Chapter 1

The Agricultural Model Intercomparison and Improvement Project: Phase I Activities by a Global Community of Science

Cynthia Rosenzweig[1,2], James W. Jones[3], Jerry L. Hatfield[4], John M. Antle[5], Alexander C. Ruane[1], and Carolyn Z. Mutter[2]

[1]*NASA Goddard Institute for Space Studies, New York, NY, USA*

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

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

[4]*United States Department of Agriculture, Agricultural Research Service, Ames, IA, USA*

[5]*Oregon State University, Corvallis, OR, USA*

Introduction

The Agricultural Model Intercomparison and Improvement Project (AgMIP) was founded in 2010. Its mission is to improve substantially the characterization of world food security as affected by climate variability and change, and to enhance adaptation capacity in both developing and developed countries.

The objectives of AgMIP are to:

- Incorporate state-of-the-art climate, crop/livestock, and agricultural economic model improvements into coordinated multi-model regional and global assessments of future climate impacts and adaptation and other key aspects of the food system.
- Utilize multiple models, scenarios, locations, crops/livestock, and participants to explore uncertainty and the impact of data and methodological choices.
- Collaborate with regional experts in agronomy, animal sciences, economics, and climate to build a strong basis for model applications, addressing key climate-related questions and sustainable intensification farming systems.

- Improve scientific and adaptive capacity in modeling for major agricultural regions in the developing and developed world, with a focus on vulnerable regions.
- Improve agricultural data and enhance data-sharing based on their intercomparison and evaluation using best scientific practices.
- Develop modeling frameworks to identify and evaluate promising adaptation technologies and policies and to prioritize strategies.

The AgMIP Community of Science

There are now over 700 members of the AgMIP global community of science. AgMIP has built a dynamic and innovative international community of agricultural researchers to enable more robust agricultural-sector decision-making from local to global scales. One of AgMIP's biggest successes has been its ability to demonstrate goodwill and honest collaboration across previously competing modeling groups, providing a productive space to undertake challenging research endeavors. AgMIP Global Workshops anchor this community and facilitate collaboration to set agendas, design protocols for AgMIP activities, and encourage in-kind contributions to unravel the most difficult challenges in food-security modeling. Attendance at AgMIP's Global Workshops has risen by an average of ~50% each year, with 250 participants at the latest workshop held in 2013. AgMIP also maintains a project listserve and website featuring information and tools for the scientific and lay public (Fig. 1) (www.agmip.org).

International AgMIP community activities are designed to further the mission of AgMIP toward conducting state-of-the-art assessments of climate impacts on food security at local, regional, and global scales. Among other functions, AgMIP maintains a science integration and coordination office at Columbia University in New York, conducts training on multiple crop and economic models, and creates information-technology tools.

Science Approach

Since 2010, AgMIP has engaged stakeholders and researchers to assess climate impacts on food security and plan for a more resilient future. AgMIP has built a cutting-edge assessment framework on both global and regional scales, which links climate, crops, livestock, and economics to help decision-makers better understand how climate change will reverberate through complex agricultural systems and markets. Prior to AgMIP, the majority of studies on the impacts of climate change on the agricultural sector utilized only a single crop model, did not address economic implications or the potential for adaptation, and featured methodological differences

Fig. 1. Screenshot of AgMIP website (www.agmip.org).

that severely limited comparison or aggregation of studies. AgMIP's approach eliminates these shortcomings and increases the rigor of scientific information that can aid in stakeholder decisions.

AgMIP brings together world leaders in climate, crop, livestock, and economic modeling to form the necessary framework to understand climate impacts on food security (Fig. 2) (Rosenzweig *et al.*, 2013b). That framework is based on a two-track science approach, with Track 1 focusing on model intercomparison and improvement, and Track 2 focusing on climate change multi-model assessment. Three cross-cutting science themes are *uncertainty*, *aggregation and scaling*, and *representative agricultural pathways* (RAPs; see Part 1, Chapter 5 in this volume). To accomplish this scientific approach, the work of the first phase of AgMIP was carried out by four teams: Climate, Crop Modeling, Economics, and Information Technology.

AgMIP Initiatives

AgMIP enables, supports, and provides oversight for a range of initiatives. These include (clockwise from top of Fig. 3) global economic assessments and global crop

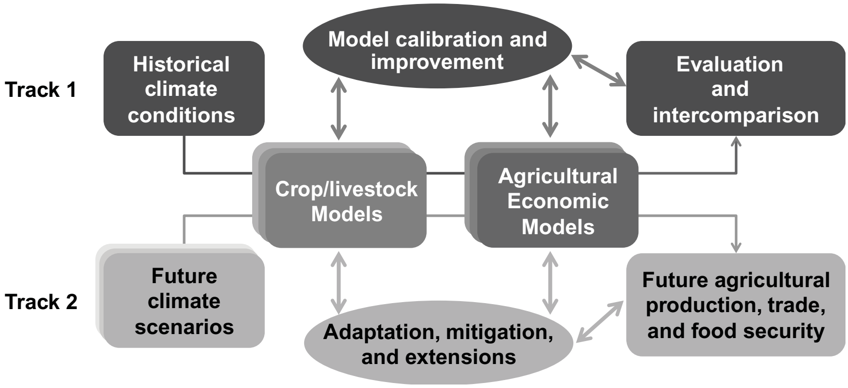

Fig. 2. AgMIP's dual scientific tracks create a robust framework capable of analyzing adaptation and policy decisions (from Rosenzweig *et al.*, 2013b).

modeling activities (via AgGRID; AgMIP GRIDded Crop Modeling Initiative), the development of next-generation models incorporating enhanced economic and environmental interactions, data and tools to facilitate multi-model and multi-discipline assessments, activities to understand and improve existing crop and livestock models, cross-cutting themes to help interpret agricultural model results for decision-making, and efforts to include the wider network of crop modelers around the world for future assessments (C3MP; Coordinated Climate-Crop Modeling Project).

To fulfill its mission, AgMIP is carrying out these initiatives on global and regional scales. Results from these initiatives contributed to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (e.g., Asseng *et al.*, 2013; Rosenzweig *et al.*, 2013a; Rosenzweig*et al.*, 2013b; Müller and Robertson, 2013; Nelson *et al.*, 2013; Piontek *et al.*, 2013). They provide important context for national and regional stakeholders interpreting climate change risks, further state-of-the-art global food-security assessments and agricultural models, and deliver important inputs, such as commodity prices, into regional integrated assessments.

Crop model intercomparison and improvement

AgMIP's wheat, maize, rice, sugarcane, potato, livestock, and sorghum/millet teams were organized to test the robustness of crop model projections of climate impacts on agricultural production with a particular emphasis on intermodel uncertainty and validation against high-quality field data (Asseng *et al.*, 2013; Bassu *et al.*, 2014; Li *et al.*, 2014). Each crop model intercomparison and improvement study selected a number of high-quality field sites, which ranged from partial information (to mimic data available at most locations) to nearly complete information levels

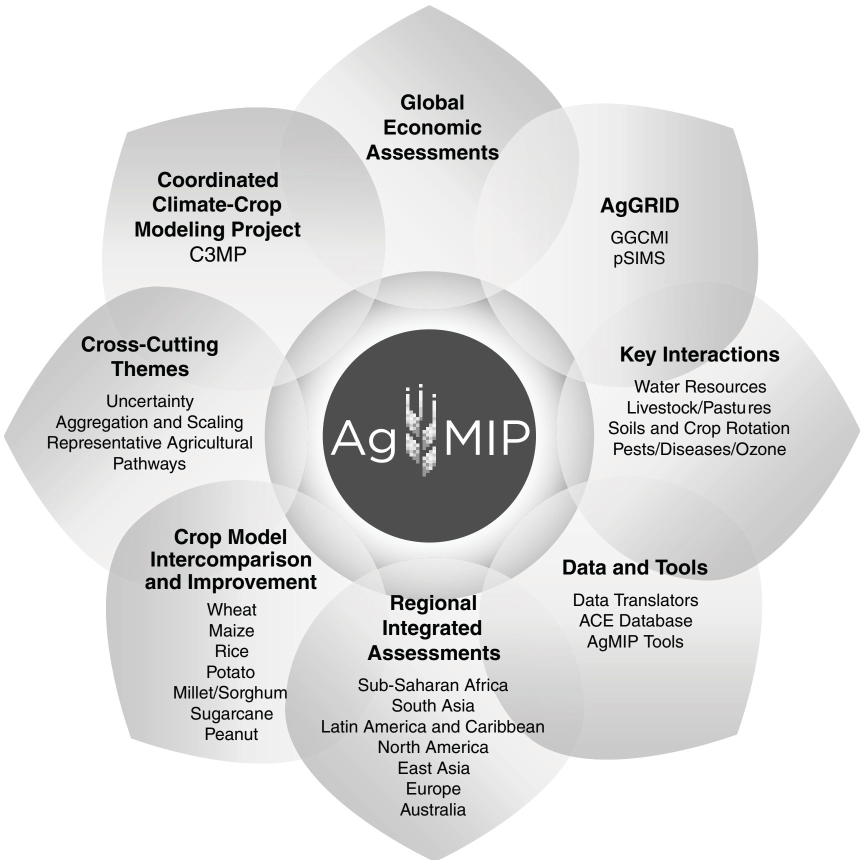

Fig. 3. AgMIP research and applications activities in support of integrated assessment of food security and agricultural impacts of climate change. GGCMI, Global Gridded Crop Model Intercomparison; pSIMS, Parallel System for Integrating Impact Models; ACE, AgMIP Crop Experiment database.

in order to gauge fundamental responses to temperature, rainfall, and CO_2 concentration changes. Each study includes sites in developing country regions, including Sub-Saharan Africa and South Asia, e.g., Delhi, India (wheat); Ludhiana, India (wheat); Morogoro, Tanzania (maize); La Mercy, South Africa (sugarcane); and Gisozi, Burundi (potato).

Figure 4 shows temperature and CO_2 responses from 27 models participating in the wheat model intercomparison, which reveal substantial intermodel uncertainties around a robust decline in yields with higher temperatures and increase in yields with higher CO_2 (Asseng *et al.*, 2013). Intercomparisons such as these provide important information to stakeholders who must manage risk with access to only one or perhaps two sets of crop model results.

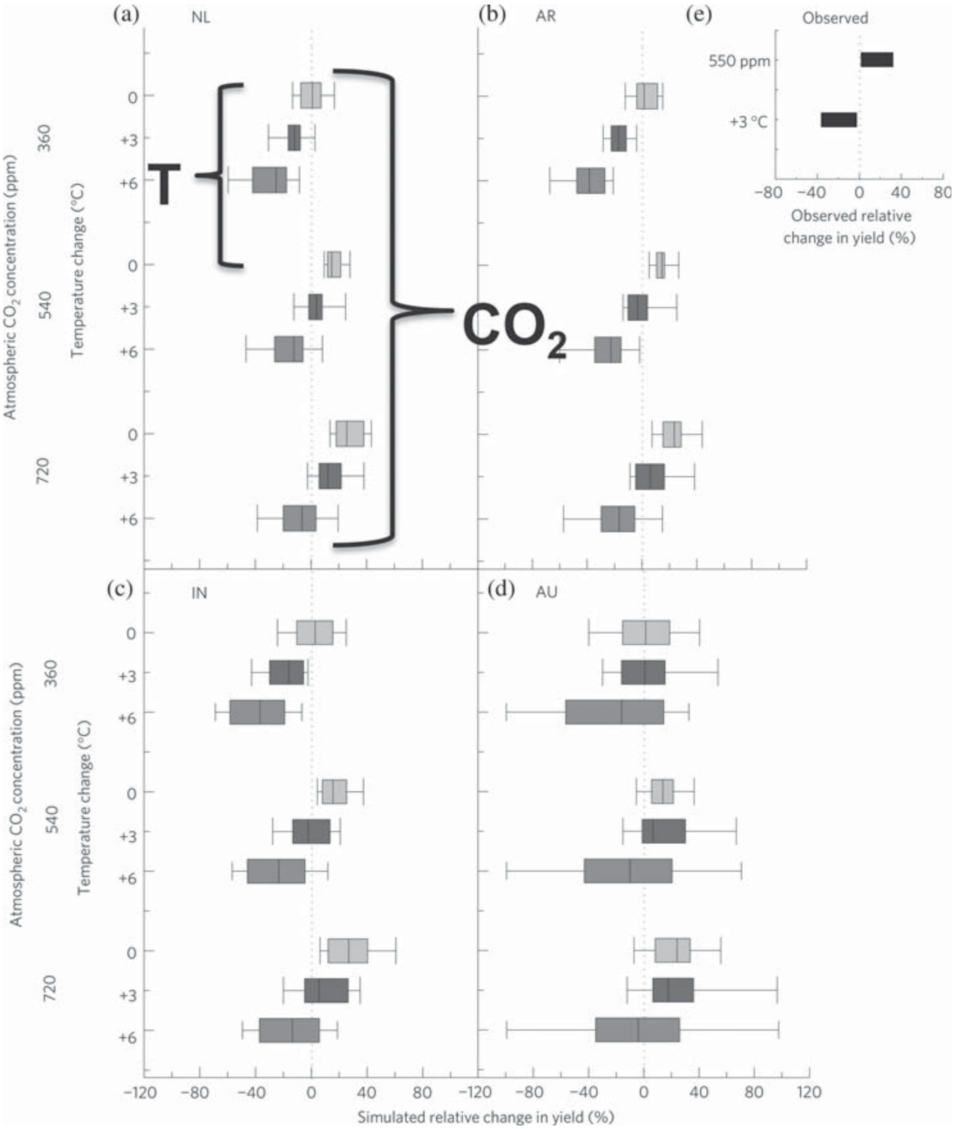

Fig. 4. Response of 27 wheat models to temperature (T) and CO_2 changes from the AgMIP wheat team. AR=Balcarce, Argentina; NL=Haarweg, the Netherlands; IN=Delhi, India; AU=Wongan Hills, Australia. From Asseng *et al.* (2013).

Coordinated Climate-Crop Modeling Project (C3MP)

AgMIP's Coordinated Climate-Crop Modeling Project (C3MP) engages with the world's crop modeling community, providing simple protocols and tools to assess fundamental climate responses on a diverse network of sites and crop models (Fig. 5).

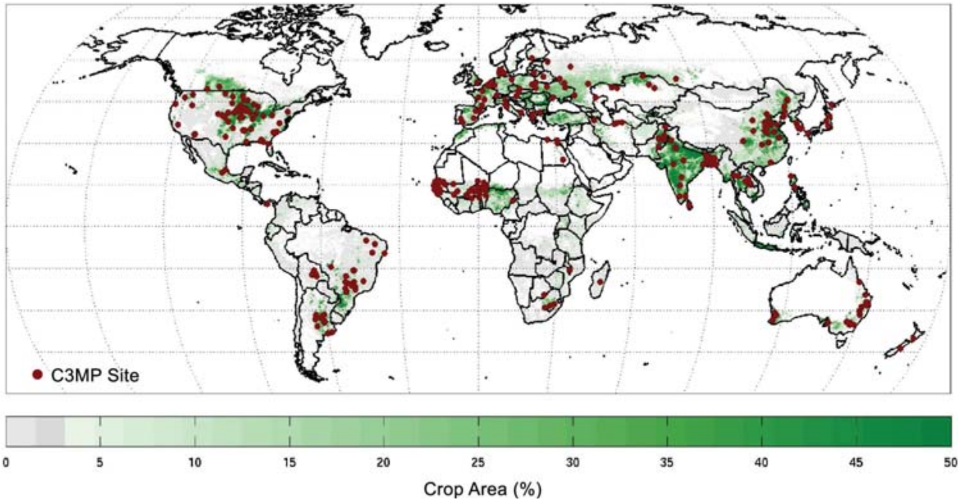

Fig. 5. C3MP model sites (dots) and major croplands (% area; green shading) as of January 24, 2014. (See Part 1, Chapter 8 in this volume.)

At present more than 100 participants have registered, with simulation sets contributed from 56 countries, 18 crops, and 23 crop models (see Part 1, Chapter 8 in this volume). Results are displayed on impact response surfaces that help stakeholders to visualize climate impacts.

C3MP aims to improve understanding of the impact of climate change on future agricultural production by utilizing site-calibrated crop models to coordinate projections of crop response under probabilistic climate change scenarios. Collaborations among crop modelers with expertise at specific modeling sites can provide improved estimates of how agricultural production will be impacted by climate change and can help assess how consistent these estimates are across climate and crop models. The results from C3MP will also contribute to wider assessments undertaken by AgMIP.

Through the C3MP protocols, crop modelers are invited to run a set of common climate sensitivity simulations, provided by C3MP coordinators, at sites where their models are already calibrated, and where detailed weather, cultivar, management, and soil information and data are available. Should weather information not be available, the C3MP coordinators provide a bias-adjusted MERRA (Modern-Era Retrospective Analysis for Research and Applications) weather time-series corresponding to the site (AgMERRA; Ruane *et al.*, 2014). Modelers submit results via a template to the C3MP coordination team. The archived results are vetted and fit with an emulator to estimate yield response surfaces. These response surfaces may then be used to analyze the impacts of projected climate changes, beginning with the CMIP5 (Coupled Model Intercomparison Project Phase 5 (Taylor *et al.*, 2012)) global climate models (GCMs).

AgGRID and Global Gridded Crop Model Intercomparison

AgGRID provides a central organizing hub for a new generation of gridded crop modeling activities within AgMIP, including the Global Gridded Crop Model Intercomparison (GGCMI). The goal is to build a lasting community of GGCMI researchers that collaborate to perform coordinated global and regional high-resolution impact assessments and model intercomparison studies. In turn, these improve GGCMI applications and understanding of climate impacts on global food production, as well as regional and temporal variations in these responses.

AgGRID leverages existing AgMIP strengths by bringing together AgMIP members from the climate, crop modeling, IT, economics, RAPs, aggregation and scaling, and uncertainty teams. Together, they develop new initiatives for improving quality and access to gridded data, models, computing, and scenario development and coalesce the international community of large-scale gridded crop modelers around important topics at the interface of food and climate.

The GGCMI facilitates a diverse international community of crop modelers to perform climate impact assessments, and to conduct model intercomparisons and improvements on the global scale. The GGCMI currently includes more than 15 modeling groups from nine countries. For those groups that have experience running models regionally, the project can provide the necessary data products and support to scale their existing frameworks up to global simulations. By working with the whole group, the coordination team establishes a consistent methodology, including simulation protocols and comparison metrics, for intercomparison and improvement of gridded model applications.

The coordination team also provides access to assimilated gridded environmental, socio-economic, and climate datasets, as well as all outputs and analyses to enable individual and collaborative studies within the GGCMI network. The GGCMI leverages resources and IT infrastructure (Earth System Grid Federation, Globus, etc.) developed at Argonne National Laboratory in Chicago, Illinois to facilitate data-sharing and discovery. This resource, which already serves 10 TB of climate and impact model outputs for the AgMIP and ISI-MIP (Inter-Sectoral Impact Model Intercomparison Project) communities (Warszawski *et al.*, 2013), will be updated and managed as an ongoing resource for the impacts community for years to come.

In 2012, AgMIP led a GGCMI intercomparison fast-track project in coordination with ISI-MIP. This project included seven GGCMs and focused on updating the state-of-knowledge on climate change vulnerabilities, impacts, and adaptations using current climate model outputs (CMIP5). The fast-track project culminated with the publication of six papers in a special issue of the *Proceedings of the National Academy of Science of the United States of America*.

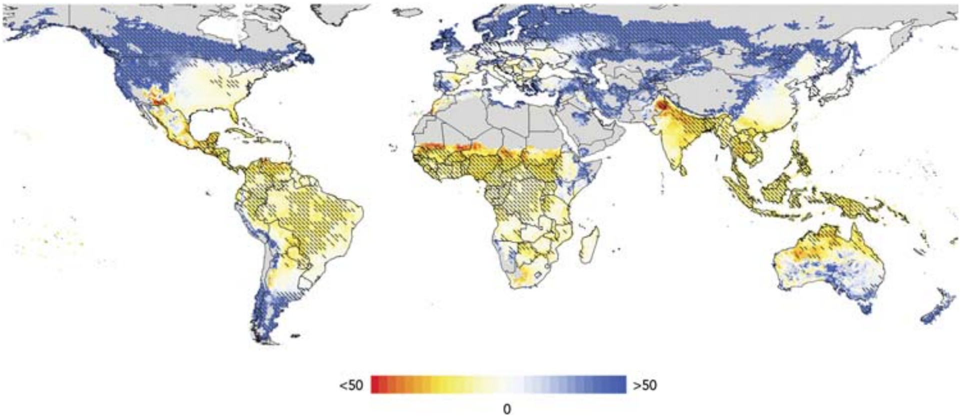

Fig. 6. Median end-of-century (2070–2099) maize yield changes (%; compared to 1980–2009 period) as simulated by seven global gridded crop models driven by five GCMs for RCP8.5. Hatching indicates regions where more than 70% of simulations had the same sign of maize yield changes (from Rosenzweig *et al.*, 2013a).

The intercomparison of seven global gridded crop models (GGCMs) analyzed climate impacts on maize, wheat, rice, and soybean across a global domain using high-performance computers (Fig. 6) (Rosenzweig *et al.*, 2013a). Crops in lower latitudes (including much of Sub-Saharan Africa and South Asia) demonstrate greater vulnerability as rising temperatures push cropping systems further from optimal conditions.

In contrast to previous assessments, results with realistic nitrogen fertilization show steadily decreasing yields for wheat, maize, and soybean in mid- and high-latitude regions even for small temperature increases. The design of the intercomparison allowed AgMIP to characterize uncertainty for the first time, highlighting the need for continuing rigorous model evaluation and improvement now being pursued in further phases of AgGRID. A new set of protocols for the next phase of the GGCMI, which focuses on data quality, harmonization, model evaluation, and improvement has been developed for five GCMs utilizing Representative Concentration Pathway 8.5 (RCP8.5) (Moss *et al.*, 2010).

Global economic assessments

AgMIP's Global Economic Model Intercomparison Team provided the first comprehensive investigation of uncertainty in projections of future commodity prices, agricultural land use, and agricultural gross domestic product (GDP). Climate change is projected to exert upward pressure on agricultural prices, but with large uncertainty (Fig. 7). Economies respond by eliminating poorly yielding areas (buffering overall yield declines), increasing agricultural land use, and reducing consumption

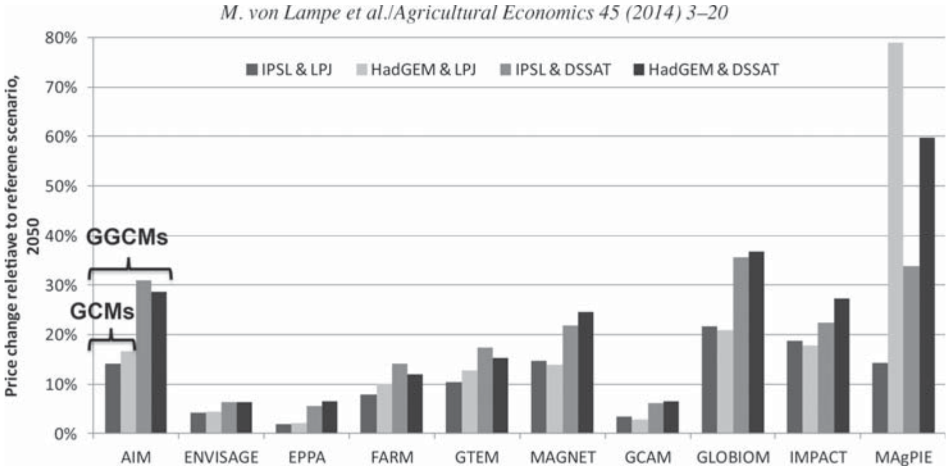

Fig. 7. Changes in world average producer prices for five main crops in 2050 due to climate change relative to no climate change. (Model results as of February 15, 2013.) *Note*: All changes relative to the reference scenario for the same year.

compared to the reference case with no climate change. While these reduce some of the detrimental impacts of climate change, there is still potential for large negative economic effects. Price uncertainties on the global market arise largely from the economic models, with smaller contributions from crop and climate models, although these can be substantial on the regional scale.

Comparisons between partial equilibrium (PE) models and computable general equilibrium (CGE) models revealed that the latter had a greater ability to buffer agricultural impacts through shifts in other economic sectors, but across all economic models projections were dependent on assumptions about the ease of land-use conversion, management intensification, and trade. Interactions within these models also shed light on how climate impacts drive economic responses; for example various countries take actions to reduce yield loss, increase crop area, and reduce consumption in the simulations.

Data and tools

The AgMIP IT team enables the compilation, archiving, and exchange of data and information for the AgMIP research community and stakeholders. The main objectives of the team are to develop an IT infrastructure for AgMIP projects that allows easy and secure access to shared data, models, and results of researchers in the AgMIP consortium, with both a short- and long-term perspective; facilitate the use of data by models and exchange of model results and the linking of models relevant for reproducible and repeatable applications; explore state-of-the-art information and communications technologies relevant to improve agricultural modeling with a long-term perspective, including web-based model executions and service-oriented architecture (bio-informatics); and to organize the online dissemination of AgMIP data and outputs.

At the core of AgMIP is the use of multiple models for the purposes of quantifying model uncertainties and improving the performance of all participating models. The general categories of AgMIP tools that enable the multiple climate, crop, and economic models to be used for model intercomparisons and assessments are shown in Fig. 8.

One of the goals of AgMIP is the comparison of simulated results from various crop models for the purposes of quantifying model uncertainties and as a basis for model improvement. Multiple crop models are used to generate simulated estimates of crop yields and other data using identical input data for each model. However, the format of the input data varies among the models. Some models use text file inputs,

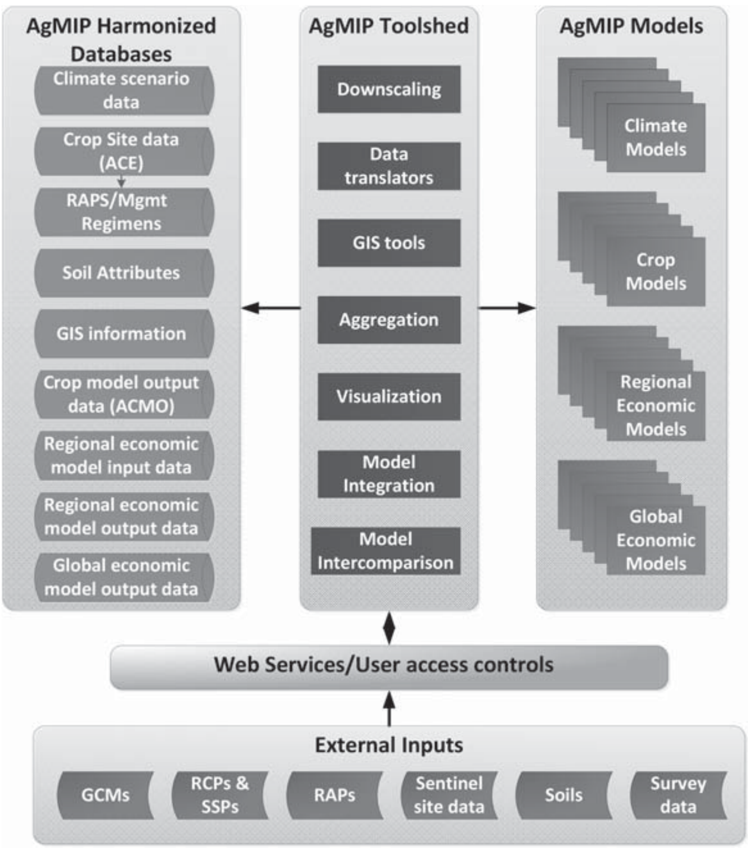

Fig. 8. AgMIP tools that enable multiple climate, crop, livestock, and economic models to be used for model intercomparisons and assessments.

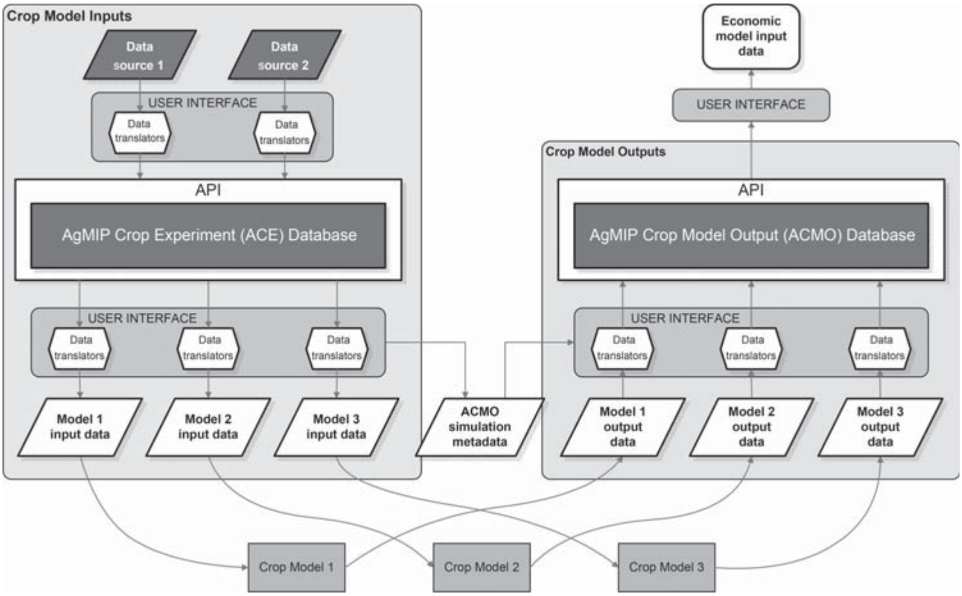

Fig. 9. AgMIP data-harmonization tools.

some use XML files, some use Excel spreadsheets, etc. Manual translation of data into the various model formats is not practical for the large amounts of data that are processed by AgMIP researchers.

To solve the problem, AgMIP stores crop experiment data in a harmonized data format and the harmonized data are exported to the formats specific to each model (Fig. 9). The AgMIP IT team has developed data translation tools to create the input data specific to each model. The AgMIP IT team works with the crop model development teams for each crop model to accomplish this goal. A series of development workshops have focused on programming the applications necessary for exporting data from the AgMIP harmonized crop experiment database to the data formats specific to each of the major crop models associated with AgMIP (see Part 1, Chapter 6 in this volume).

Regional Integrated Assessments

A major focus of AgMIP's activities in Phase 1 was the development of new methods for regional integrated assessments of climate change impacts on agricultural systems. The Sub-Saharan Africa and South Asia regional integrated assessments were organized into several distinct phases designed to create and execute a newly designed research and application agenda (Fig. 10).

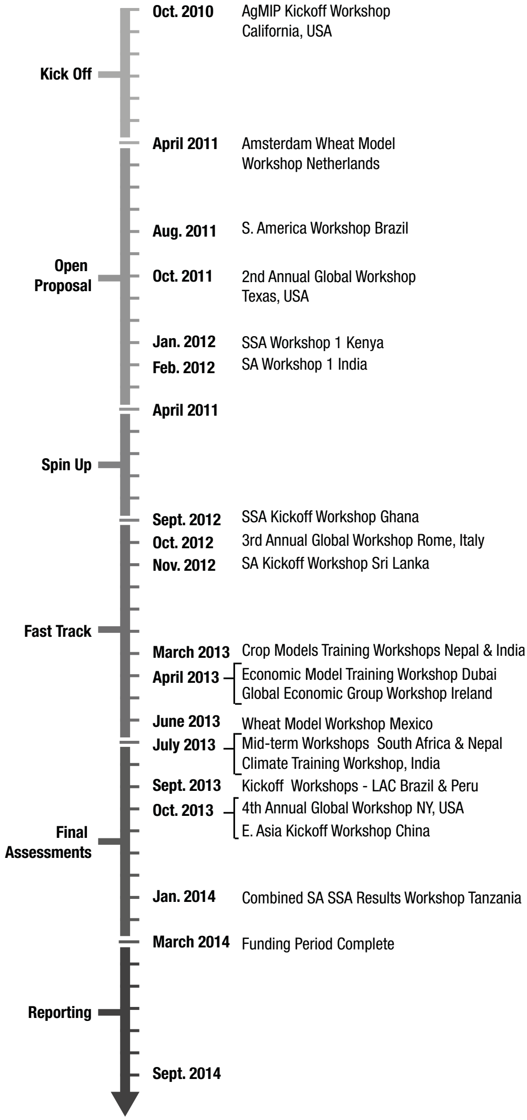

Fig. 10. Major project phases and project workshops for AgMIP Sub-Saharan and South Asia regional integrated assessments. For the report of the Fourth Annual Global Workshop see Appendix 3 in Part 1 of this volume.

AgMIP worked with regional research teams to conduct integrated assessments of climate impacts on the agricultural sector across Sub-Saharan Africa (with teams in East, West, Southern, and Southeastern Africa) and South Asia (with teams in the Indo-Gangetic Basin, Pakistan, Southern India, and Sri Lanka). These assessments developed and used innovative methods to understand how climate stresses on production systems will affect agricultural productivity and livelihoods in diverse study regions (see Part 2, Chapters 1–10 in this volume).

As part of the project, the international network of AgMIP researchers built relationships with multiple groups of stakeholders, including national and regional agricultural planners, and demonstrated a transdisciplinary modeling framework to address specific questions related to adaptation investment and policy development. This community of stakeholders and researchers is now primed to carry out targeted evaluations of agricultural development and adaptation packages and to deliver results in a way that directly informs stakeholder and policymaker decisions as climate risks evolve.

Theory of change

AgMIP's theory of change drove researcher and stakeholder engagement throughout the project to ensure decision-relevant findings with development impact (Fig. 11). Key components of the AgMIP theory of change include:

- AgMIP develops the advanced multi-model framework for evaluating technologies and policies aimed at achieving development impacts.

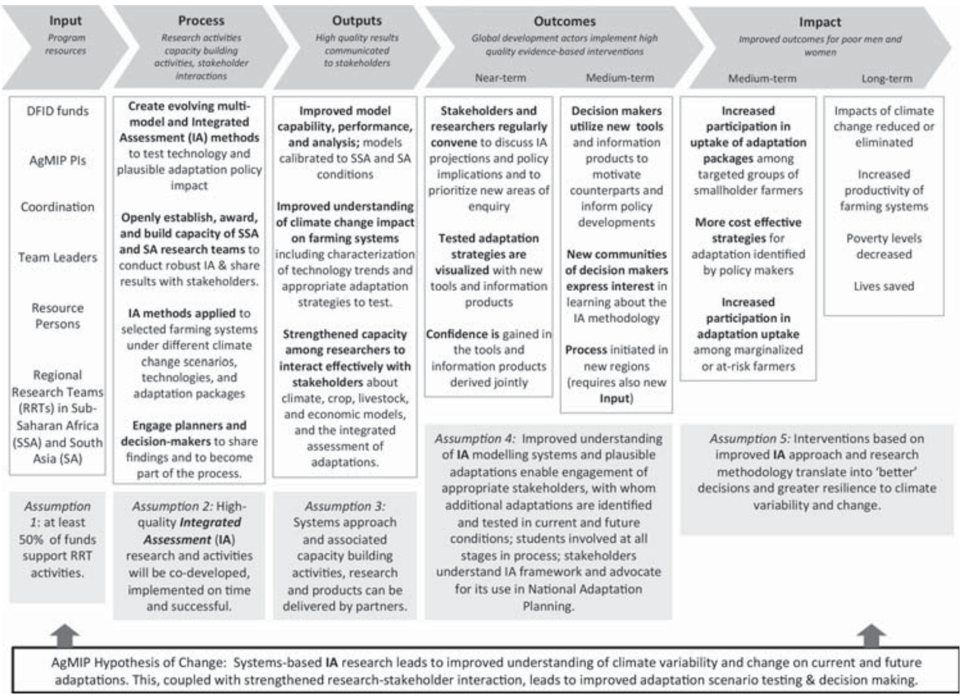

Fig. 11. The AgMIP theory of change.

- AgMIP helps regional researchers identify and engage appropriate stakeholders who provide critical links between research and development.
- AgMIP multi-disciplinary teams conduct regional integrated assessments and build regional capacity for effective use of the framework with stakeholders as partners.
- Stakeholders and researchers in the region adopt the AgMIP framework to achieve development impacts.

Stakeholder process

The selection of regional research teams included a criterion for stakeholder engagement, and each team met with stakeholders early in the project to prioritize regions and challenges for focused study. Stakeholders included representatives from agricultural ministries, farmer organizations, national and regional adaptation planners, crop breeders, non-governmental organizations, and extension agents. Stakeholders participated in each AgMIP workshop and also facilitated the dissemination of project information to the wider community.

Much of AgMIP's first phase was focused on developing the modeling framework and required capacity to conduct integrated assessment of policy options and adaptation packages, and a pilot of each was developed in consultation with regional stakeholders. Now that the multi-model framework is well established and a prototype application has been conducted in each region, stakeholder feedback from the final AgMIP Workshop provides a strong starting point for ongoing stakeholder engagement and co-exploration of policy and adaptation options in the next phase of AgMIP activities in Sub-Saharan Africa and South Asia.

Impact of AgMIP in Sub-Saharan Africa and South Asia (2010–2014)

On the regional scale, AgMIP enables decision-makers to have access to information that can be used to evaluate and prioritize climate change adaptation strategies for smallholder agricultural households. This information is based on rigorous new data and methods for climate impact and adaptation assessment on the local and regional scales relevant to decision-makers, and supported by regional research teams. These findings directly inform planning across a wide range of local, regional, national, and international stakeholders, many of whom have been involved via AgMIP's stakeholder-engagement process. Results have led to improved scientific capacity around the world.

AgMIP's innovative approach encompasses the range of smallholder households within a region, representing farm systems (e.g., including minor crops, livestock, labor, and off-farm income) and allowing more realistic analysis of adaptation strategies including farm management, economic decisions, and regional policies. As opposed to the majority of previous studies that simulated a representative field with little recognition of heterogeneity and economic responses, AgMIP results offer a more practical projection of how climate change will affect different types of households, providing information about winners and losers in the face of climate and economic changes as well as those most likely to adopt proposed adaptation packages.

AgMIP assessments found that climate change adds pressure to smallholder farmers across Sub-Saharan Africa and South Asia, with winners and losers within each area studied. Temperatures are expected to increase in all locations, and rainfall decreases are projected for the western portion of West Africa and Southern Africa. Rainfall patterns are less certain in central West Africa and East Africa, although increases in rainfall are projected for eastern West Africa and all study regions of South Asia. Climate changes lead to yield decreases in most study regions except South India and areas in central Kenya, as detrimental temperature effects overcome the positive effects of CO_2. AgMIP researchers are examining the responses in multiple crop models to improve understanding of the nature of climate impacts and to inform the development of targeted adaptation packages.

Working with the input of regional stakeholders, AgMIP regional research teams developed and tested pilot climate change adaptation packages, finding that there is potential for partial compensation of yields as well as income and poverty metrics. Adaptations include relatively simple adjustments to management (e.g., shifts in planting date or plant populations) as well as decisions over a longer horizon including investments in water resources, agricultural subsidies, and new seed varieties.

AgMIP is creating a legacy through substantial gains in capacity achieved by African and South Asian climate scientists, agronomists, and economists, including women scientists and both junior and senior researchers. At the global scale, AgMIP has emerged as an international leader in the use of agricultural models for assessment of climate impacts on crop production, food security, economic development, and adaptation strategies.

AgMIP has built a network of researchers across the globe who conduct integrated analyses of climate change impacts on food security and agricultural economics. These researchers understand the importance of using multiple models and linking climate, crop, livestock, and economic models to examine both current and future agricultural systems as a distribution of households rather than a single block. Capacity gains included increased modeling experience for more than 200 participants, training of more than a dozen agronomists in a second crop model, improvements in regional economic modeling capacity, increased interactions with vital stakeholder communities, new capabilities for climate scenario generation, and increased collaboration between scientists from different disciplines, countries, institutions, universities, genders, and seniority levels.

Major Achievements and Findings from AgMIP Phase 1

New methods

- Climate change impacts on food security, income, and poverty assessed for current farming systems and the types of farming systems that are likely to occur in the future, giving a more realistic projection of how climate change will facilitate or impede economic development.
- Future farming systems may be more capable of absorbing yield losses than the farming systems in current practice.
- First comprehensive regional integrated assessment of climate change impacts on smallholder farming systems in Sub-Saharan Africa and South Asia led by regional researchers and using best available data and multiple models.
- New methods integrating climate, crop, livestock, and economic models to conduct multi-model climate change impact assessments that characterize differential impacts on smallholder groups within a given region.
- Direct evaluation of yield, income, and poverty outcomes from pilot adaptation packages and development pathways.

Global assessments

- Crops in lower latitudes (where most developing countries are located) show greater vulnerability to climate change.
- In contrast to previous assessments that projected a period of increasing crop yields before temperature effects reduce yields, the AgMIP global gridded crop model results with realistic nitrogen fertilization show steadily decreasing yields for wheat, maize, and soybean in mid- and high-latitude regions even for small temperature increases (Rosenzweig *et al*., 2013a); this finding is backed up by an independent analysis conducted for the IPCC of individual climate impact studies (IPCC, 2014).
- Climate change is projected to exert upward pressure on global agricultural prices, but with large uncertainty. Price uncertainty on the global market comes largely from economic models, with smaller contributions from crop and climate model uncertainty, although these can be substantial on the regional scale. Economic models differ primarily in assumptions about ease of land use conversion, intensification, and trade.

- Economic systems respond to climate impacts by taking actions to reduce yield loss, increase crop area, and alter demand.

Regional assessments

AgMIP conducted the first set of comprehensive regional integrated assessments of climate change impacts on smallholder farmers in Sub-Saharan Africa and South Asia, led by researchers from the regions themselves. The project developed new methods integrating climate, crop, livestock, and economic models to conduct climate change impact assessments that characterize impacts on smallholder groups. AgMIP projections of climate change impacts on agriculture are more realistic than previous assessments because they take agricultural development into account. Using the best available data and models, the assessments directly evaluated yield, income, and poverty outcomes including the effects of adaptation packages and development pathways. The studies found that climate change will slow the pace of development in many current smallholder agricultural systems and that even in cases where average impact is near zero, vulnerability (i.e., those at risk of loss) can be substantial even when mean impacts are positive. See Part 2, Chapters 1–10 in this volume for further description of AgMIP regional assessments.

Sub-Saharan Africa

Agriculture in Sub-Saharan Africa (SSA) is already experiencing climate change-related effects that call for regional integrated assessments, yet capacity for these assessments has been low (see Part 2, Chapter 1 in this volume). AgMIP is advancing research on integrated regional assessments of climate change involving climate, crop, and economic modeling and analysis. Through AgMIP, regional integrated assessments are increasingly gaining momentum in SSA, and multi-institutional regional research teams centered in Eastern, Western, and Southern Africa are generating new information on climate change impacts and adaptation in selected agricultural systems (see Part 2, Chapters 2–5 in this volume). Key findings include:

- Even with agricultural development, climate change generally will exert negative pressure on maize yields of smallholder farmers in SSA, ranging across the four different regions and systems assessed.
- Without adaptation, climate change leads to increased poverty in some locations in SSA compared to a future in which climate change does not occur.
- Adaptation can improve smallholder farmer responses to climate change in SSA.
- However, many farmers lack the capability to respond effectively to the increasing climate risks projected for their regions. Some smallholder farmers will gain from climate change, but most farmers will lose.

- In the four regions assessed, AgMIP expert teams identified improved varieties, sowing practices, fertilizer application, and irrigation applications as prioritized adaptations. These targeted adaptation packages were able to overcome a portion of detrimental impacts but could not compensate completely in many locations.

South Asia

Understanding the response of current agricultural production to climate variability and future climate change is of utmost importance to secure food and livelihoods for South Asia's growing population. AgMIP South Asian regional research teams undertook climate–crop–economic integrated assessments of food security for districts in these countries, with the goal of characterizing the state of food security and poverty across the region, and projecting how these are subject to change under future climate conditions (see Part 2, Chapters 7–10 in this volume). Key findings include (Fig. 12):

- Even with agricultural development, climate change generally will exert negative pressure on rice yields of smallholder farmers in South Asia.
- Without adaptation, climate change leads to increased poverty in many locations in South Asia compared to a future in which climate change does not occur.
- Adaptation can significantly improve smallholder farmer responses to climate change in South Asia for all but the smallest farm sizes.
- Many farmers lacked the capability to respond effectively to the increasing climate risks projected for their regions.
- In the four regions assessed, AgMIP expert teams identified improved varieties, sowing practices, fertilizer application, and irrigation applications as prioritized adaptations. These targeted adaptation packages were able to overcome a portion of detrimental impacts but could not compensate completely in many locations.

Evolving to the AgMIP Global Program

AgMIP has now launched regional projects on six continents and is building a global program to formalize collaboration and decision-making between AgMIP and regional leaders (Fig. 13). AgMIP's Science Integration and Coordination Office at Columbia University spearheads interactions with national agricultural ministries, international development agencies, and research teams, which in turn lead to interactions with stakeholders and decision-makers across multiple scales. Building on

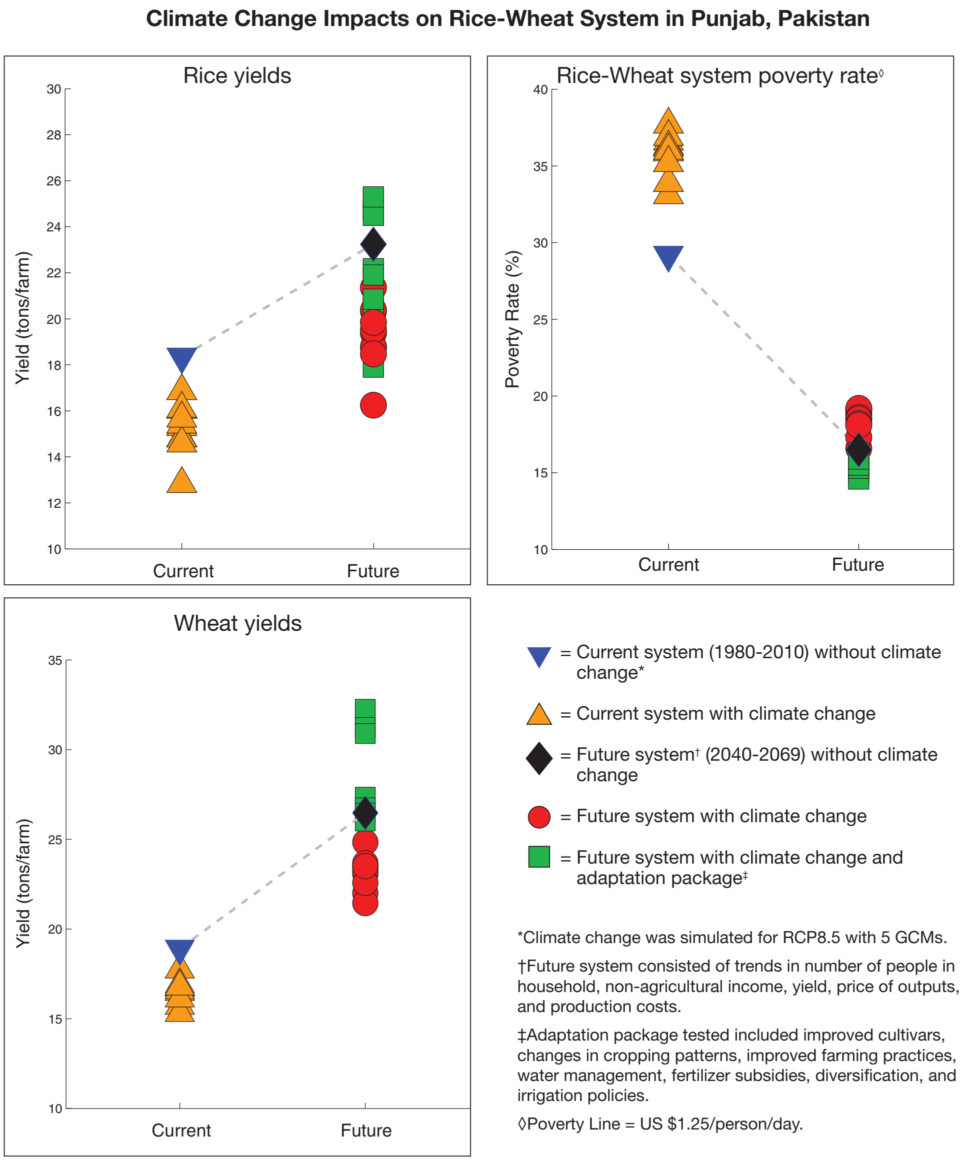

Fig. 12. Impacts of climate change on current and future rice-farming systems in the Punjab, Pakistan, with and without adaptation.

these interactions, AgMIP is organizing coordinated global and regional assessments of climate change impacts on the food system and the development of the next generation of agricultural models that can be used to develop and evaluate sustainable technologies.

Fig. 13. AgMIP regional programs (darker tone indicates DFID-funded regions) and crop model intercomparison sites from Phase 1.

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). Uncertainty in simulating wheat yields under climate change, *Nat. Clim. Change*, **3**(9), 827–832.

Bassu, S., Brisson, N., Durand, J.-L., Boote, K. J., Lizaso, J., Jones, J. W., Rosenzweig, C., Ruane, A. C., 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. L., Hoek, S., Izaurralde, C., Jongschaap, R., Kemanian, A., Kersebaum, K., Müller, C., Nendel, C., Priesack, E., Nin, M. V. P., Sau, F., Shcherbak, I., Tao, F., Teixeira, E., Makowski, D., Timlin, D., and Waha, K. (2014). Do various maize crop models give the same responses to climate change factors?, *Global Change Biology*, **20**, 2301–2320.

Cecil, L. D., Horton, R. M., Gordón, R., McCollum, R., Brown, D., Killough, B., Goldberg, R., Greeley, A. P., and Rosenzweig, C. (2013). Climate change impact uncertainties for maize in Panama: Farm information, climate projections, and yield sensitivities, *Agric. For. Meteorol.*, **170**, 132–145.

Intergovernmental Panel on Climate Change (IPCC) (2014). *Climate Change 2014: Impacts, Adaptation and Vulnerability*, IPCC Working Group II contributions to AR5.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J. Stouffer, R. J., Thomson, A. M., Weyant, J. P., and Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment, *Nature*, **463**(7282), 747–756.

Müller, C. and Robertson, R. D. (2013). Projecting future crop productivity for global economic modeling, *Agric. Econ.*, **45**(1), 37–50.

Nelson, G. C., van der Mensbrugghe, D., Ahammad, H., van der Mensbrugghe, D., Ahammad, H., Blanc, E., Calvin, K., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Lotze-Campen, H., von Lampe, M., d'Croz1, D. M., van Meijl, H., Müller, C., Reilly, J., Robertson, R., Sands, R. D., Schmitz, C., Tabeau, A., Takahashi, K., Valin, H., and Willenbockel, D. (2013). Agriculture and climate change in global scenarios: Why don't the models agree, *Agric. Econ.*, **45**(1), 85–101.

Piontek, F., Müller, C., Pugh, T. A. M., Clark, D. B., Deryng, D., Elliott, J., de Jesus Colón González, F., Flörke, M., Folberth, C., Franssen, W., Frieler, K., Friend, A. D., Gosling, S. M., Hemming, D., Khabarov, N., Kim, H., Lomas, M. R., Masaki, Y., Mengel, M., Morse, A., Neumann, K., Nishina, K., Ostberg, S., Pavlick, R., Ruane, A. C., Schewe, J., Schmid, E., Stacke, T., Tang, Q., Tessler, Z. D., Tompkins, A. M., Warszawski, L., Wisser, D., and Schellnhuber, H. J. (2013). Multisectoral climate impact hotspots in a warming world, *Proc. Natl. Acad. Sci. USA*, *(ISI-MIP Special Feature)*, **111**(9), 3233–3238.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H., and Jones, J. W. (2013a). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison, *Proc. Natl. Acad. Sci. USA*, **111**(9), 3268–3273.

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. (2013b). The Agricultural Model Intercomparison And Improvement Project (AgMIP): Protocols and pilot studies, *Agric. For. Meteorol.*, **170**, 166–182.

Taylor, K. E., Stouffer, R. J., and Meehl, G. A. (2012). An overview of CMIP5 and the experiment design, *Bulletin of the American Meteorological Society*, **93**(4), 485–498.

von Lampe, M., Willenbockel, D., Ahammad, H., Blanc, E., Cai, Y., Calvin, K., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Lotze-Campen, H., d'Croz, D. M., Nelson, G. C., Sands, R. D., Schmitz, C., Tabeau, A., Valin, H., van der Mensbrugghe, D., and van Meijl, H. (2014). Why do global long-term scenarios for agriculture differ? An overview of the AgMIP Global Economic Model Intercomparison, *Agric. Econ.*, **45**(1), 3–20.

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O., and Schewe, J. (2014). The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project framework, *Proceedings of the National Academy of Sciences*, **111**(9), 3228–3232.