Protocols for AgMIP Crop Model Improvement Teams

K. J. Boote and J. W. Jones

May 14, 2013

Rationale for Crop Model Improvement Teams

Crop growth models play an important role in systems research when used as tools to synthesize and interpret benefits of various technologies (improved cultivars, management, etc.) for improving production under present-day as well as future climate conditions. They also play an important role in evaluating options and analyzing them to extend information from field trials. Crop modeling has advanced considerably over the past 30 years and has become more widely used in many applications. However, mechanisms in crop models need to be improved in a number of areas, for predicting heat, drought, and biotic stresses under climatic change world-wide, as well as improving predictions of soil nutrient uptake and rooting systems for production under infertile, stressful environments in tropical and subtropical regions.

AgMIP crop model improvement teams are organized to re-evaluate existing crop models (or develop new models for orphan crops) for use under a wide range of conditions and to improve their effectiveness in predicting productivity using traditional as well as new technology options. These teams include crop modelers and experimentalists working to add new capabilities to existing models for addressing the various stresses that limit productivity, working with experimental data to develop, test, and document improved capabilities. In this document we suggest approaches and organizational strategies for crop model improvement teams to follow to improve models, using experimental data for developing, testing, and documenting improved abilities as well as improving the physiological, physical, and chemical functional relationships contained in the computer code and model parameterization.

Well-developed and tested models exist for some crops (i.e., maize, wheat, and rice); however, most of these models lack some of the capabilities needed to address constraints faced by farmers and dealing with extreme climate events such as water deficit, water-logging tolerance, and heat stress as well as genetic by environment by management interactions. For these crops, the model improvement teams will focus on assembling data from past experiments and designing new experiments to provide data needed to evaluate and improve model capabilities. For other important crops, such as sorghum, soybean, bean, cowpea, and peanut, there are an intermediate number of models (several), but the same problems persist. Also important, is the fact that crop models for some tropical subsistence crops (e.g., cassava, sweet potato, banana, yam, and millet) are very few in number and these models are very rudimentary. There is an urgent need to develop models for these orphan and lesser-known crops, and to include them in an experimental effort to obtain data for use in developing and evaluating them.

Crop models need improvement in a number of areas. Improvement are needed for under-developed tropical and subtropical regions in which crop models need better prediction of root growth (depth progression) and nutrient uptake in difficult tropical soils with low water-holding capacity, low organic matter, aluminum saturation, low pH, and impeding zones characteristic of tropical soils. Better root growth algorithms are needed to account for static and dynamic soil properties (aluminum saturation, pH, soil temperature, soil impedance, soil fertility, soil water deficit as well as hypoxia stresses). Feedback effects from poor root growth or root signals (from drying soil or impedance) are needed to reduce shoot growth. Very few crop models account for P uptake and P stresses on growth. The APSIM and DSSAT models have some capabilities in this area, but the models are not well parameterized or tested. There is an urgent need to include soil fertility/soil chemistry scientists in some teams who can help model phosphorus exchange and availabilities in the soil, P uptake by roots, and P effect on plant growth and yield.

Most crop models currently handle soil water deficit reasonably well based on soil water balance and evapotranspiration approaches. However, very few models do a good job of predicting effects of hypoxia (oxygen deficit) associated with water-logging. In visits with rice and maize plant breeders, we learned that target breeding traits they considered to be most important included varieties with higher yield potential, along with tolerance to abiotic stress environments to include drought, heat, water logging (submergence in rice), and acid soil-Al saturation.

Almost all crop models have a soil nitrogen (N) balance, with functions to compute N uptake from the soil, and a plant N balance that accumulates N in vegetative tissue, and re-distributes it to grain during reproductive growth. However, under conditions with low N in infertile soils characterized by low organic matter content in tropical and subtropical regions, the models need improved soil organic carbon (C) models to accurately predict crop yield responses to low N inputs. Input knowledge required for good predictions is considerable, including the ratio of stable to readily-mineralizable organic C, the amount and type of prior crop residue, the initial soil nitrate and ammonium, as well as initializing the soil water balance at sowing. This area will require good experimentation as well as improvement of model code. A spin-off of this effort is that the models will thus also be improved for predicting nutrient cycling, nutrient management, and nutrient leaching under intensive production agriculture.

Model improvement for climatic change effects of elevated temperature and heat stress is needed for nearly all crop models. There is a special need to test and improve crop models for heat stress effects on grain-set near the time of anthesis and reproductive setting, as this is rarely found in crop models. The models need to be more mechanistic in this respect. The CG centers are actively screening germplasm of various crop cultivars of maize, rice, sorghum, millet, chickpea, and groundnut for tolerance to elevated temperature, under the threat of future climate change. Prior to using crop models as viable tools for evaluating heat-tolerance germplasm, it is important to put heat-stress mechanisms into the correct places in the various crop models. This will require attention of crop modelers in conjunction with crop physiologists.

Proposed Goals of Model Improvement Teams:

> To test and improve models that simulate important crops and livestock systems so that they respond to the full range of soil, climate, and management conditions in both developed and developing countries that farmers face now and are likely to face in future climate conditions.

Framework for Proposed Crop Model Improvement Activities

Teams composed of crop modelers and experimentalists will be organized to improve models for each selected crop. Concepts and data will be shared among the team members through a series of WebEx meetings to evaluate existing models (including functional relationships used to model different processes), to design new experiments when needed, and to develop improved models with components that can be adopted by various modeling groups that are participating in the teams. We have demonstrated the considerable interest in doing this with a current AgMIP maize model improvement team working together. We envision a team for each of several selected crops, plus a team for soil nutrient-limitation issues, and teams for each of several major disease models. Each team will need resources for an experienced crop modeler (part time) to lead the team, a full time post doc to implement model improvements (and handle correspondence and data organization), and a graduate student to assist with data and analyses as well as to learn from the interactions. The leadership of each team will facilitate data entry, data sharing, code improvement, model testing, and paper-writing in a way that fully involves and credits those who collected the data. Involvement of CG centers in these teams is valuable for linkage to good experimental data on crops, and providing meeting venues.

We suggest that an open community of like-minded crop modelers be linked in some type of project, where ideas are shared in WebEx type meetings on approaches for modeling certain biological processes for responses to given abiotic and biotic stresses. We propose that existing data be assembled (also new experiments designed as needed and time and resources permit) and made broadly available for testing and developing such improved crop model features, again in a sharing mode to discuss the reasons, methods, and benefits for taking a given approach. The AgMIP community of multiple crop modelers has begun to establish such crop modeling communities centered around individual crops (wheat modelers, rice modelers, maize, sorghum-millet, groundnut, potato, etc.). Those communities are right now beginning to test their crop models against elevated temperature data and elevated CO_2 data. Of particular note, a group of us are involved in the Maize Model Improvement Group, which is doing code improvement and maize model testing with open WebEx meetings. Such crop modeling groups could be encouraged to participate in similar activities around critical model improvement needs listed above, as the problems are the same across many of the models. Sharing of data and ideas across different models will be facilitated as we get better interoperability of crop models, which is being assisted by AgMIP development of translators that convert model-ready files from one model to another crop model.

We also suggest improved linkage with experimentalists at CG centers, NARS, and developed countries, for the purpose of sharing and making use of already collected data that has potential value for model improvement. And of interest to the experimentalists, additional secondary publications with impact from their research will result. Depending on funding, needed crucial experiments could be set up with scientists in tropical and developing as well as developed countries to collect data needed to test new algorithms. Again, shared publications and knowledge sharing and transfer would result.

We hope to identify data that needs to be collected for improving the parameterization of the different crop models. Which CG centers or NARS stations can this work be done at? Are we thinking about genetic coefficients for cultivars? If so, expand that and document why that is needed (baseline for impact studies?) Or generically, to test N balance or water balance or water-logging effect or heat-stress or P stress? What do we need to do? In all cases, it is important to also collect good weather data, soil characteristics, crop and soil measurements in those various experiments designed to collect data to improve crop models or test new production technologies.

Collected data needs to be stored in a way that it is available for the future community of scientists who may see a future need. Where data is collected from region-wide yield surveys, that data may need a spatial dimension for storage and access. The AgMIP project has an ongoing effort to create a database system for such information and is working to link with AgTrials and CCAFS on databases.

Suggested Guidelines for AgMIP CMITs (Crop Model Improvement Teams)

1. Overall CMIT Leader with responsibilities of establishing specific model improvement goals, activities and a timetable, organizing and coordinating team meetings (virtual and in person), and communicating to all team members, AgMIP, and funding authorities. The CMIT Leader may be a crop modeler or an experimentalist. If an experimentalist, he/she would generally be responsible for coordinating the data gathering aspects and leading the discussions on process responses to climate, soil, and management conditions. If a modeler, he/she would generally be responsible for development and evaluation of

functional relationships for specific processes and for a person (i.e., post doc) who would develop code for an improved model that would be made available to all participants.

2. A CMIT Co-Leader who would complement the expertise of the overall Leader as noted above. The Leader and Co-Leader will work with AgMIP leaders who will endorse the team's proposed goals and activities and help the leaders attract participants with expertise and data for contributing to model improvement.
3. Participants who are crop modelers and experimentalists who are contributors to the data and the various model testing and improvement activities defined by the team.