had completed them, while DSSAT and AquaCrop groups gave feedback from Day 4.

Closing remarks from trainers and host

All the trainers started by thanking the host for the well-organized and impactful workshop training.

Karuturi Rao

Rao told the participants that learning and applying crop models could be achieved through five steps:

1. Understanding the software
2. Understanding the science behind the processes
3. Preparing to run models using own data
4. Calibration and validation to ensure the model represents the system better
5. Application to real situations and problems you want to solve

He went on to say that nothing is directly transferable. To learn more, one has to practice more. He also highlighted that there is a need to follow up with the participants after the training.

Sue Walker

Walker encouraged the participants to always to ask the right questions to get the right answers and that there is a need to understand the models. She also said modellers always need to remember whom they serve. Walker highlighted that participants should keep trying to address "models" errors and consult the after-training platforms to be created for assistance. Lastly, she shared an inspiring quote, "Failure is often the backdoor to success, keep pushing and working hard"**.**

Siyabusa Mkuhlani

Mkuhlani mentioned that much investment had been done across the continent for crop modeling and there is a need to improve the capacity of people in modeling. He also encouraged the participants to go and practice modeling using their data, to know the strengths and weaknesses of the models and to add value to crop modeling. Siyabusa also highlighted a need to increase capacity development in crop modeling, including using R and Python software. Complementary training in these areas and paper writing training should also be part of capacity development.

Dirk Raes

Raes mentioned that most of the focus during the training exercises was on yield but water use efficiency should have also been addressed. He noted that in one of the examples, yield did not increase much in millet, but a lot of water was used, which might have been used better for another crop.

Diego Peqeuno

Pequeno advised the team always to work hard when using crop models because their use requires learning through solving problems. He also encouraged them to keep asking questions and work together to solve problems and give feedback which will inform the organizers of their expectations for the next training session.

Vimbayi Chimonyo

Chimonyo thanked the trainers and participants. She also thanked EiA and SI-MFS for making the workshop possible and CIMMYT Zimbabwe for organizing it.

Evaluation survey

After the workshop, participants evaluated the workshop through the Google Form tool. Post-training evaluation gives an idea of what the learners thought of the course, but more importantly, it tells what has worked and what has not. Participants provided valuable insight into the training program from the learner's perspective for future training. Figure 1 indicates participants who were involved in AQUACROP, APSIM and DSSAT. Participants were fairly distributed based on which model one wanted to learn.

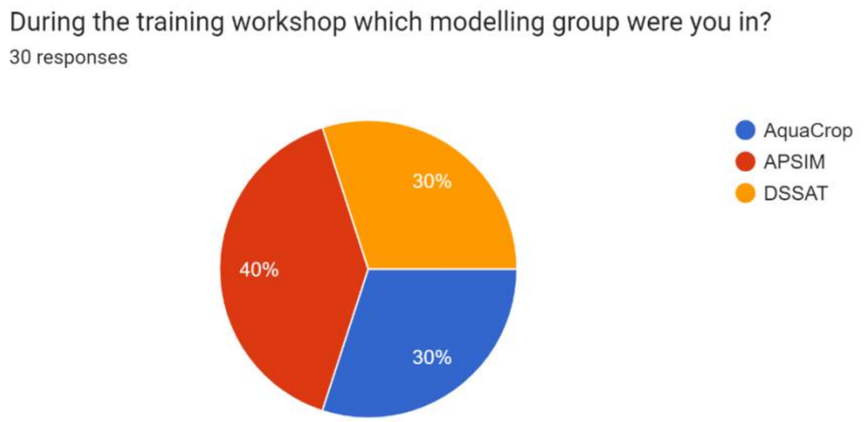

Figure 1: Percentage of participants of who attended AquaCrop, APSIM and DSSAT.

Several participants (63%) were familiar with APSIM and DSSAT, whilst 12 (40%) participants were familiar with AquaCrop. There were some participants who were familiar STICS, EPIC, SUCROS COCOA, RETC and Hydrological models as shown in Figure 2.

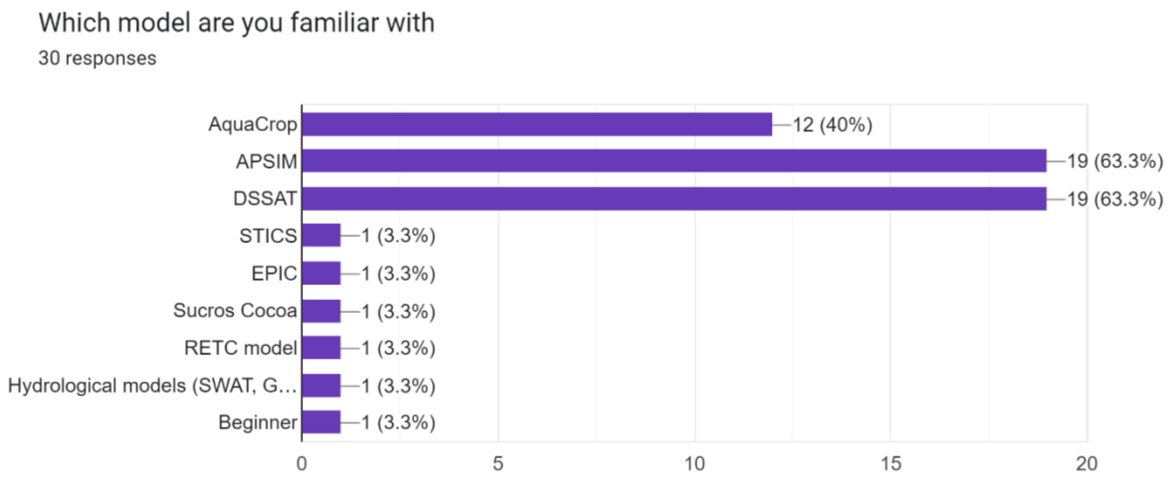

Figure 2: Distribution of expertism in crop models

Participants were asked which exercise they were most interested in and the answers are shown in Figure 3. About 80% of participants were interested in sensitivity analysis.

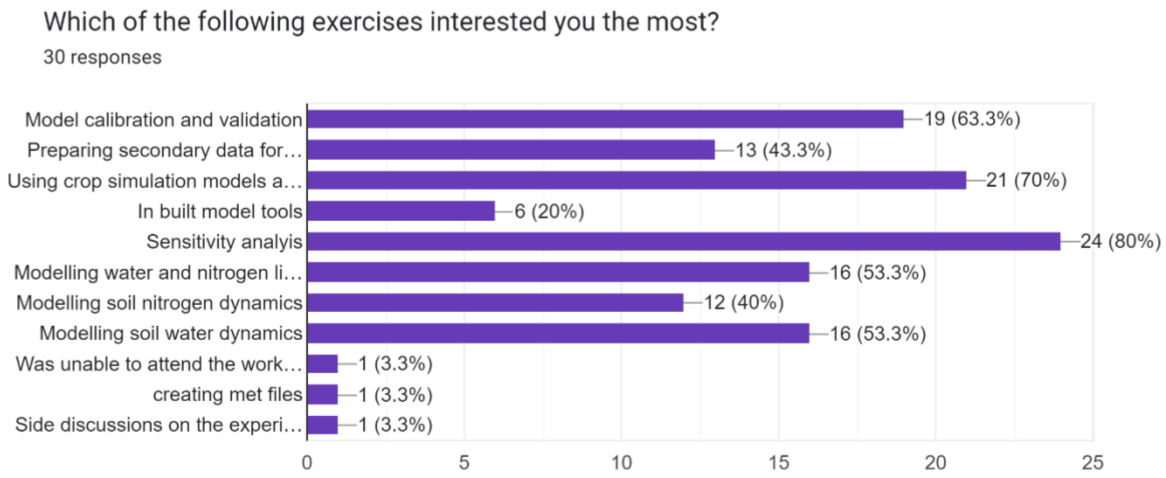

Figure 3: The exercise that interested participants.

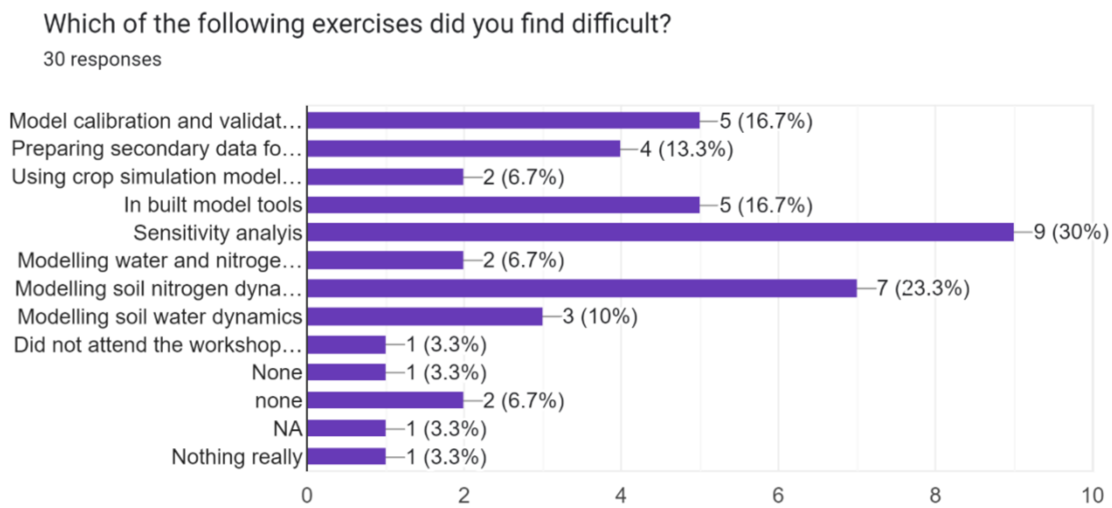

Figure 4: Exercise that participants found difficult.

Key findings and suggestions from participants

The evaluation form was used to summarize the key findings, suggestions, and future areas of research by crop modellers (Table 1).

Table 1 : Open-ended questions from evaluation forms

Questions	Responses	Recommendations
Why did you find the exercises chosen in the earlier question difficult?	• Modelling soil nitrogen dynamics was not available in AquaCrop, and since I was interested in this, I had to join the DSSAT group for the exercise • Because it takes time to evaluate the contributions of the genetic parameters to the variance of model predictions • We do not get enough time to run the model using the data provided. • The data was not enough for the exercise and had not yet been arranged (it takes time to solve issues • As an AquaCrop user, I felt the exercises were more tailored for programmers and other models (APSIM + DSSAT) • Too many parameters to adjust and simulations to run • Preparing the T file where the data is overlaid on the location and multiple years The data is in-depth, multi-location and multi-year, and we couldn't fully assess it due to limited time • Using DOS (non-window interface) for sensitivity analysis is time consuming has no option to go back if you miss a step; you to lose all progress and start again	• Experiment sites and weather stations to collect adequate data to carry out sensitivity analysis • More training and practical sessions are needed build capacity of crop modellers on sensitivity analysis
How are you using the model to address your research questions?	• Address future climate change effects on crop production • Predicting impacts of climate change on crop yields and soil fertility assessment studies • To assess the impact of climate change on different crop production systems and identify adaptation strategies • I will use the DSSAT model to assess the impact of climate change on crop yield and the dynamics of nutrients with the change in climate and soil management • Using it to simulate crop and biomass yields for the maize-legume intensifications in Malawi • To calibrate and validate the model using new maize varieties • To characterize sites in their potential yield • I will use AquaCrop for suitability analysis of selected indigenous crops	• Crop modellers to carry out scenario analysis to solve what-if questions for decision making at all levels (strategic, tactical, and operational)

	• Assessing the impact of climate change on water-energy-food (WEF) nexus. • Using the model to determine water limited yield • I will use the crop model to analyze, evaluate, and predict the crop growth and production in relation to nitrogen and water • I am using the models to help smallholder farmers and my country to cope with climate change • To address multiple research questions related improving productivity of targeted crops • I am using APSIM to evaluate crop diversification options under rainfed conditions	
What crop simulation modeling aspect would you like to learn more about?	• DSSAT • Crop simulation modeling for perennial crops • Climate risk and trade-off analysis • Whole APSIM • How does the model interact with data input to predict variables • Water and nitrogen-limited yield, to quantify the effect of climate change on crops • Water and nitrogen-limited yield and to quantify effects on crops • Linking APSIM simulations with geospatial analysis and R or Python • To find the effects of intercropping on crop yield	• Crop modellers to do more geospatial analysis using machine learning skills • Crop modellers to use crop models for climate risk and trade-off analysis • Researchers to understand water and nitrogen-limited yield and to quantify effects on crops

Annexes

Annex 1. Program/Agenda

Agenda (all times GMT+2)

Time	Agenda Item	Facilitator
Day 1	08h30: Registration	CIMMYT
	Introductions and overview - History of crop modeling - Minimum data sets required for crop modeling - Modelling calibration and validation - Modelling confidence testing (statistics) - Simulating phenological development - Simulating basic growth processes 13h30 – 17h00: - Lecture 1: Multi-modeling approaches (ALL) - Overview of Aqua Crop, DSSAT and APSIM crop models (ALL) - Exercise 1: Model calibration and validation (Group work) - Group presentations and discussion	
Day 2	8h30 – 12h30: - Recap from the previous day (ALL) - Lecture 2: Data and databases (Global adaptation atlas, Carob) for crop modeling (ALL) - Exercise 2: Preparing secondary data for modeling (ALL) - Group presentations and discussion (ALL) 13h30 – 17h00: - Recap from the previous day (ALL) - Lecture 3: Limitations of crop modeling approaches and alternate approaches (ALL) - Exercise 3: In-built model tools (Group work) - Group presentations and discussion	CIMMYT
Day 3	Model sensitivity and yield gaps 8h30 – 12h30: - Recap from the previous day (ALL) - Lecture 4: Sensitivity analysis (ALL) - Exercise 4: Sensitivity analysis (Group work) - Group presentations and discussion 13h30 – 17h00: - Lecture 5: Water and nitrogen-limited yield (ALL) - Exercise 5: Modelling water and nitrogen-limited yield (Group work) - Group presentations and discussion 1. Workshop background and objectives – IWMI	CIMMYT

Day 4	Soil, nitrogen and water dynamics 8h30 – 12h30: - Recap from the previous day (ALL) - Lecture 6: Modelling soil carbon and nitrogen dynamics (ALL) - Exercise 6: Modelling soil nitrogen dynamics (Group work) - Group presentations and discussion 13h30 – 17h00: - Lecture 7: Modelling soil water dynamics (ALL) - Exercise 7: Modelling soil water dynamics (Group work) - Group presentations and discussion	CIMMYT

Annex 2. List of Participants

S/N	Name	Organization	Country
1.	Bethel Geremew Shefine	Haramaya University	Ethiopia
2.	Vimbayi Chimonyo	CIMMYT	Zimbabwe
3.	Sue Walker	ARC	South Africa
4.	Tafadzwa Mabhaudhi	IWMI	South Africa
5.	Antony Whitbread	ILRI	Tanzania
6.	Karuturi Rao	ICRISAT	India
7.	Dirk Raes	KU Leuven	Belgium
8.	Diego Pequeno	CIMMYT	Mexico
9.	Nirman Shrestha	IWMI	Nepal
10.	Siyabusa Mkuhlani	IITA	Kenya
11.	Folorunso Akinsye	ICRISAT	Senegal
12.	Rose Faju	CIMMYT	Zimbabwe
13.	Macdonald Makombe	University of Ghana	Ghana
14.	Abdhullahi Tofa Nigeria	IITA	Nigeria
15.	Bello Muhammed	Bayero University	Nigeria
16.	Helen Peter	IITA	Nigeria
17.	Kamalludin Tiijan	IITA	Nigeria
18.	Pacsu Simwaka	DARS-Malawi	Malawi
19.	Kizito Kwena	Kenya	Kenya
20.	Paulina Ansaa Asante	Wageningen University	Netherlands
21.	Ali Malam Labo Mohammed	ICRISAT	Niger
22.	Mendy- Ndhlovu Makhathini	University of Kwazulu Natal	South Africa
23.	Cuthbert Taguta	University of Kwazulu Natal	South Africa
24.	Siboniso Magwaza	University of Pretoria	South Africa
25.	Nurudeen Abdul Rahman	IITA	Ghana
26.	Tendai Chibarabada	ZSAS	Zimbabwe
27.	Dennis Choruma	CTAFS	Zimbabwe
28.	Eleanor Matsamba Magwaza	CIMMYT	Zimbabwe
29.	Tarirai Muoni	CIMMYT	Zimbabwe
30.	Tinashe Dirwai	IWMI	South Africa
31.	Jacob Emmanuel	ILRI	Tanzania
32.	Donald Nyamayevu	CIMMYT	Zimbabwe
33.	Constance Madembo	CIMMYT	Zimbabwe
34.	Adebayo Oke	IWMI	Ghana
35.	Almaz Meseret Gazagegn	EIAR	Ethopia
36.	Firew Gebremariam	Haramaya University	Ethopia
37.	Girma Chala Tulu	EIAR	Ethopia
38.	Hirut Getachew Feleke	Ambo University	Ethopia
39.	Theodrose Sisay Hailu	EIAR	Ethiopia
40.	Mekides Woldegiorgis Gardi	University of Hohenheim	Ethopia
41.	Elliot Ronald Dossou- Yovo	ARC	Cote d’lvoire
42.	Laminou Kombi Ibrahim	Sokoine University of Agriculture	Ethiopia
43.	Birhan Abdulkadir Indris	CIMMYT	Ethopia
44.	Gebrekidan Feleke Mekuria	EIAR	Ethopia
45.	Helen Teshome Tesfaye	Wolaita Sodo University	Ethiopia
46.	Wuletawu Abera Worku	ABC	Ethopia

47.	Hillary Mugiyo	Ministry of Agriculture	Zimbabwe
48.	Tawanda Hove	CIMMYT	Zimbabwe
49.	Jane Mugo	IITA	Kenya
50.	Bolyne Chapeyama	University of Zimbabwe	Zimbabwe

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