AgMIP Regional Integrated Assessments : High-level Findings, Methods, Tools, and Studies (2012–2017)

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Chapter 5

AgMIP Regional Integrated Assessments: High-level Findings, Methods, Tools, and Studies (2012–2017)*

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Introduction

This chapter summarizes the overall findings, methods, tools, and results of the Agricultural Model Intercomparison and Improvement Project's (AgMIP) Regional Integrated Assessments (RIA) from 2012–2017.

*Text from this summary chapter is taken from the individual chapters of this volume.

High-level Findings

Across the entire AgMIP RIA project, undertaken from 2012 to 2017, several new findings and major messages emerged:

- In the current climate, integrated strategies including management and market interventions, such as improved cultivars, switches in cropping systems, and market development, can significantly improve smallholder farming livelihoods in many locations.
- Regions with minimal fertilizer applications are often more limited by soil fertility than by climate factors. Improving fertility is essential in these regions.
- In the future, even with anticipated agricultural development, climate change generally will exert negative pressure on farmer livelihoods in most locations.
- Furthermore, the changing climate will not affect all farmers in the same way. Aggregated reporting of impacts hides significant variability in vulnerability and poverty among different groups of farmers.
- Climate change is more detrimental to some crops than others and these differences need to be taken into account in developing adaptation packages.
- Future adaptations are able to overcome a portion of negative climate change impacts on smallholder farmers, but will not compensate completely in many locations. Targeted adaptations for future climate change include improved heat- and drought-tolerant crop and livestock varieties, sowing practices, and fertilizer applications.

AgMIP RIA Methods and Tools

AgMIP RIA methods and tools included the first-ever use of multiple crop models in regional climate change impact assessments. This provided key insights into the differences between the Agricultural Production Systems Simulator (APSIM) and the Decision Support System for Agrotechnology Transfer (DSSAT), two of the major crop models in wide use today.

Understanding differences in climate sensitivity simulations of the APSIM and DSSAT crop models

The CO_2, temperature, water, and N fertilization (CTWN) protocol has helped us to understand the differences between the APSIM and DSSAT crop models in their responses to environmental and management factors (see Part 1, Chapter 2 in this volume). The CTWN simulations with different models at different sites have been highly valuable for understanding the differential sensitivity of the APSIM and DSSAT models to climate and nitrogen, and have provided several key insights.

The first insight is that APSIM and DSSAT models mostly agree on their CO_2 responsiveness for different crops. But more important, crop responses to CO_2 show interactions with N fertilization being considerably muted in highly N-deficit systems; thus we are not seeing the benefit of the rising CO_2 that exists in well-fertilized fields (both crop models predict this). This means that underdeveloped regions will benefit less from elevated CO_2 than expected and that models that do not account for degraded soils and low N fertilization will give incorrect (too optimistic) responses to CO_2.

The second insight is that the simulated sensitivity to rainfall is less than expected (for both models) because the simulated leaf area index (LAI) for N-deficient crops is so low that transpiration demand and soil water depletion are not major problems; thus sensitivity to rainfall is less (except as was found in the case of well-fertilized fields in the Republic of South Africa). In addition, simulations of rainfall response under low N fertilization indicate that higher rainfall actually reduces yield because the small amount of available mineralized N is leached before the crop can capture it all (both the APSIM and DSSAT models simulate this effect).

These two observations confirm strong interactions between rainfall variation and N fertilization. This cautions against the use of crop models that cannot account for degraded soils and low N fertilization because they will likely give incorrect (too much) response to rainfall variation. The highly N-deficit systems may also affect the simulated response to N fertilization, where there may be positive effects of temperature where they are not expected. For example, soil N mineralization responds to rising temperature to provide more available N, thus altering the temperature optimum for production. However, the APSIM and DSSAT models vary in respect to soil N mineralization.

The third insight is that the APSIM and DSSAT models often differ in their temperature responses for different crops, which is not surprising considering they were separately developed and thus have different temperature parameterizations for life cycle phenology, leaf area expansion, radiation use efficiency (RUE)/photosynthesis, grain set, and rate of grain filling. The DSSAT-CERES-Maize model is more sensitive than the APSIM-Maize model to elevated temperature, an outcome associated primarily with different parameterizations of the rate of single grain growth. There are also minor contributions caused by maize model differences in temperature parameterizations of RUE and soil C mineralization. For three Kenyan sites differing in temperature (due to elevation), the two crop models give different temperature responses with APSIM showing optimum yield at $+2^{\circ}$C, $+4^{\circ}$C, and $+6^{\circ}$C depending on site.

The sorghum models in APSIM and DSSAT appear to have very minor differences in temperature response, with reasonable temperature response curves simulating optimum yield at $+2^{\circ}$C. The millet models differ in temperature response with the APSIM-Millet model showing almost no response to temperature over the range (+2°C to +8°C) and the CERES-Millet model in DSSAT has moderate temperature sensitivity with optimum at +2°C. Both the APSIM-Wheat and DSSAT-CERES-Wheat models show similar declining yield responses to rising temperature for both Pakistan and northern India. The APSIM and DSSAT rice models similarly show reduced yield with rising temperature in Pakistan and northern India. For both wheat and rice crops at these already warm sites, yield in both models is improved with −2°C simulations.

While there are variations among the APSIM and DSSAT crop models on their temperature responses, we cannot give definitive statements as to which model is right because the necessary data on growth and yield at elevated temperatures for testing the models are often lacking. And even where such data are becoming available, the models have not yet been tested or modified based on those data. The AgMIP-Wheat modelers have evaluated their models against the Hot Serial Cereal experiment, followed by model improvements. However, the APSIM and CERES wheat models used in this RIA study were versions prior to any modifications based on those tests. Likewise, AgMIP-Rice modelers are evaluating rice models against elevated temperature experiments, but the present rice models have not yet benefited (or been modified) based on those tests.

A fourth insight is that these exercises for low-input production on degraded soils have helped us to understand and guide model calibration for response to N fertilization relative to degraded soil conditions. The stable soil organic carbon (SOC) fraction (DSSAT-CENTURY) or the fraction of inert SOC (APSIM) must be adjusted to match the low yields obtained under zero-N fertilization (the present sites used, depending on region, had small amounts of N fertilizer). The full response to N fertilization must be simulated (0 to 210 kg N ha^{-1}) in order to match the genetic potential of the cultivar. It is too easy (commonly done and too often), but absolutely incorrect, to modify genetic parameters of a cultivar to mimic the low yields under low input production. The challenge is to design experiments that characterize the genetic potential of the cultivar in question for N response.

An additional caution for assessing climate change impacts in low-input agriculture regions is the re-initiation of the crop models every year (as done in these simulations) in contrast to continuous sequence/rotation stimulations. It has been reported that +3°C warming (climate change) will cause that loss of SOC when simulated with carry-over sequences over the long term and that the loss in SOC and N causes an additional reduction in yields when compared to re-initiating the models every year.

Transforming agricultural farming systems: The role of Representative Agricultural Pathways for decision support

The AgMIP Representative Agricultural Pathway (RAP) process is useful in unpacking the complexity of technical, institutional, and policy issues from local to national levels (see Part 1, Chapter 3 in this volume). It helps to build scientist confidence in distilling powerful key messages that can be used to inform decision processes. Nurturing opportunities for stakeholder contributions support buy-in, ownership, and continuity, e.g., in jointly designed research processes, options verified with communities, and from local to national levels.

In the AgMIP Regional Integrated Assessment (RIA) in SSA and SA each research team member became proficient in the research objectives and contents, across disciplines, and was able to guide multidisciplinary dialogue with stakeholders. Inconsistencies, opportunities, and challenges were identified beyond individual disciplines and affiliations, and across local (district) provincial and national levels.

Key findings from the RAP process include:

- Establishing solid research results and context understanding at a local level and taking that to national levels was seen as a useful direction, as it provides facts and legitimacy, where decisions are often political rather than information-based.
- Engaging national research organizations and ministries in scenario generation and multi-model simulations would be transformative, also in accessing and using scenarios for strategic exercises (e.g., vulnerability assessments, adaptation costing, policy making, Adaptation NDC revision, NAP, GCF feasibility studies/projects development, academic studies, or National Communications).
- Presenting feedback from AgMIP research, scenarios, and impact assessments helps to set national-to-local priorities for policy, research, and development, which currently are often development–based, without understanding the possible climate challenges of the future.
- Strategically providing national departments and networks with context-specific information on vulnerability and adaptation impacts for specific agricultural production systems informs adaptation options and processes.
- Developing capacity of national scientists and government staff in accessing and using climate and other scenarios and simulations broadens the use of these approaches and leads to implementation and verification.
- Creating a clear road map for agricultural policy can guide decision makers in regard to desired trajectories and targets, and how to reduce barriers along the way to adoption.

The RAP process is one element of the AgMIP RIA approach that is transforming climate change research through integrated, simplified, protocols-based approaches. This is helping to achieve a more sustainable impact on development, planning, and investment.

Recommendations include the following:

- Direct research funding towards long-term (dynamic) research programs that can continue improving, up-scaling, and providing better, more accurate information that tackles more complex issues.
- Set clear policy directions, articulate decision-making needs, and improve cross-sectoral coordination.
- Explore knowledge systems and behavioural responses in order to understand and address the root causes of poverty.
- Use cross-scale networks, improve communication, and build capacity to raise commitment from stakeholders for sustainability goals.

Design, development, and evaluation of the AgMIP impacts explorer: Applying a user-centered approach in of an interactive visualization tool

The development of the AgMIP Impacts Explorer supports the recommendations of several authors to adopt user-centered design methods (see Part 1, Chapter 4 in this volume). Applying this strategy enabled us to recognize the diversity of requirements of the different user groups and led to the design of three distinct (but connected) tool components. In the evaluation, participants generally appreciated this design idea and the different (textual and visual) information presentation techniques.

The experience with the AgMIP Impacts Explorer leads to the following recommendations.

1. **Involve stakeholders and other professionals (i.e., the intended users of the platform) in the design and evaluation of a tool.** Stakeholders often have different questions and information needs than the climate impact researchers might anticipate. The researchers also tend to overestimate the effort individuals are willing to spend on an online tool, like reading instructions or background information. User testing reveals that users tend to skip introductions and are quickly discouraged when they are not able to find what they anticipated.
2. **Establish a representative set of data and related content (e.g., descriptive texts) as soon as possible to allow sufficient time for effective and valid testing and evaluation.** In this way, tool developers will be less impacted by delays in the availability of actual research results. A representative set of data and other

content (descriptive texts for instance) will maximize the time for design and testing of the interactive visualizations and improvement of tool prototypes.

3. **Represent the tool for what it is to facilitate interaction about what it might become.** Online tools and portals with limited amounts of data and key messages are useful in co-learning or discussion exercises. However, unless this stage of development is clearly communicated, the tool may be felt to be of limited use or interest and therefore quickly become obsolete.
4. **Detail project plans to ensure sufficient resources and expertise for the many facets of tool development.** Application design, software development, data visualization, and testing require specific skills that are essential for producing successful tools. Time and resources are also needed for key message and info-graphic development by design-oriented communications experts prior to coding.
5. **Tools require maintenance and updating and may quickly become obsolete if they are not kept up to date.** If the intention is to further develop and maintain the tool in the future, a plan for maintenance and support should be included from the start.

AgMIP Regional Integrated Assessment Studies

Each of the Regional Integrated Assessments (RIAs) in Sub-Saharan Africa and South Asia provide key findings and recommendations for the farming system studied.

Impact of agricultural intensification and climate change on the livelihoods of farmers in Nioro, Senegal, West Africa

The AgMIP CIWARA Regional Integrated Assessment studied the probable changes in climate, crop, economic, and livelihood outcomes in smallholder agriculture in West Africa, as well as adaptation benefits by applying the most advanced RIA methods available, based on quantitative multi-model simulations informed and verified by multiple stakeholders (see Part 2, Chapter 1 in this volume). The study indicates that temperatures will increase in the near future by 1°C–3°C across climate scenarios and showed potential for either increase or decrease in precipitation. Cereal yields are projected to be negatively impacted by climate change with maize being the most vulnerable, while sorghum and millet were marginally impacted. Peanut production will, however, benefit from climate change mainly due to CO_2 fertilization effects.

Except for in the hot/dry climate scenario that combines high temperature and insufficient water, climate change is expected to have positive impacts on farmer livelihoods based on the current production system in Nioro, mainly because it is a peanut-dominant farming system and climate change impact on peanut is generally positive. Also, we found that at least three smallholder households out of four are potential adopters of a basic increased fertilizer and improved crop management package, but at most one in 10 would adopt a compound fertilizer combined with an improved variety.

In tomorrow's production systems and socio-economic conditions, climate change would also have a positive impact on Nioro farmer livelihoods in all cases simulated, especially under the high price scenarios, mainly due to the importance of peanuts in the households. However, under low price scenarios, climate change would have a negative impact on Nioro farmer livelihoods in most cases. In the future, at least one smallholder household out of two are potential adopters of a basic package of heat-tolerant crop varieties.

AgMIP provides powerful decision support tools. In the future, we plan to further engage with higher levels of policy and decision-makers to design with them the most desirable outcomes in order to move away from business-as-usual and to address the major obstacles of agriculture development (low input use, increased weather variability, high risks, lack of financing, etc.). These analyses enable us to pinpoint the main hurdles that need to be tackled in the changing environment and help to define potential solutions to be co-generated with the main stakeholders (such as policy makers, elected officials, farmers organizations, and NGOs).

An integrated assessment of climate change impacts and adaptation in maize-based smallholder crop-livestock systems in Kenya

This Regional Integrated Assessment provides insights into the potential impact of climate change and adaptation on maize-based systems in Kenya (see Part 2, Chapter 2 in this volume). All the climate models used in the assessment predict a warmer future compared to the current climate; the future scenarios are warmest in the higher emissions pathway. The projected increase in temperature is lowest at the coast and increases westward, with the largest increases at the sites near the Kenya–Uganda border. The climate models are in less agreement on the direction of change in precipitation compared to current levels. Under both emission scenarios, the wettest scenarios indicate increases in precipitation and the driest scenarios predict decreases in precipitation during the growing season. Based on previous work, there is reason to believe that climate models have relatively low skill in reproducing East Africa precipitation climatology, which leads to uncertainty as to whether the region will be wetter or drier in the future.

This assessment finds that the projected climate change in Kenya negatively impacts current maize-based systems. Crop model simulations indicate that, with current management, maize yields are lower in future climate scenarios compared to the current climate. The decrease in maize yields leads to lower farm net returns for a majority of farms across the future climate scenarios and across the maize-producing regions of Kenya. However, there is heterogeneity in the impacts across Kenya: the farms in the high maize potential zone (MPZ) are the most vulnerable to climate change. In the worst-case climate scenario, maize yields in this area are predicted to decrease by a larger degree than in the low and medium MPZs. Moreover, farms in the high MPZ are more reliant on maize than in the other MPZs, where household income is relatively diversified across off-farm work, maize, other crops, and livestock.

In terms of potential adaptation, a large portion of farms in current maize-based systems may benefit from a policy intervention aimed at decreasing fertilizer prices and increasing milk productivity. This intervention is represented by a subsidy that lowers the prices farmers pay for commercial fertilizers and improves access to fertilizers with investment in infrastructure and lower transaction costs associated with participating in fertilizer markets. The intervention also includes technical assistance programs to improve feeding strategies for milking cows and the donation of one improved breed milking cow to every farm, similar to the basic elements of the East Africa Dairy Development project. Both maize and milk productivity are predicted to increase under the intervention, which leads to increases in farm net returns for households across Kenya. By increasing farm net returns, the intervention is expected to increase the per capita income and decrease the poverty rate.

As in current production systems, a large majority of farms in future production systems are predicted to benefit from a policy intervention aimed at increasing fertilizer application and milk production. This intervention is modeled with increased fertilizer and manure application and the provision of two-to-three improved breed cows to each farm in future production systems. The changes in maize management increase yields and offset negative climate impacts. The provision of multiple improved breed cows increases both milk production and milk productivity. As a result, maize and milk net returns tend to increase for farms across Kenya, leading to increases in per capita income and decreases in poverty in each of the future scenarios. The large increase in milk net returns is the main driver in the positive outcomes associated with the intervention. This result suggests that policy interventions aimed at increasing the farm focus on milk production, including the use of improved breeds, have the potential to greatly improve livelihoods in future maize-based systems of Kenya.

Adoption and impacts of small-scale irrigation in Kenya's maize-based farm households

Studies that assess the *ex ante* impacts of climate change and related adaptation measures have increasingly moved towards the use of more integrated approaches to deal with the uncertainties of future conditions (see Part 2, Chapter 3 in this volume). However, several studies fall short of adequately incorporating adaptation in the analysis and effectively assessing distributional economic impacts. Similarly, advances in recent literature on the use of biophysical crop models for this type of analyses have suggested that multi-model ensembles result in a more accurate estimation of grain yield for various crops compared to any single model. Overall, the complex behavior of semi-subsistence crop-livestock-based agricultural systems poses many challenges in policy analysis. This chapter demonstrates the use of an integrated assessment framework that can be a useful tool to assess impacts of policy interventions aimed to improve agricultural production systems.

We use an integrated modeling framework for this analysis, combining a gridded crop simulation model and a household dataset with a disaggregate farm-level model. A fundamental feature of agricultural households is their biophysical and socio-economic heterogeneities. This analysis captures the site-specific biophysical processes and farm-level behavior by stratifying farms based on their biophysical and economic environments and using the gridded crop simulation output from two iterations of the DSSAT model in the Trade-off Analysis Model for Multi-Dimensional Impact Assessment (TOA-MD) framework. An important feature of this framework is the integration of adoption behavior of farmers and their choices between different systems. By modeling adaptation and adoption of technological intervention measures, we can model shifts in supply from both adopters and non-adopters and the consequent distributional impacts.

Our findings provide important insights into the potential impact of climate change and adaptation on maize-based systems in Kenya. Results from the two iterations of the DSSAT model predict average negative impacts of climate change on current maize-based systems in Kenya. Under current management, maize yields are predicted to be lower across most zones in the future climate scenarios compared to the current climate. The decrease in maize yields leads to lower farm net returns across most maize-producing households in Kenya.

However, there is significant heterogeneity in these impacts — farms in the high potential maize zone are the most vulnerable to climate change because they are more reliant on maize than the other zones, where household income is relatively diversified across off-farm work, maize, other crops, and livestock. Moreover, although DSSAT model predicts increased yields for farmers in the low maize potential zone, these higher yields do not necessarily lead to positive impacts because of the heterogeneity in impacts across the farms in this zone. Despite the aggregate outcomes, the strata-level results predict that climate impacts differ based on locational agroecology and household income diversification.

In terms of potential adaptation, a large portion of farms in the current maize-based systems may benefit from irrigation expansion in Kenya. By increasing maize yields and subsequent farm net returns, irrigation expansion is expected to increase the per capita income and decrease the poverty rate. The impacts of irrigation also show significant heterogeneity across zones; for example, farmers in the low potential zone have lowest impacts on farm income and poverty despite having the highest adoption rates. Overall, results suggest that policy interventions aimed at irrigation expansion have the potential to improve livelihoods in future maize-based systems of Kenya.

Assessing the impact of climate change on the staple baskets of Botswana and South Africa

In this RIA in Southern Africa, it has become clear that in order for stakeholders, policy-makers, and farmers to make informed decisions on climate change adaptation in agriculture they require reliable evidence to support their planning process (see Part 2, Chapter 4 in this volume). The structure and methodology of this study linked quantitative and qualitative evidence in a scientific process to unpack complex research questions in a manner that is well documented and replicable. For stakeholders and policy-makers, outputs are made accessible through visualization, i.e., graphs and maps.

The study has proven that, although optimal data were not available (i.e., household surveys with production and economic information), substitute information could be used because of the spatial linkages. The introduction of a spatial component to the RIA framework allowed for this methodology to be implemented with the AgMIP protocols.

Using two crop models has demonstrated that uncertainty about probable future yields is not only due to the uncertainty of projected climate but may also be due to crop model uncertainties. Conclusions on probable future yields in climate change studies should therefore not be based on a single crop model but should include an ensemble. Along with using a model ensemble, the crop models should each not only be tested for their sensitivity to the variables that are important to climate change, *viz.* CO_2, temperature, water, and N fertilization (CTWN), but these tests should also include some of the variables that are important in the adaptations. Examples are radiation use efficiency (RUE) and temperature at which maximum development rate occurs for reproductive stages (ROPT). This would enable the discovery of further areas of crop models improvement.

All in all, the study indicated that on average, for the two plausible futures simulated, farmers will still be able to be profitable and the Free State will still be able to deliver to South Africa's *Staple Basket* and food security under projected climate change. The future of small-scale farming systems in Botswana will however still be under pressure even if they introduce adaptation measures, such as heat- and drought-tolerant cultivars.

Transforming smallholder crop-livestock systems in the face of climate change: Stakeholder-driven multi-model research in semi-arid Zimbabwe

The multi-model framework utilized in this study provides an explorative analysis of the potential impacts of climate change on smallholder agricultural activities in Nkayi district, representing typical farming conditions in semi-arid Zimbabwe (see Part 2, Chapter 5 in this volume). The major findings include:

1. **Sensitivity to climate change, current conditions.** In areas like the Nkayi district, where productivity is currently very low (maize yield $< 500\,\text{kg/ha}$), the impacts of climate change were found to be generally small, though this varied by farm activity (i.e., crop type and/or livestock). The impact to farmers depended on the extent to which their activities were already diversified.
2. **Impact of improved management, current conditions.** Under conditions of extremely low productivity, there was high potential for integrated interventions (i.e., technologies, institutions, and policies) to increase farm net returns. Increasing the importance of more profitable crops, e.g., groundnuts, had major contributions to increased farm net returns, without compromising food self-sufficiency.
3. **Impact of climate change, future conditions.** By 2050 the conditions for farming improved under both the Sustainable Development RAP and the Rapid-Economic Growth RAP, due to greater investments in technologies, improved institutions, and dedicated policies, even under higher temperatures and rising CO_2 levels. This would enable farmers to implement improved farm management, diversified and intensified crop and livestock production, and set more of their land in value. Even though climate change impacts were higher with higher yield levels, farmers would be better off as compared to today and climate change impacts on overall farm net returns would be reduced. Climate effects would be influenced by the relative importance and sensitivity of farm sub-activities and price changes.
4. **Impact of climate change adaptation, future conditions.** Under those future conditions where agricultural production systems would have intensified and expanded on more profitable farming activities as compared to today, adaptation to climate change was less significant. The main issue was that increasing temperatures (high evaporation, hence less water available for crops) caused reduction of cereal crop yields due to accelerated growth with little time for biomass accumulation. Hence lengthening of crop life cycle can be used to reduce the negative effects of climate change on cereals. For grain legumes, such as groundnuts, increased CO_2 levels, to a large extent, negated the negative effects of increased temperatures. Improvements in crop drought tolerance can reduce the effects of climate change; it would also be important for improving

both quality and quantity of livestock feed, and also soil fertility if used as mulch.

Key messages for decision-makers

The study results generated key messages to inform decision processes across local to national scales.

- There is great urgency to enhance agricultural production and technical actions in the present that can be undertaken to the benefit of farmers, including the poorest. Lifting the farmers out of poverty does not necessarily require new technology, but does require improvement and reconfiguration of what is already there. Improving access to currently available technologies is one of the challenges. Even though high-yielding crop varieties are available, farmers fail to access them and hence normally use recycled seeds.
- Results show that what is driving the system to improved crop and feed management is clearly increased yields through greater availability of nitrogen, making it possible to convert land to more productive and profitable uses. Improved soil fertility management would therefore benefit the poorest most, often with N-depleted soils, and through improved feed and manure biomass would also benefit those with cattle.
- If N supply combined with land conversion from maize to groundnuts leads directly to production and welfare effects, what limits its application? Most likely this is a question of institutional failure, non-functional output markets combined with unavailability and unaffordability of inputs, thus poor returns on invested inputs. These institutional barriers demotivate farmers from intensifying land use.
- Food and feed legumes, for a long time neglected in support programs, are more climate-resilient and profitable crops, and an opportunity, especially for the extremely poor. There is a critical need to address feed gaps for those with more cattle. Market links to affordable local feed and commercial stock feed are critical if the region is to profit from its comparative advantage in livestock production.

Development of Climate Change Adaptation Strategies for Cotton–Wheat Cropping System of Punjab, Pakistan

Climate change is a great threat for current agricultural production systems in Pakistan (see Part 2, Chapter 6 in this volume). Cotton and wheat are important cash crops and support the agro-based Pakistan economy. Climate change is projected to bring an increase in mean maximum temperature of 2.5°C to 3.6°C and mean minimum temperature of 2.7°C to 3.8°C by mid-century in Punjab, Pakistan. Decrease in rainfall would be about 33% to 52% during the cotton-growing season and 36%

to 42% during the wheat-growing season with hot/dry conditions. Reductions in cotton yield of 7% to 42% and wheat yield of 2% to 4.5% would result. The cotton crop is relatively more sensitive to climate change than wheat. Wheat is benefited by future increases in CO_2 concentrations but harmed by rising temperature.

Economic results show that there would be drastic impacts on farm income due to the increase in temperature and humidity in the cotton–wheat cropping system. Seventy-eight percent of households are vulnerable to climate change, with simulated increases of 69% in farm poverty through reductions of 27% net returns in the current cotton–wheat cropping system. The crop yield reductions can be minimized by management interventions on farms that increase sowing density and fertilizer application in cotton and change the sowing dates and fertilizer application methods in wheat. Those would increase net returns by 15% and reduce poverty for about 70% of farm households (69% are vulnerable in the case of the Sustainable Development Pathway and 74% in the Unsustainable Development Pathway) in the future agricultural production system. Poverty would increase by 53% due to a 19% decrease in net farm returns. The proposed adaptation package includes increase in sowing density, balanced use of fertilizer, and improved genetic cultivars. The adoption rate of this adaptation package is projected to be 56%, and it reduces farm poverty levels on average by 36%.

Integrated Assessment of Climate Change Impacts on Rice–Wheat Farms of IGP-India through Multi-Climate-Crop Model Approach — A Case Study of Meerut District, Uttar Pradesh, India

Climate change impacts are increasingly visible in South Asia (SA) with greater variability of the monsoon, noticeably a declining trend with more frequent deficits. There has also been an increase in the occurrence of extreme weather events, such as heat waves and intense precipitation, that affect agricultural production and thereby the food security and livelihoods of many small and marginal farmers, particularly in the more stress-prone regions of the central and eastern Indo-Gangetic Plain (IGP) (see Part 2, Chapter 7 in this volume). This study shows that, under current production systems, although the magnitude of decline in net farm returns and per capita income may look small, it will adversely affect a large proportion of farms (49%–74%). The adaptation strategy for the current production system enhances rice yield by 6%–14% (APSIM and DSSAT) and wheat yields by 11%–18% (APSIM and DSSAT). These changes in the production system result in 11%–14% increase in mean net farm returns and 7%–8% increase in per capita income (APSIM and DSSAT), which result in 2%–3% decline in population poverty rate. The adoption rate of the adaptation strategy in the current production system would be 57%–62%.

The TOA-MD analysis shows that though the gains in mean net farm returns (15%–25%) are comparatively higher than the losses (15%–16%) under five climate scenarios, a substantial proportion of households (33%–51%) remains vulnerable to the adverse impacts of climate change even if the Sustainable Development Pathway (RAP4) is adopted. The proportion of vulnerable households is the highest (50%–51%) under hot/wet and hot/dry global climate models (GCMs). The net impact on farm returns is negative for these two scenarios. The sensitivity analysis (to low prices) shows that mean net farm returns and per capita income decline by 11%–16% and 8%–11%, respectively, under hot/wet and cool/dry GCMs, and 53%–80% of the population remain vulnerable to climate change. The proportion of vulnerable households under high price scenario is comparatively lower as compared to low price scenario (RAP 4). In comparison to the Sustainable Pathway (RAP 4), the net farm returns are lower by 36.5% under Unsustainable Development Pathway (RAP 5) under the low price scenario.

Under the Unsustainable Development Pathway (RAP 5), there are negligible increases in mean net farm returns (up to 5%) except in the hot/wet and hot/dry scenarios, which show a decline in net farm returns (up to 2.6%). Overall, 41%–51% of farm households remain vulnerable to climate change under RAP 5. The price sensitivity analysis under RAP 5 shows that mean net farm returns and per capita income are lower in comparison to the high price scenario, but the net returns in RAP 5 are about 30% lower than those in RAP 4. When prices are high, the net gains are negative only under the hot/wet and hot/dry climate scenarios. But the sensitivity analysis shows that net gains under all five climate scenarios become negative under the low price scenario. This means that even the high growth trajectory under the low price scenario will not be able to withstand the negative impacts of climate change on farm returns, poverty, and per capita income. This will increase the vulnerability of a substantial proportion (42%–68%) of the population to climate change. In contrast, the Sustainable Development Pathway (RAP 4) will minimize the adverse impacts of climate change.

Assessment of Climate Change Impacts on the Maize–Rice Farming System in Trichy District, Tamil Nadu, India

Vulnerability of current system to climate changes

The current production system would be more regularly affected by the high emission scenario (RCP 8.5) than the low emission scenario (RCP 4.5) during the mid-century (see Part 2, Chapter 8 in this volume). In the future, the reduction in maize productivity is expected to be greater under hot/dry climatic conditions than under the other climatic conditions for both RCP 4.5 and RCP 8.5 scenarios. Maize yield is expected to decline up to 14% with the RCP 4.5 scenario and 24% with the RCP 8.5

scenario under hot/dry climatic conditions. Rice yield is expected to decrease up to 18% under hot climatic conditions for the RCP 8.5 scenario.

Potential adaptation in current system under current climate

In the region, crops are planted without following a specific sowing window. Sowing the crops at the optimum sowing window could improve crop productivity by creating better environmental conditions during the crop growing period, as a climate-smart practice. Application of 25% of an additional dose of nitrogen was also included in the adaptation package. The adaptation package increased the maize yield around 10% and rice yield around 13%.

Vulnerability of future system to climate changes

Climate change impacts on the future system would be slightly lower than the current system. In the future system, modifications in crop genetics that increased crop duration and resilience to temperature changes and additional application of manure reduced the impact of climate change. Maize yield reduction would be around 9% with the Sustainable Development Pathway (RAP 4) and around 10% with the Unsustainable Pathway (RAP 5) under hot climatic conditions. In RAP 4, climate change is expected to reduce rice yield around 14% and 4% with RAP 5 under hot climatic conditions.

RIA of Climate Change Impacts on the Rainfed Farming System in Kurnool District, Andhra Pradesh, India

The AgMIP RIA framework was used to assess the vulnerability of current and future crop-livestock production systems to climate change in the Kurnool district of Andhra Pradesh, India (see Part 2, Chapter 9 in this volume). This study used socio-economic data from a representative household survey conducted across the state of Andhra Pradesh on chickpea-based rainfed farming systems, together with downscaled climate data and site-specific weather and multi-location crop trial data to calibrate crop models. We stratified our sample households into the following: (1) Farm households located in low rainfall regions and (2) Farm households located in medium-to-high rainfall regions in the Kurnool district.

The research revealed important findings. First, the climate analysis reveals that all the five GCMs used in this study predict that the Kurnool district will average higher (warmer) temperatures in the 2050s in the high emission scenario (RCP 8.5). All projections generally predict increased rainfall, although there is a clear variation across climate models: 3% to 27% higher rainfall is projected under the mid-range climate scenario and 6% to 40% higher rainfall across the five climate scenarios.

Second, the analysis showed that the majority of fallow-chickpea-based farm households are vulnerable (68% in a warmer climate and 42% in a wet climate) to climate change if current production systems continue into the future. Vulnerability is not uniform across the Kurnool district and climate impacts vary according to scenario. The simulation results for low and high rainfall groups showed that the farm households in the low rainfall region with current low-input crop production systems and less opportunity for non-farm income are highly sensitive to both cool/wet (more favorable) and hot/dry (unfavorable) climate scenarios. Overall, the integrated assessment reveals that even under a highly favorable climate scenario (cool/wet), the current rainfed production system is vulnerable, although the magnitude of vulnerability varies across climate scenarios and farm household groups with inputs from stakeholders.

To address current vulnerability, a "climate-smart" adaptation package was developed. By adopting this package, a large percentage of farm households in the fallow-chickpea-based cropping system would move from vulnerability to resilience. Nearly 80% of farm households will benefit from adopting this package today. The package includes interventions, such as promoting location-specific varieties (i.e., short-duration varieties in the low rainfall region and medium-duration varieties in the high rainfall region), providing critical irrigation using harvested rainwater, using recommended fertilizer application, introducing a new crop (foxtail millet) during the *kharif* season to enhance the system productivity, and adopting mechanical harvesters to reduce harvesting costs.

When considering this adaptation package in future climate scenarios, climate change will still have negative impacts on agricultural production — even with adaptation measures, 60% of farm households are still vulnerable in a warmer climate scenario. Though this shows many farmers to be vulnerable, this number is lower than if no adaptation was implemented. Additionally, even though chickpea yields are lower in the warmer climate scenarios, economic impacts vary. Economic models predict that prices in future climate change scenarios will be higher than prices if no climate change occurs. These higher prices will help offset the negative climate impacts on yield and reduce vulnerability.

Contribution of Stakeholder Engagement to Research and Development

Stakeholder engagement was a critical component of the AgMIP RIAs. The benefits and impacts of guiding research, building research capacity and networks through knowledge sharing, are often not visible at the end of a project, yet contribute to the relevance of its key messages. The engagement added value to the RIAs, as the research was designed and used to extrapolate the results from site-specific assessments and to influence processes in areas with similar conditions and support the urgency for transforming agriculture nation-wide. Specific stakeholder contributions to the research process included the following:

- **Refinement of research protocols.** Stakeholder engagement supported knowledge and experience sharing, which was helpful to unpack the complexity of technical, institutional, and policy issues from local-to-national levels. Stakeholder priorities brought the analyses of possible changes to farm management under current conditions to the research agenda. Verification of research results with stakeholders helped to redesign transformative changes, options, and parameters for future agricultural systems, within the boundaries of what would be possible, how it might influence other systems components beyond farms to the society and environment.
- **Strategic ways for research informing national dialogues.** The engagements helped disentangle the policy formulation process to an extent that researchers are now able to understand alternative ways for influencing decision processes. Local stakeholders were consulted at the onset of the research to consider acute needs for evidence and the way in which it should be presented. Working with stakeholders and decision-makers throughout the research-led dialogue was an important strategy for feedback and adjustment. It created researcher confidence in distilling powerful key messages that can be used to inform decision processes.
- **Stakeholder engagement not a one-off activity.** Multiple projects are nurtured through the stakeholder relationships developed in the AgMIP RIA research projects, as these projects will influence future interactions. Building trustful relations enhanced efficiency in the way research was conducted and supported dissemination of research results. How researchers handled relations in and between projects influenced sharing of information and building of new collaborations, beyond the scope of these projects.
- **Benefits from stakeholder engagement visible and acknowledged.** Nurturing opportunities for stakeholder contributions supported buy-in, ownership, and continuity from local-to-national levels, e.g., in jointly designed research processes, adaptation options verified with communities, how workshops were conducted, interpretation and publication of research results, and dissemination of outputs.
- **Appreciation for interdisciplinary research teams.** For effective research and outcomes, research teams were necessarily interdisciplinary, and with representation of national research organizations. Each research team member was proficient in the research objectives and contents, across disciplines, to be able to guide multidisciplinary dialogue with stakeholders. It was emphasized that researchers

must have listening, documentation, and facilitation skills to capture the richness of the stakeholder dialogues.

The AgMIP RIAs built increased confidence in the use of research results for interdisciplinary collaboration. The engagement process created the understanding that stakeholders 'own' the RAPs, as well as the improved management and adaptation packages. Inconsistencies, opportunities, and challenges were identified — beyond individual disciplines and affiliations — across local (district) provincial and national levels. The dialogue broke narratives of conventional development thinking, leading to new discussions of how farmers could reconfigure their agricultural production systems and how they could benefit, if conditions of farming were more conducive, and input and output markets for crops and livestock transactions better integrated.

The project also created an informed cross-scale dialogue. The RAP methodology provided a structured approach for assessing possible futures of farming in Sub-Saharan Africa and South Asia. The AgMIP global science network provided credibility in the approach, which was seen to be very relevant for the countries where institutional and policy barriers sometimes restrict the full potential of agriculture and climate change adaptation.

Establishing solid research results and context understanding at the local level and then taking that to national levels was seen as the right direction, as it provided facts, clear adaptation options, and legitimacy to policy-makers who often make decisions without credible research and scientific testing. The engagement of key stakeholders enabled the studies to be a new type of operational research that enables co-generation of knowledge and quick uptake of research results by various stakeholders and/or study users who include government program directors, scientists, extension workers, and farmers alike.

Stakeholders themselves, by understanding the process and being involved in setting up the parameters, enabled real-time adjustments of the research process and gained confidence in the research results. This helped them to set new priorities for agriculture, e.g., changes in the cropping system with a greater proportion of small grains and legumes, fertilizer application, and fodder production. There is now greater confidence to promote the technology packages and synergies in the context of climate change.

A new perspective was created that research on influencing cross-scale decision processes is important. Cross-scale dialogue is powerful for raising awareness of gaps, opportunities, and challenges. Stakeholders responded by recommending AgMIP research to improve the relations among research, policy, and communications. The research approach should be further designed to enhance each country's capacity to generate relevant products and services inclusive of climate-informed scenarios to guide other applications. Engaging national research organizations and ministries in scenario generation and multi-model simulations would be transformative, also in accessing and using scenarios for strategic exercises (e.g., vulnerability assessments, adaptation costing, policy-making, adaptation in Nationally Determined Contribution (NDC) revisions, the National Adaptation Plans (NAPs), the Green Climate Fund (GCF) feasibility study/project development, academic studies, and the United Nations Framework Convention on Climate Change (UNFCCC) National Communications).