AgMIP The Agricultural Model Intercomparison and Improvement Project

PHASE 1 Summary Report

Regional Integrated Assessments of Farming Systems in Sub-Saharan Africa and South Asia

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Phase 1 Summary Report – Regional Integrated Assessments of Farming Systems in Sub-Saharan Africa and South Asia

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1. Executive Summary

During the period 2011-2014, the Agricultural Model Intercomparison and Improvement Project (AgMIP) engaged global and regional stakeholders and researchers to assess climate impacts on food security and plan for a more resilient future. AgMIP built a cutting-edge framework linking climate, crops, livestock, and economics to help decision-makers better understand how climate change will reverberate through complex agricultural systems and markets. This framework is intended to support decisions by national agricultural ministries, breeding companies, non-governmental organizations, regional adaptation planners, extension agents, and smallholder farming groups in Sub-Saharan Africa (SSA) and South Asia (SA).

AgMIP worked with Regional Research Teams and Regional Coordination 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 productions systems will affect the agricultural productivity and livelihoods of diverse study regions.

In this first phase of AgMIP work (also called AgMIP Phase 1), the international network of AgMIP researchers built relationships with multiple groups of stakeholders, including national and regional agricultural planners, and demonstrated a trans-disciplinary 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.

A wealth of information about AgMIP is available at www.agmip.org. This includes stories, reports, protocols, publications, data, and much more.

Major Messages:

Overall:

- Climate change impacts on food security, income, and poverty can now be assessed for current farming systems and the types of farming systems that are likely to occur in the future, giving much more realistic projection of how climate change will facilitate or impede economic development.

- Consideration of economics and adaptation gives a more realistic and more optimistic picture of projected impacts of climate change on the agricultural sector, as future farming systems are more capable of absorbing yield losses than the farming systems under current practice.

- This is the 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 models.

- The new methods integrate climate methods integrating climate, crop, livestock and economic models to conduct multi-model climate change impact assessments that characterize differential impacts on smallholder groups even within a given region.

- The approach provides direct evaluation of yield, income, and poverty outcomes from pilot adaptation packages and development pathways.

Sub-Saharan Africa and South Asia:

- AgMIP regional integrated assessments in Sub-Saharan Africa and South Asia are capable of evaluating impacts, adaptations, and policies related to agricultural development and climate change resilience.

- AgMIP assessments show that climate change adds pressure to small-holder farmers across Sub-Saharan Africa and South Asia, with gainers and losers within each area studied.

- Climate changes lead to reduced incomes and increased poverty in most locations compared to a future in which climate change does not occur.

- Using the AgMIP distributional approach to integrated assessment enables decision-makers to target specific interventions to improve food security and reduce vulnerability.

- 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.

- The future of the agricultural sector agricultural sector in Sub-Saharan Africa and South Asia is projected to be more resilient to climate change impacts and therefore better able to absorb yield losses due to economic development, more diversified farming systems, and increased commodity prices.

Global Assessments:

- Crops in lower latitudes (where most developing countries are located) show greater vulnerability to climate change, and climate change will slow the pace of development in many current smallholder agricultural systems (Rosenzweig et al., 2014).

- In contrast to previous assessments that projected a period of increasing crop yields before temperature effects reduced yields, 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; a finding backed up by an independent analysis conducted for the IPCC of individual climate impact studies (Rosenzweig et al., 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 (von Lampe et al., 2014).

- Economic systems respond to climate impacts by taking actions to reduce yield loss, increase crop area, and change demand (von Lampe et al., 2014).

2. Introduction

Climate change poses new risks for agricultural systems in Sub-Saharan Africa and South Asia that are already challenged to develop rapidly. In addition to local impacts of rising temperatures and changing precipitation patterns, stakeholders in these regions will also be affected by distant agricultural disruptions that have the potential to alter international commodities markets.

AgMIP brings together world leaders in climate, crop, livestock, and economic modeling to form the necessary framework to understand climate impacts on food security (**Figure 1;** Rosenzweig et al., 2013a). Prior to AgMIP the vast 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 that severely limited comparison or aggregation of studies. AgMIP's approach eliminates these shortcomings and dramatically increases the rigor of scientific information that can aid in stakeholder decisions.

Since its launch in 2010 with support from USDA-ARS, AgMIP has worked with national and regional stakeholders (e.g., national adaptation planners in Kenya and Botswana, rice breeders in Sri Lanka, farming collectives in Ghana) to simulate development and adaptation strategies in a manner that can facilitate decision-making while advancing the rigor of agricultural modeling and integrated analysis. In this first phase AgMIP was able to test pilot policy and adaptation strategies in a way that demonstrated the framework's utility for decision-makers and encouraged further analyses of specific options currently being considered.

The UK Agency for International Development supported AgMIP activities in Sub-Saharan Africa and South Asia beginning in 2011, enabling engagement with decision-makers, the development of an innovative AgMIP researcher community, international coordination of major research projects, and regional integrated assessment of climate impacts on vulnerable agricultural smallholder systems.

AgMIP's activities in Sub-Saharan Africa and South Asia were organized in several distinct phases designed to create and execute an ambitious research and application agenda (**Figure 2**).

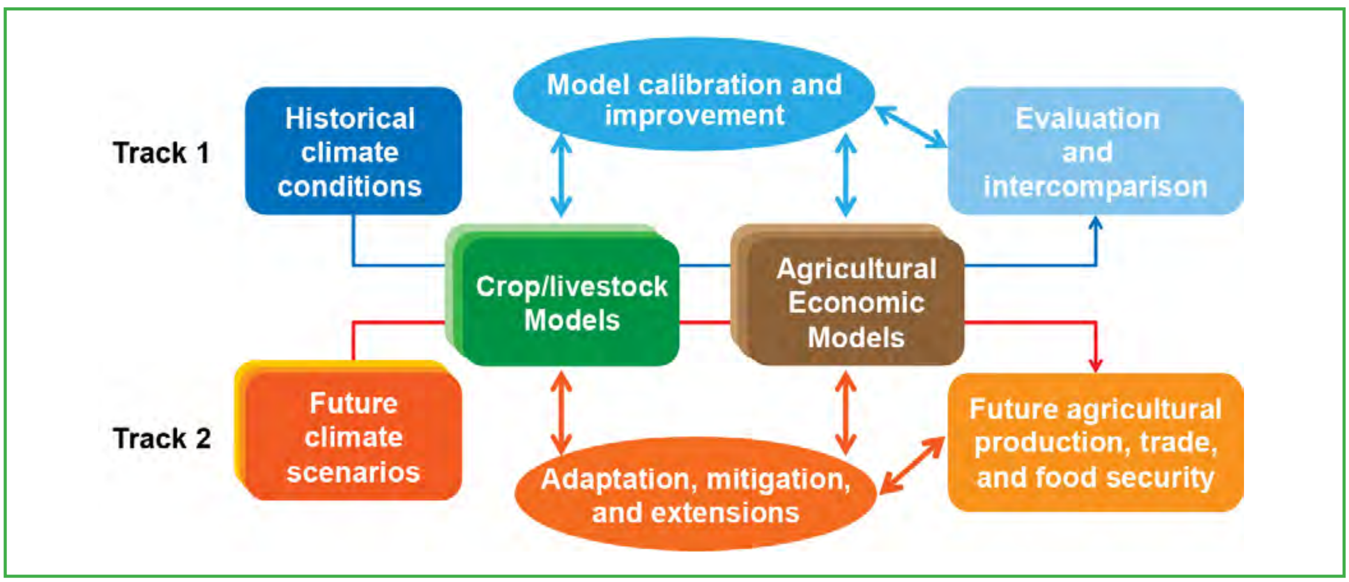


Figure 1: *AgMIP's dual scientific tracks to create robust framework capable of analyzing adaptation and policy decisions. From Rosenzweig et al., 2013a.*

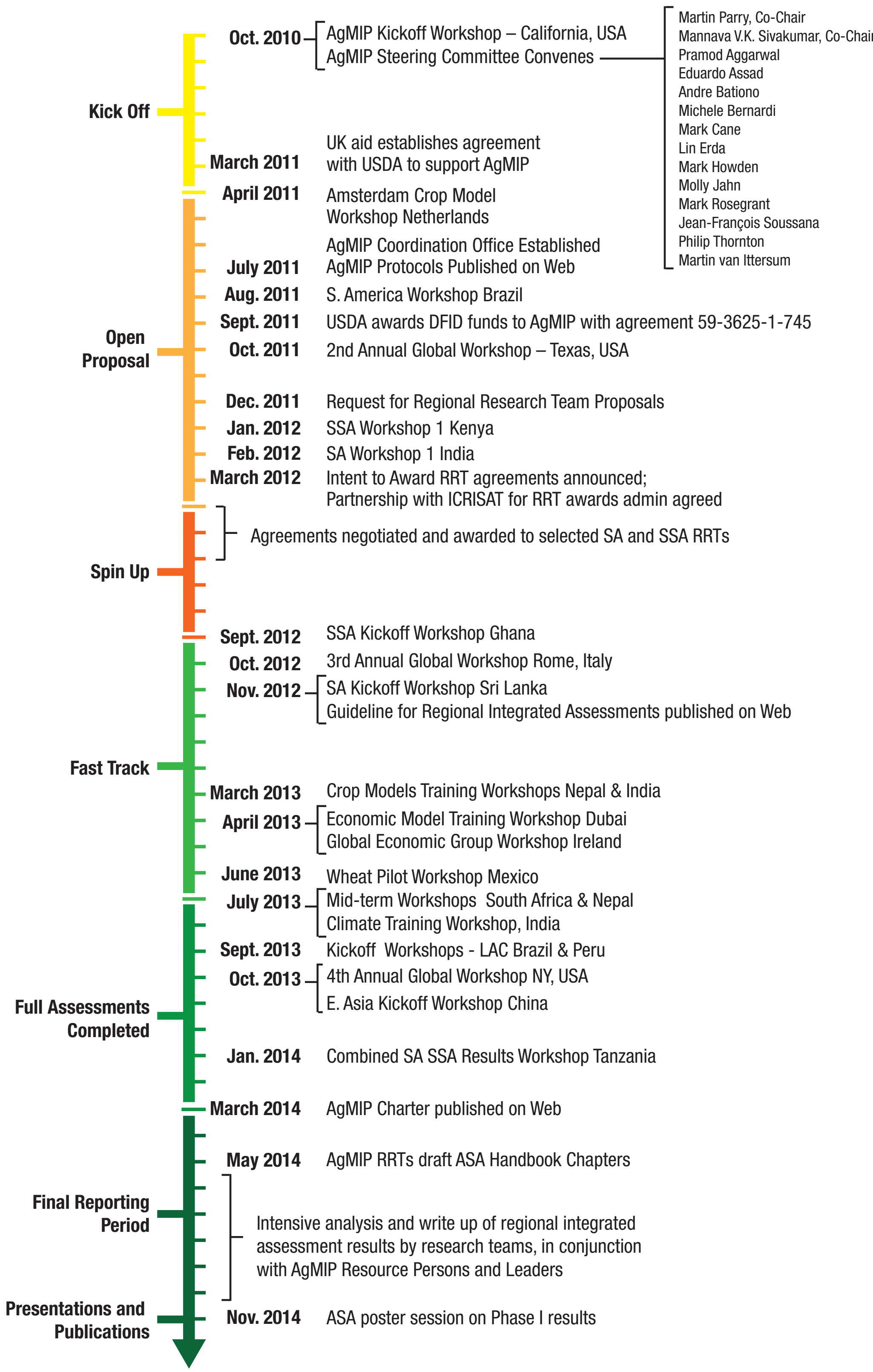


Figure 2: *Major project phases and project workshops for AgMIP Phase 1. Note that project planning began in 2010 but project funding initiated in March, 2011.*

3. Theory of Change

AgMIP's theory of change drove research and stakeholder engagement throughout the project to ensure decision-relevant findings with development impact (**Figure 3**).

- AgMIP develops advanced multi-model framework for evaluating technologies and policies aimed at achieving development impacts;
- AgMIP helps regional researchers identify and engage appropriate stakeholders who provide the critical links between research and development;
- AgMIP contributes to the RRTs' regional integrated assessments and builds regional capacity for effective use of the framework with stakeholders as partners; and,
- Stakeholders and researchers in the region adopt the AgMIP framework to achieve development impacts.

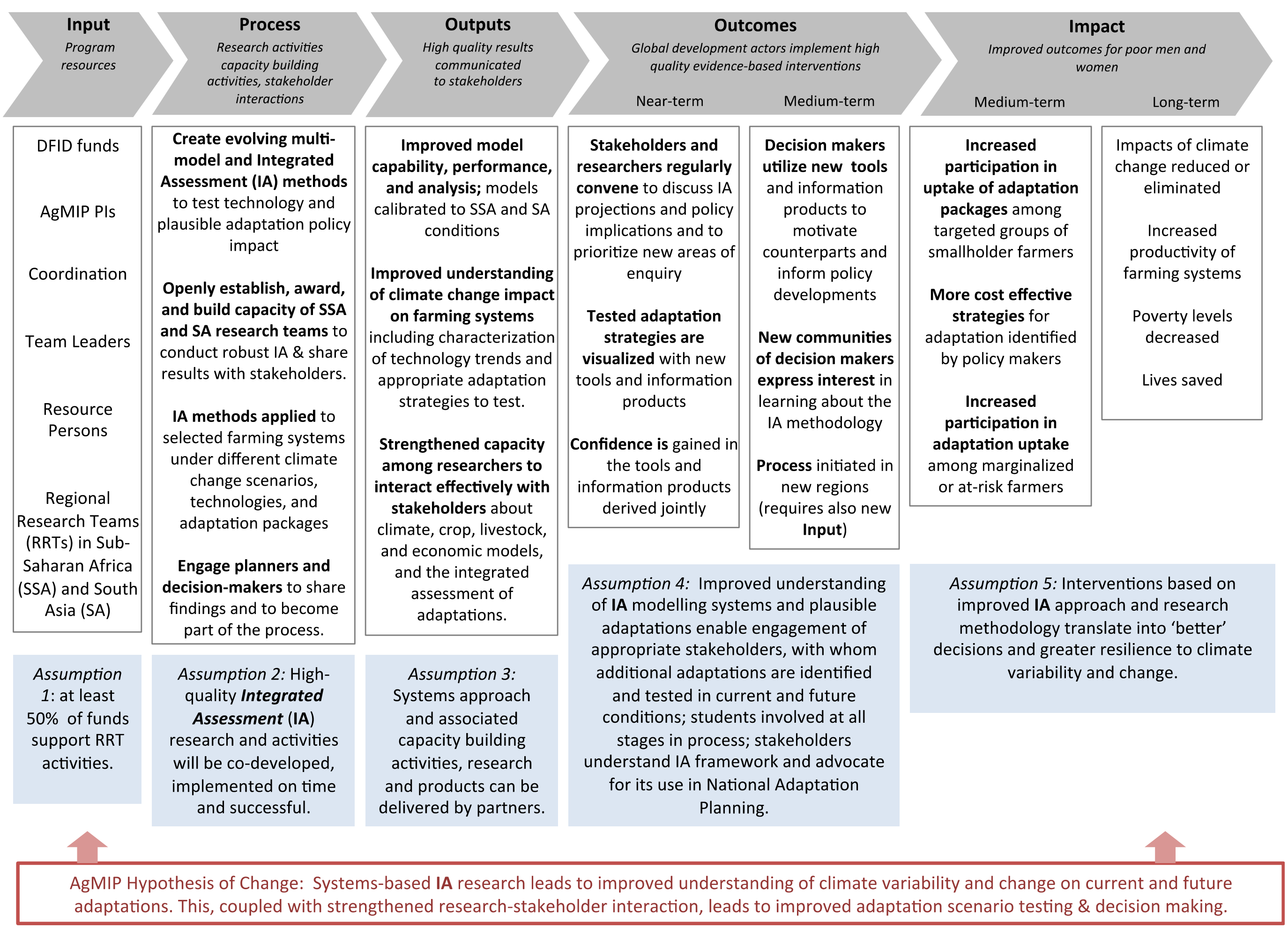


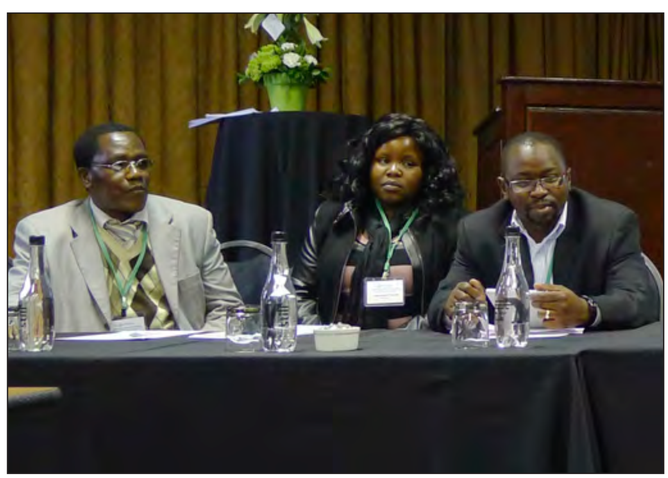
Figure 3: *The AgMIP Theory of Change.*

4. Stakeholder Process

The selection of regional research team (RRT) proposals included a criterion for stakeholder engagement, and each RRT met with regional 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 stakeholder and research community.

At the final workshop in Arusha, Tanzania RRTs collaborated with AgMIP leaders on slides developed with key messages for stakeholders in mind. These stakeholder targeted presentations included visual illustrations of some of the results (double channel communication with numbers and visuals), reduced technicality of the graphs, and a final wrap-up slide with main conclusions.

A stakeholder session followed with attendees from Pakistan, Botswana, Kenya, Zimbabwe, and India. Making science useful to stakeholders is a communication challenge, and the stakeholders were asked to assist AgMIP in finding the best ways to create impact through improved interpretation, visualization and presenting. After each region (SA and SSA) presented, a panel of the invited stakeholders gave remarks about their roles and the key climate change-related challenges in their countries and regions. They also provided feedback to the teams about the clarity of their presentations and messages.



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 Phase 2.

5. Regional Results

a. Regional Integrated Assessment Methodologies

AgMIP selected regional research teams (RRTs) across Sub-Saharan Africa and South Asia through an open and competitive process to deliver climate impact information that aids decision-makers. Each RRT included climate, crop, and economics experts with critical knowledge about local farming systems and challenges. Teams were also encouraged to include representatives from the national agricultural research organizations, universities, and CGIAR centers.

An important aspect of this work was the co-development of methodologies linking cutting-edge models and providing simulations that addressed decision points within each study region (resulting in a common protocol published at www.agmip.org). In addition to average impacts on yields, incomes, and poverty indicators, AgMIP integrated assessments utilized distributions of farms and households 60-400 farm sites per region) to provide additional detail on the types of populations and households that were most strongly affected. AgMIP researchers were thus able to provide stakeholders with plausible projections of future outcomes, facilitating cost-benefit analysis, targeted interventions, and risk management.

AgMIP identified the following core questions that motivate research activities for regional integrated assessments (**Figure 4**):

1. *What is the sensitivity of current agricultural production systems to climate change?* This question addresses climate change impacts assuming that the production system does not change from its current state. This question is the root of the vast majority of previous climate impacts studies yet is most useful in motivating critical further research to overcome climate challenges.

2. *What is the impact of climate change on future agricultural production systems?* This question evaluates the isolated role of climate impacts on the future production system, which will differ from the current production system due to development in the agricultural sector not directly motivated by climate changes. Stakeholders engaged in the design of these experiments by providing agricultural development decisions that may be evaluated.

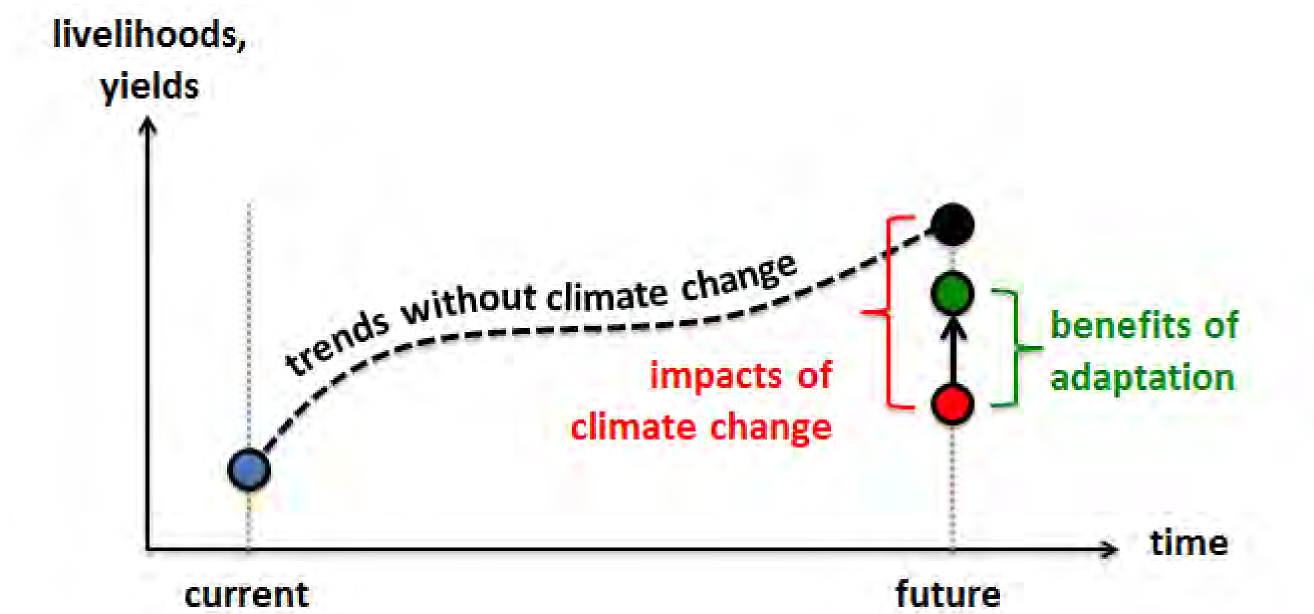


Figure 4: *Conceptual illustration of future agricultural outcomes, affected by agricultural development (dashed line), the impacts of climate change (red bracket), and the benefits of adaptation (green bracket).*

3. *What are the benefits of climate change adaptations?* This question analyzes the benefit of potential adaptation options in the production system of the future, which may offset or capitalize on climate vulnerabilities identified in Core Question 2 above. Decision-makers considering particular adaptation investments helped to design adaptation packages for evaluation.

The SSA and SA Regional Research Teams were led by regional PIs and supported by AgMIP Leadership through workshops and regular communications. An AgMIP Resource Person was assigned to each RRT to provide additional expertise, strengthen interactions between the RRT and Leadership, and build relationships to facilitate continuing collaborations. A Coordination Team was also established within South Asia and within Sub-Saharan Africa in order to facilitate interactions among RRTs and between AgMIP and stakeholders in each continent. In the course of project analysis it also became clear that adding an additional test of adaptation packages without climate change will be necessary for Phase 2 to identify adaptation packages that substantially benefit farming systems regardless of projected climate changes.

b. Sub-Saharan Africa

AgMIP research in Sub-Saharan Africa was conducted by four regional research teams (East, West, Southern, and Southeastern Africa) with regional coordination provided by a team based out of Nairobi, Kenya. AgMIP teams investigated climate impacts using models in 12 regions, with each team focusing

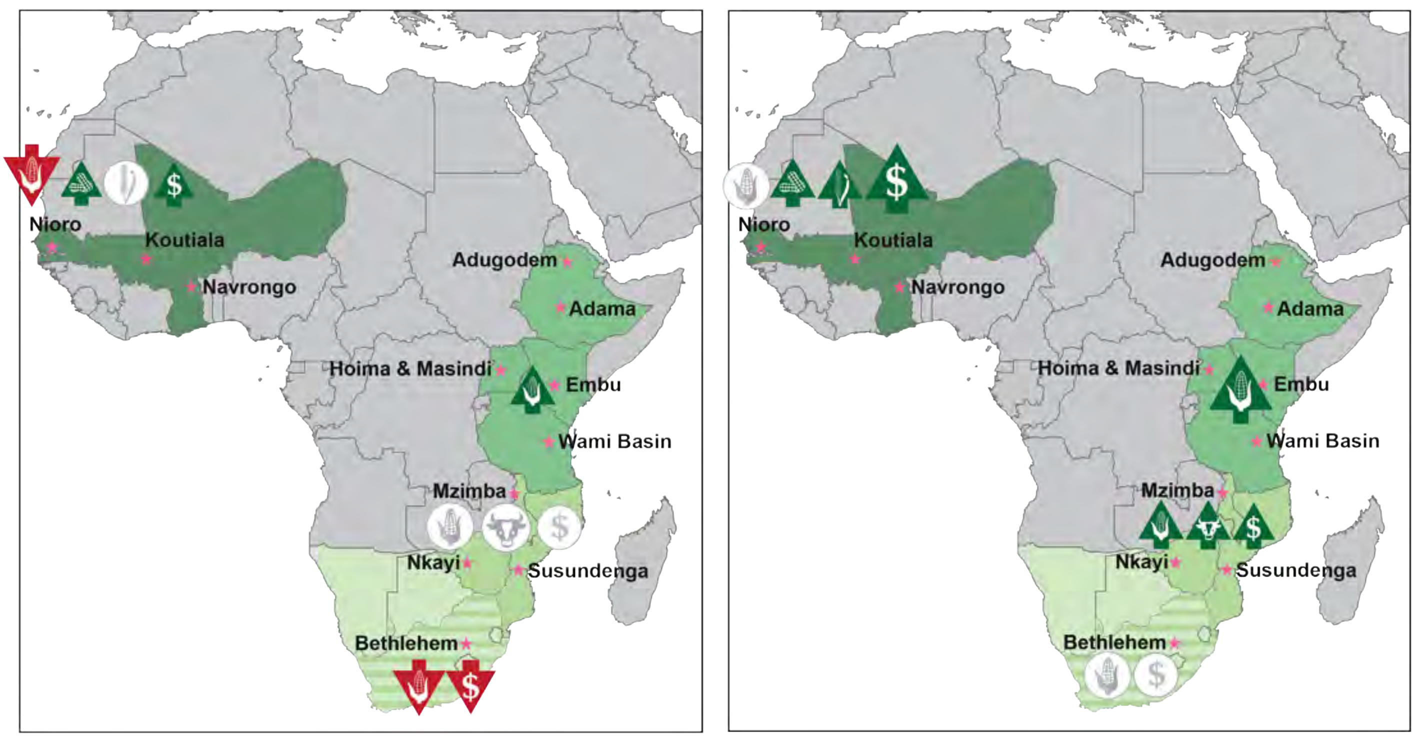


Figure 5: *Yield and income impacts projected by Sub-Saharan Africa regional integrated assessments for (left) climate change but no adaptation; (right) climate change with adaptation. Green arrows represent yield or income increases in comparison to a future without climate change; red arrows represent yield or income decreases; white circles represent yield or impact changes of less than 5%; symbols represent maize, rice, wheat, and cattle. Larger arrows indicate a greater amount of projected change. Country shading indicates the geographical domain of each AgMIP regional research team.*

primarily on the distribution of effects upon dozens of farming households spanning regional conditions (Kihara et al., 2015: Adiku et al., 2015; Rao et al., 2015; Beletse et al., 2015; Masikati et al., 2015) .

- Climate finding: Temperature increases are projected to affect agricultural production across Sub-Saharan Africa, with regional precipitation changes exacerbating risk in some regions (particularly the western Sahel and Southern Africa), and alleviating detrimental outcomes in others (e.g., the eastern Sahel and northern portions of Eastern Africa).

- Impact finding: Climate changes lead to reduced incomes and increased poverty in many study regions of Sub-Saharan Africa, although others are positively affected by increased carbon dioxide concentrations and wetter conditions. Impacts are varied even within a given region, as different farming systems and household types demonstrate yield and income changes of different magnitudes and even signs.

- Impact finding: Livestock in Zimbabwe and Botswana projected to benefit from increased forage and grassland production.

- Adaptation finding: Adaptation packages including varieties targeted for warmer climates, shifted planting dates, and irrigation improvements can reduce the negative impacts of climate change.

Findings in focus regions (**Figure 5**) include:

- Nioro, Senegal (see Adiku et al., 2015, for further details and discussion): Maize yields are negatively affected by warmer and drier conditions, while median peanut yields increase slightly and median millet yield changes are not very different from those that would be expected in a future without climate change. In net, this leads to increased incomes. Adaptations are demonstrated to increase yields for all three crops, leading to positive yield changes for millet and peanut, bringing maize yields back in line with the no-climate-change situation, and elevating incomes overall.

- Nkayi, Zimbabwe (see Masikate et al., 2015, for further details and discussion): Climate change has minimal effects on maize and cattle production as elevated carbon dioxide concentrations generally counter the detrimental effects of warmer temperatures. Corresponding income changes are small. Tested adaptations can push yields and incomes higher.

- Bethlehem, South Africa (see Beletse et al., 2015, for further details and discussion): Maize yields decline as warmer temperatures and drier conditions affect the region and lower average incomes compared to a future without climate change. The simulated adaptation package was able to bring yield changes and incomes back in line with what would be expected if climate change did not occur.

- Embu, Kenya (see Rao et al., 2015, for further details and discussion): Maize yields increase across a number of strata spanning different elevations in the Kenyan highlands. At these high elevations temperature is not a limiting factor, allowing plants to take advantage of higher carbon dioxide and the potential for higher rainfall. Implementing the tested adaptation leads to even larger yield increases.

As an example of the type of simulation and analysis conducted by AgMIP's Regional Research Teams in Sub-Saharan Africa, we provide a fuller description of the distribution of results from the Nioro site in West Africa (Adiku et al., 2015). Two crop models were run for maize, millet, and peanut at a network of farms around Nioro (similar simulations were conducted for Khoutiala, Mali, and Navrongo, Ghana). Yields were simulated for historical conditions and across five future scenarios based upon prominent global climate models run for the 2050s under higher greenhouse gas emissions (RCP8.5), resulting in 10 simulations of yield and economic impacts of climate change. These simulations were run without, and then with an adaptation package designed to recoup losses and/or take advantage of changing conditions for higher yields and income.

Climate models project that the whole region will experience rising temperatures, but median rainfall changes follow an east-west dipole, with western countries projected to become drier and eastern portions projected to experience wetter conditions in the 2050s (**Figure B1.1**). Maize is negatively across the central 80% of simulations, with yield changes declines ranging from 10% to 57%. Both peanut and millet show positive and negative yield change projections, although the majority of projections are positive for both and the median change for peanut is substantially positive (+7%). Gains in millet and peanut tend to push incomes higher, although some scenarios reveal a risk of reduced incomes. An examination of various farm types within Nioro reveals that income losses and poverty rates are higher in millet-maize farmers than in those with only millet. Adapted varieties increase yields across all crops, leading to some maize yield gains and more confident yield increases for peanut and millet. The adapted farming system also demonstrates substantially higher and robust income gains, reducing much of the uncertainty in direction of future changes.

Box 1: West Africa

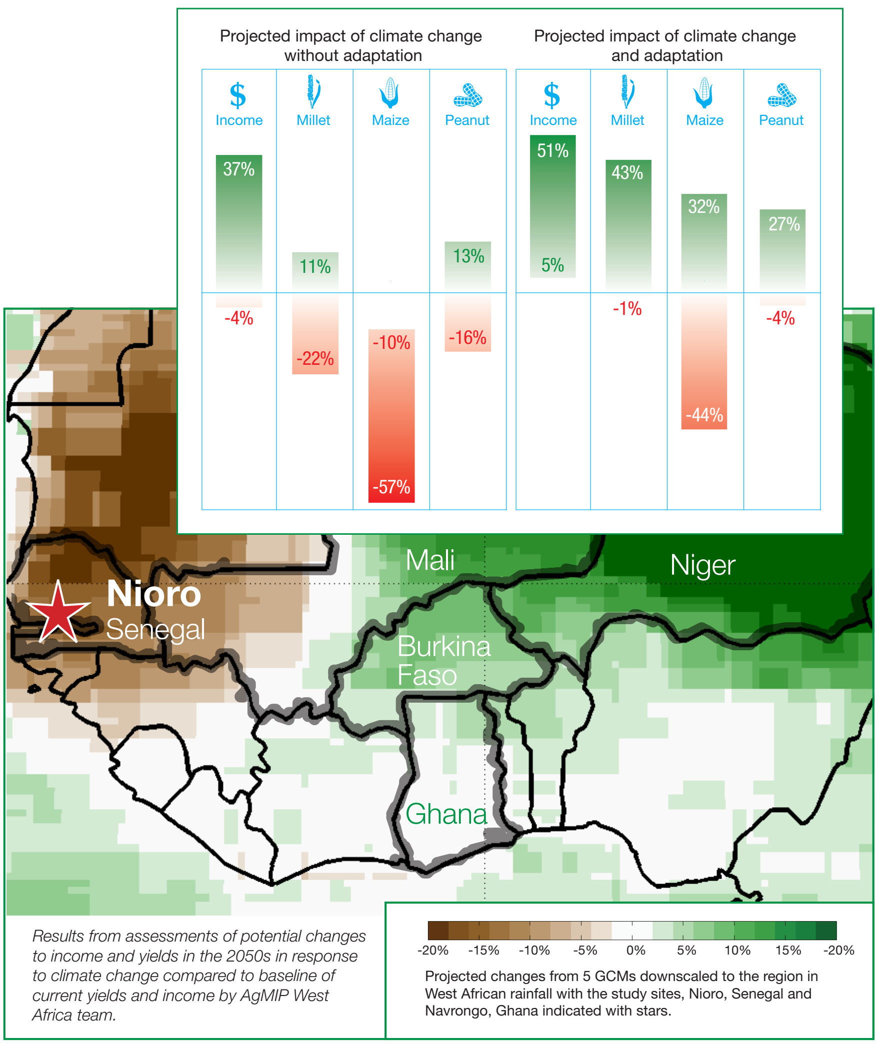


Figure B.1.1: *Projected impacts (compared to a future without climate change or adaptation) on incomes and yields of maize, millet, and groundnut under future climate and agricultural conditions, with and without adaptation (inset; showing range of middle 80% of simulation results). Map shows the Nioro, Senegal, integrated assessment site of primary focus overlaid on median projected changes (as % of historical totals) in annual precipitation from 20 CMIP5 GCMs for the RCP8.5 mid-century period. Countries participating in AgMIP's West African Team (CIWARA) are outlined and labeled.*

c) South Asia

AgMIP research in South Asia was conducted by four regional research teams (Indo-Gangetic Basin, Pakistan, Southern India, and Sri Lanka) with regional coordination provided by a team based out of Hyderabad, India. AgMIP teams investigated climate impacts on 11 regions, with each team focusing primarily on major farming systems in a region characterized by dozens of farming households across a variety of locations (McDermid et al., 2015; Ahmad et al., 2015; Subash et al., 2015, Ponnusamy et al., 2015; Zubair et al., 2015).

Major AgMIP findings in South Asia include:

- Climate: Projected intensification of the South Asian monsoon provides an increased supply of rainfall, however agriculture is detrimentally impacted by temperature changes across the region.
- Impacts: Climate changes lead to reduced incomes and increased poverty in most study regions of South Asia, although some farm systems and household types are more affected than others.
- Adaptation: Identified adaptation packages designed to take advantage of warmer and wetter mean conditions can raise yields and income levels.

Findings in focus regions (**Figure 6**) include:

- Punjab, Pakistan (see Ahmad et al., 2015, for further details and discussion): Wheat and rice yields are reduced in future climate conditions due to increased temperatures, leading to reduced average incomes. The identified adaptation package is capable of reversing rice losses into gains, leading to increased incomes despite wheat yields still being less than a future without climate change.
- Meerut, India (see Subash et al., 2015, for further details and discussion): Climate change pushes wheat and rice yields lower, however incomes are

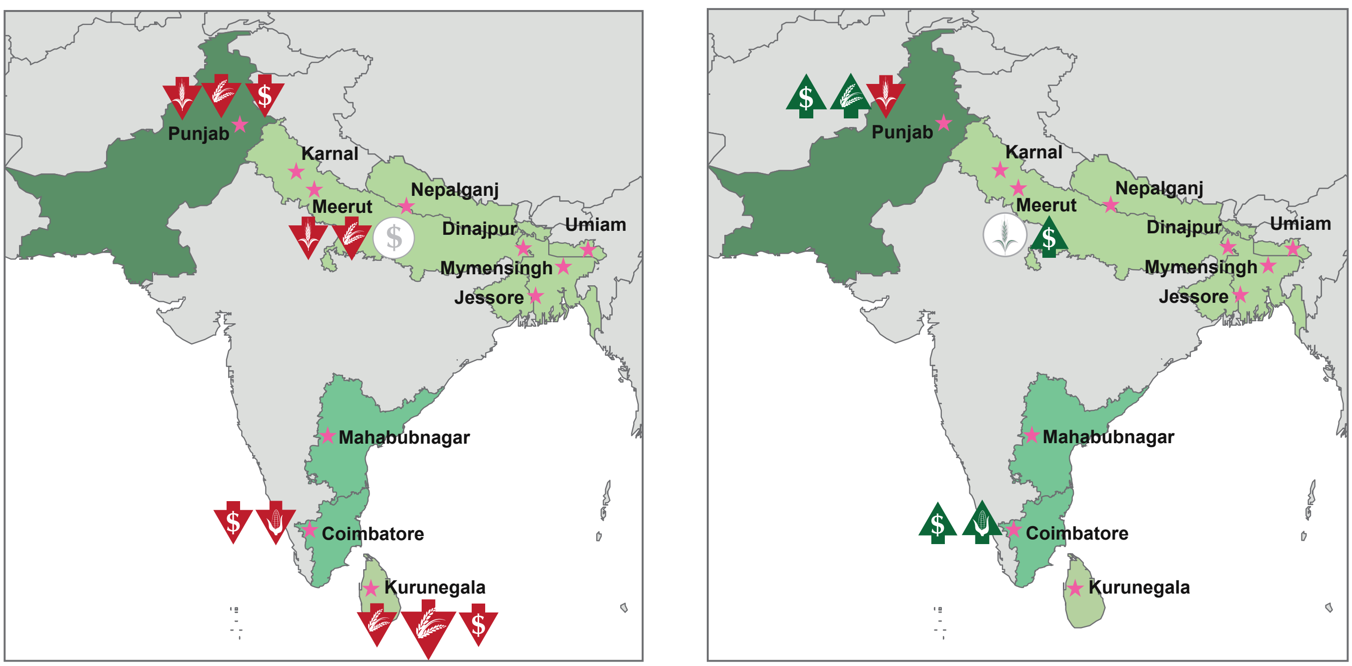


Figure 6*: Yield and income impacts projected by South Asia regional integrated assessments for (left) climate change but no adaptation; (right) climate change with adaptation. Green arrows represent yield or income increases in comparison to a future without climate change; red arrows represent yield or income decreases; white circles represent yield or impact changes of less than 5%; symbols represent maize, rice, and wheat. Larger arrows indicate a greater amount of projected change. Country and Indian state shading indicates the geographical domain of each AgMIP regional research team.*

Box 2: Pakistan

As an example of the types of analyses done within each of AgMIP's regional research teams, this box presents the work performed by Dr. Ashfaq Ahmad and his AgMIP-Pakistan team of university and government scientists (Ahmad et al, 2015). The rice-wheat farming system of Pakistan was examined using 5 districts within Punjab Province (Sheikhpura, Nankana Sahib, Hafizabad, Gujarwala, and Sialkot), with crop and economic simulations covering 155 farms in all. Climate change scenarios indicate that precipitation increases are sufficient to meet demands of currently-rainfed agriculture, although irrigated areas may see shortfalls in dry-season river and aquifer levels.

Following the methodological design illustrated in Figure 5, **Figure B.2.1** presents the simulated impacts of climate change and adaptation on rice-wheat systems in Punjab, Pakistan. A comparison between the blue and orange triangles shows the sensitivity of the current agricultural system to projected climate changes from 5 global climate models and 2 crop models for rice yields (B.2.1a; -30 to -8%), wheat yields (B.2.1b; -19 to -6%), and poverty rate (B.2.1c; increases of 3.9 to 8.5 percentage points). A pilot scenario for agricultural development (including changes in yield, household size, off-farm income, commodity prices, and production costs) is simulated via a representative agricultural pathway resulting in higher production per farm and lower poverty rates (black circles in B.2.1), although once again climate change has a detrimental effect (red triangles). Although the yield impacts are the same, poverty rates

Climate Change Impacts on Rice-Wheat System in Punjab, Pakistan

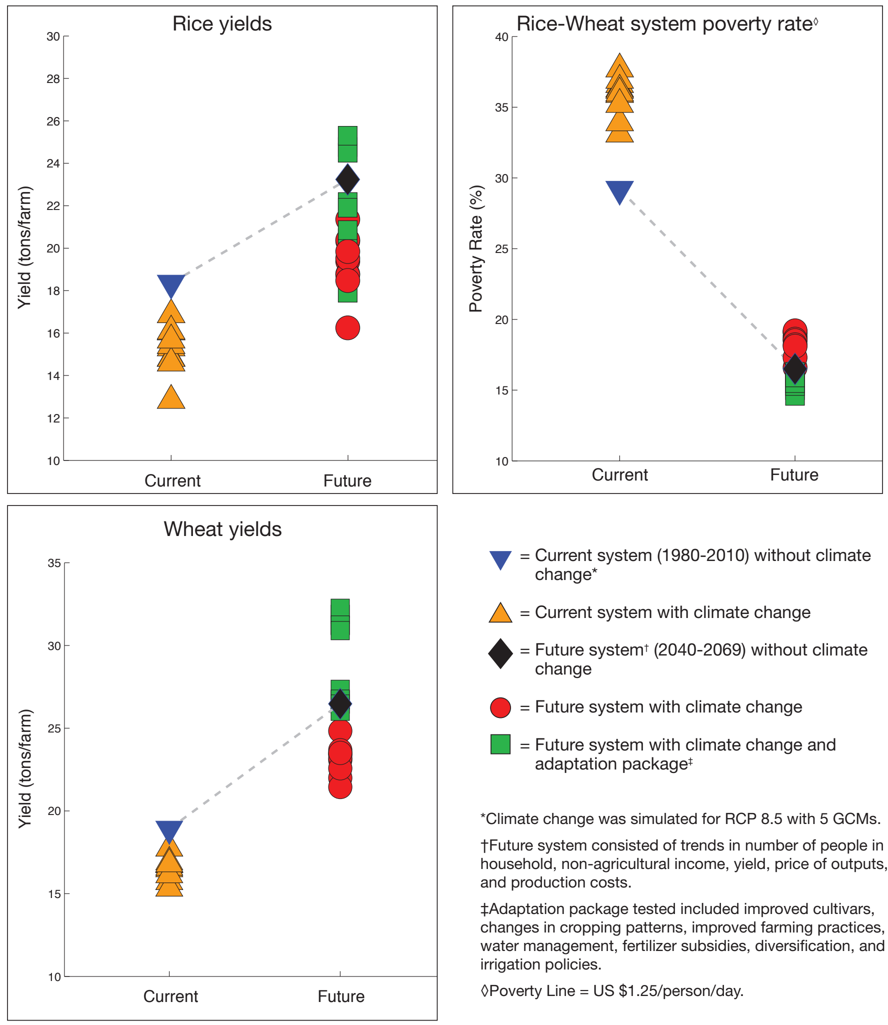


Figure B.2.1: *Rice yield (top-left), wheat yield (bottom-left), and poverty rates (top-right) under each of the scenarios investigated for AgMIP-Pakistan. A comparison between the blue and orange triangles represents the sensitivity of the current agricultural system to climate changes. The dashed line represents the pilot agricultural development pathway leading from the current agricultural system (blue triangle) to a future agricultural system (black circle) if climate change were not a factor. The impacts of future climate change scenarios are indicated by differences between the black and red circles, while the implications of the adaptation package on the future agricultural system may be assessed by comparing the red circles and green squares. From Ahmad et al., 2015; Rosenzweig et al., 2015* are more resilient under the future agricultural system; only increasing by 0.1 to 2.8 percentage points. A pilot adaptation package (consisting of improved cultivars, changes in cropping patterns, improved farming practices, water management, fertilizer subsidies, diversification, and irrigation policies) shows tremendous potential for benefit for rice yields (+2 to +24%), and wheat yields (+10 to +39%) as well as lowering poverty rates by 1.6 to 3.3 percentage points compared to the no-adaptation future.

In addition to mean yield changes across the 155 Punjab farms, the AgMIP framework provides information about how gains and losses are spread across the farms within the province (**Figure B.2.2**). In the current agricultural system an average of 74% of farms (69-83%, depending on climate and crop models utilized) would have reduced incomes under projected climate change scenarios. With agricultural development future agricultural production systems are more resilient, with only an average of 66% of farms (57-78%) facing reductions in income. Even the adaptation package that led to large yield increases is not practical for all farms, as simulations suggest only 74% of farms (69-80%,) would profit by adopting this package when all costs, benefits, and changes to the competitive balance within the community are considered. Data from Ahmad et al., 2015.

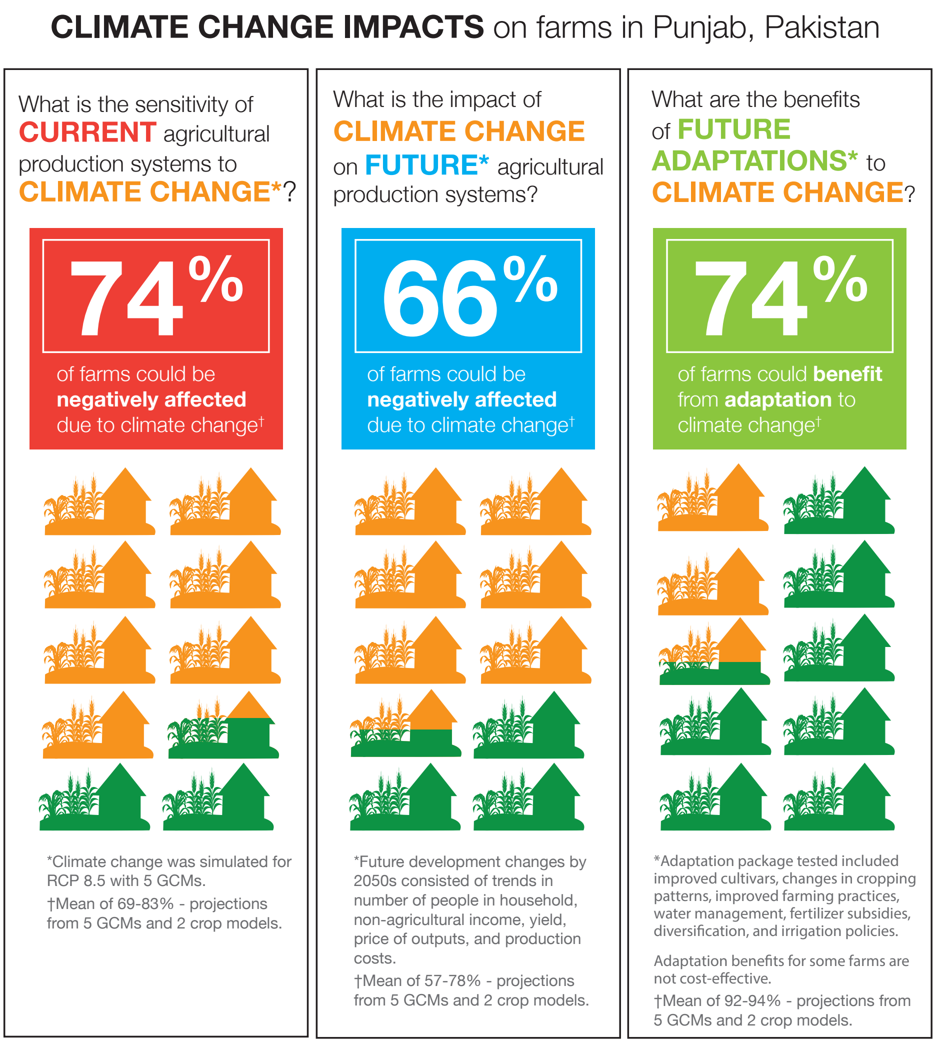


Figure B.2.2: *Breakdown of the percentage of farms within Punjab that are projected to lose income due to climate change under current (left) and future (center) agricultural systems, as well as the percentage of farms likely to adopt the pilot adaptation package (right).*

not dramatically affected. An adaptation targeting the wheat crop is able to get yields close to their levels if climate change did not occur, resulting in increases in income.

- Coimbatore, India (see Ponnusamy et al., 2015, for further details and discussion): Maize yields are negatively impacted by climate change, leading to a reduction in average incomes compared to a future without climate change. The adaptation package recouped these losses and even led to higher yields and incomes.

- Kurunegala, Sri Lanka (see Zubair et al., 2015, for further details and discussion): Rice yields for both the Maha (major) and Yala (minor) seasons were negatively affected by rising temperatures associated with climate change, with the Yala season showing larger losses due to the additional burden of an increased likelihood of drought. These shifts led to a decline in yields compared to a future without climate change.

6. Global Research Findings

This section summarizes major research findings from AgMIP global research activities. These results contributed to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5), 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 assessment.

a) Global Models

AgMIP led an intercomparison of seven global gridded crop models (GGCMs) to analyze climate impacts on maize, wheat, rice, and soybean across a global domain using high-performance computers (**Figure 7;** Rosenzweig et al., 2014)[1]. Crops in lower latitudes (including much of Sub-Saharan Africa and South Asia) demonstrate greater vulnerability as rising temperatures push farming systems further from optimal conditions.

1. DFID and USDA support enabled AgMIP leadership of this initiative, with modeling centers participating using a combination of in-kind support and small grants from the Inter-Sectoral Impacts Model Intercomparison Project (ISI-MIP). DFID's and USDA's support for AgMIP Global Workshops also provided important opportunities to develop and conduct global gridded modeling activities.

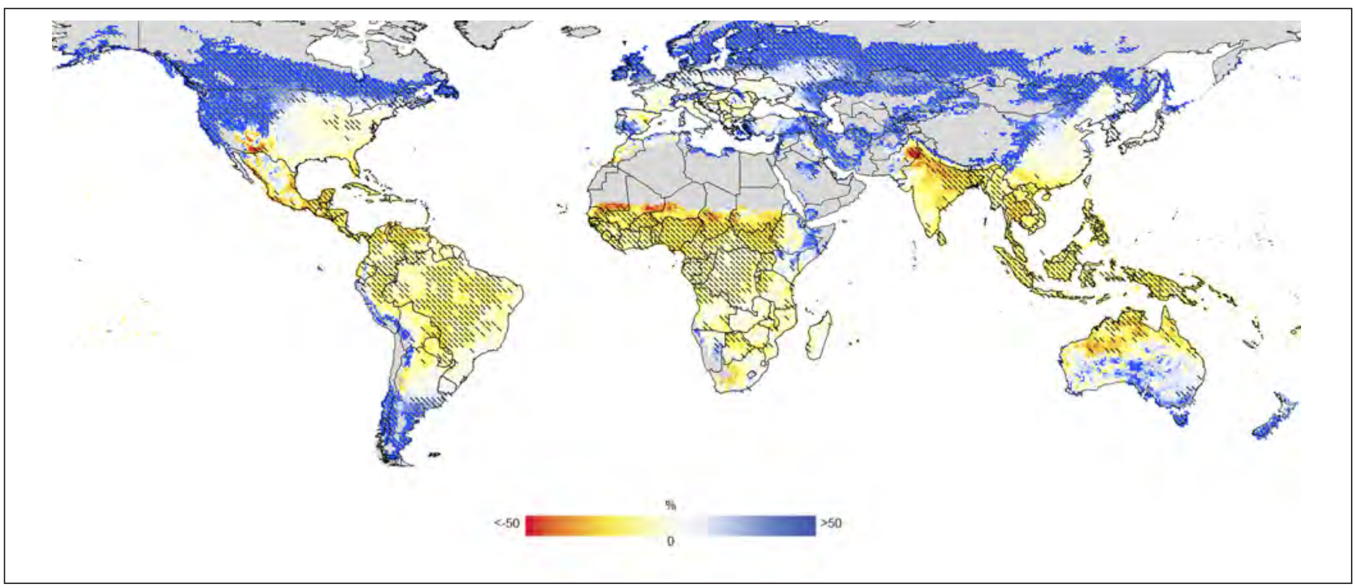


Figure 7: *Median end-of-century (2070-2099) maize yield changes (%; compared to 1980-2009 period) as simulated by seven global gridded crop models driven by five RCP8.5 GCMs. Hatching indicates regions where more than 70% of simulations had the same sign of maize yield changes (from Rosenzweig et al., 2014).*

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.

AgMIP's Global Economic Model Intercomparison also provided the first comprehensive investigation of uncertainty in projections of future commodity prices, agricultural land use, and agricultural GDP[2]. Climate change is projected to exert upward pressure on agricultural prices, but with large uncertainty (**Figure 8**). Economies respond by eliminating worst-yielding areas (buffering overall yield declines), increasing agricultural land use, and reducing consumption compared to the reference case with no climate change (Von Lampe et al.). While these reduce the negative impacts of climate change, there is still potential for large negative economic effects. 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. 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.

b) Model Intercomparisons

AgMIP's wheat, maize, rice, sugarcane, potato, livestock, and sorghum/millet teams were organized to test the robustness of crop model projections

2. DFID funding directly supported the leader of the AgMIP Global Economic Model Intercomparison and core leadership support for the development of protocols and project meetings. The Global Economic Model Intercmoparison was launched at the first AgMIP workshop in Sub-Saharan Africa, and was developed heavily at AgMIP Global workshops throughout the project period.

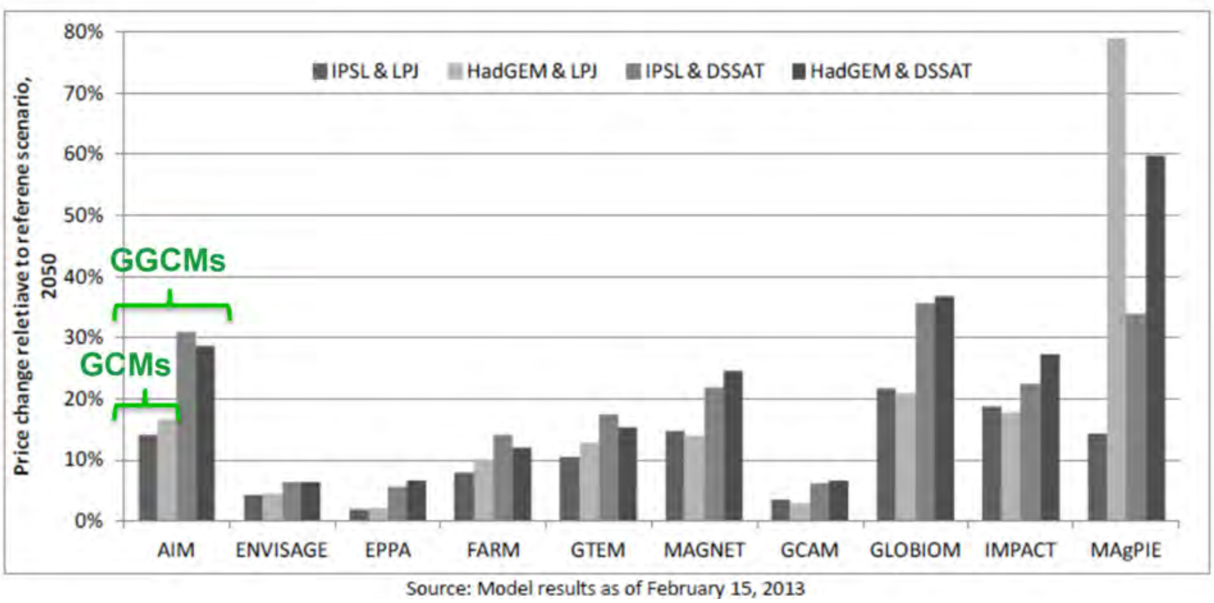


Figure 8: *International food price change for 2050 with climate change (compared to a reference 2050 scenario in which climate change did not occur) across 10 economic models driven by results from two crop models (LPJ and DSSAT) according to two GCMs (IPSL and HadGEM). Green brackets provide an example of uncertainty within the AIM economic model across global climate models (GCMs; first two bars) and across global gridded crop models (GGCMs; first two versus third and fourth bars). From von Lampe et al., 2014.*

of climate impacts on agricultural production with a particular emphasis on inter-model uncertainty and validation against high-quality field data[3]. Each pilot selected a number of high quality field sites for intercomparison, running under partial information (to mimic data available at most locations) and under nearly-complete information levels to gauge fundamental responses to temperature, rainfall, and carbon dioxide concentration (CO_2) changes. Each pilot includes sites in Sub-Saharan Africa and South Asia, including Delhi, India (wheat); Ludhiana, India (wheat); Morogoro, Tanzania (maize); La Mercy, South Africa (sugarcane); and Gisozi, Burundi (potato).

Figure 9 shows temperature and CO_2 responses from 27 models participating in the wheat model intercomparison, revealing substantial inter-model uncertainties around a robust decline in yields with higher temperatures and increase in yields with higher CO_2. Intercomparisons such as these provide important context to stakeholders who must manage risk with access to only one or perhaps two crop model results.

AgMIP's Coordinated Climate-Crop Modeling Project (C3MP) engages with the world's crop modeling community, providing a simple protocol and tools to assess fundamental climate responses on a diverse network of sites and crop models (**Figure 10**)[4]. At present more than 150 participants have registered, contributing more than 1100 simulation sets from 55 countries, 15 crops, and 18 crop models.

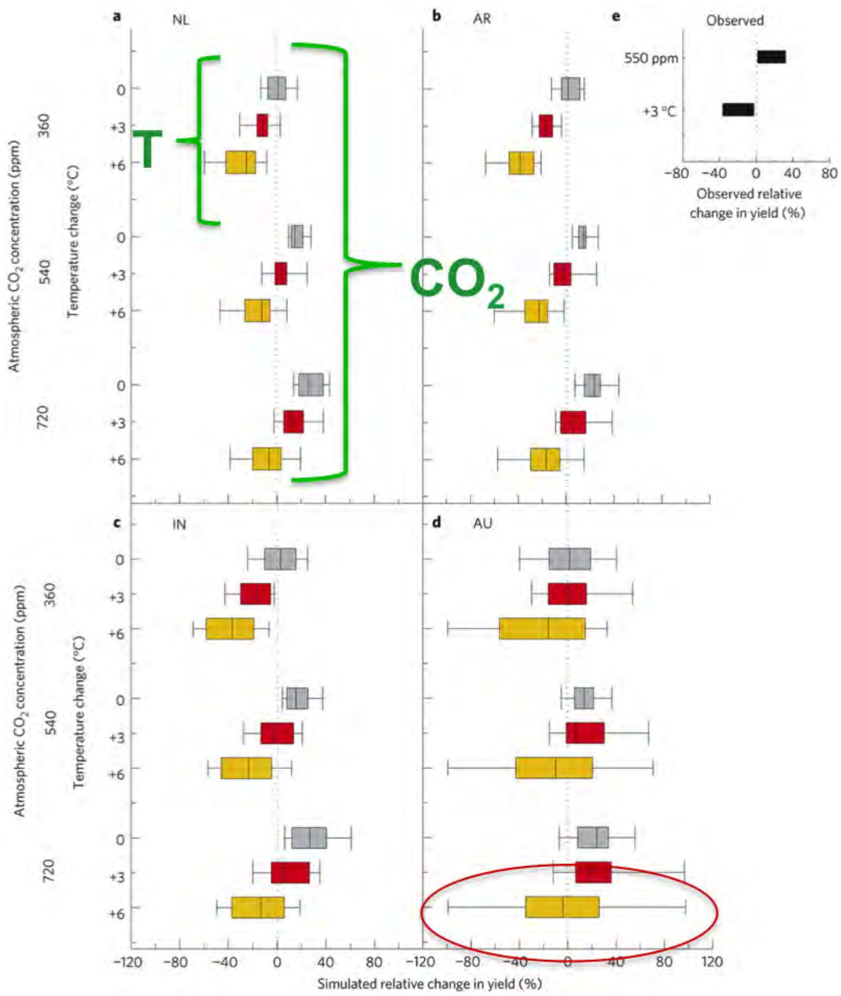


Figure 9*: Response of 27 wheat models to temperature and carbon dioxide (CO_2) changes from the AgMIP Wheat Team. AR=Balcarce, Argentina; NL=Haarweg, the Netherlands; IN=Delhi, India; AU=Wongan Hills, Australia. Note that the high temperature / high CO2 case results in lower yields in all but the Austalian case. From Asseng et al., 2013.*

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3. DFID and USDA support allowed AgMIP core leaders to develop the original protocol and call for participation in crop model intercomparisons. This support also enabled the supply of climate scenarios and helped AgMIP leaders ensure that intercomparisons shared lessons learned and common methodologies for more efficient research and more robust findings. Modelers on each crop model intercomparison team were supported by their own institutions through in-kind contributions, and the AgMIP global workshops provided annual meetings that were crucial to the development and conduct of the model intercomparisons.

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4. DFID and USDA support enabled AgMIP leadership to draft protocols and attract in-kind contributions of participation for C3MP. DFID also supported AgMIP leadership in its provision of information technology tools and web services that facilitated C3MP activities.

Results are displayed on impacts response surfaces that help stakeholders to visualize climate impacts, and C3MP methods are being utilized for a variety of further applications including global gridded crop modeling, livestock model intercomparison, and wheat model intercomparisons in Europe.

7. The AgMIP Community

Project funding has enabled AgMIP to build 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 good will and honest collaboration across previously competitive 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 list-serve (exceeding 650 members) and website featuring information and tools for the scientific and lay public (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. DFID and USDA funding supported AgMIP's coordination office, regional integrated assessments in Sub-Saharan Africa and South Asia, and the creation of AgMIP information technology tools.

DFID and USDA funding also enabled AgMIP to provide oversight and core support for a range of other AgMIP activities that support regional integrated assessment via in-kind contributions and other funding sources. These include (clockwise from top of **Figure 11**) global economic assessments and global crop modeling activities (via AgGRID), the development of next generation models incorporating more economic and environmental interactions, data and tools to facilitate multi-model and multi-discipline assessments, activities to better understand existing crop and livestock models, cross-cutting themes to help interpret model results for decision-making, and efforts to include the wider network of crop modelers around the world for future assessments (C3MP).

AgMIP has now launched regional projects on six continents and is building a global program to formalize collaboration and decision-making between AgMIP

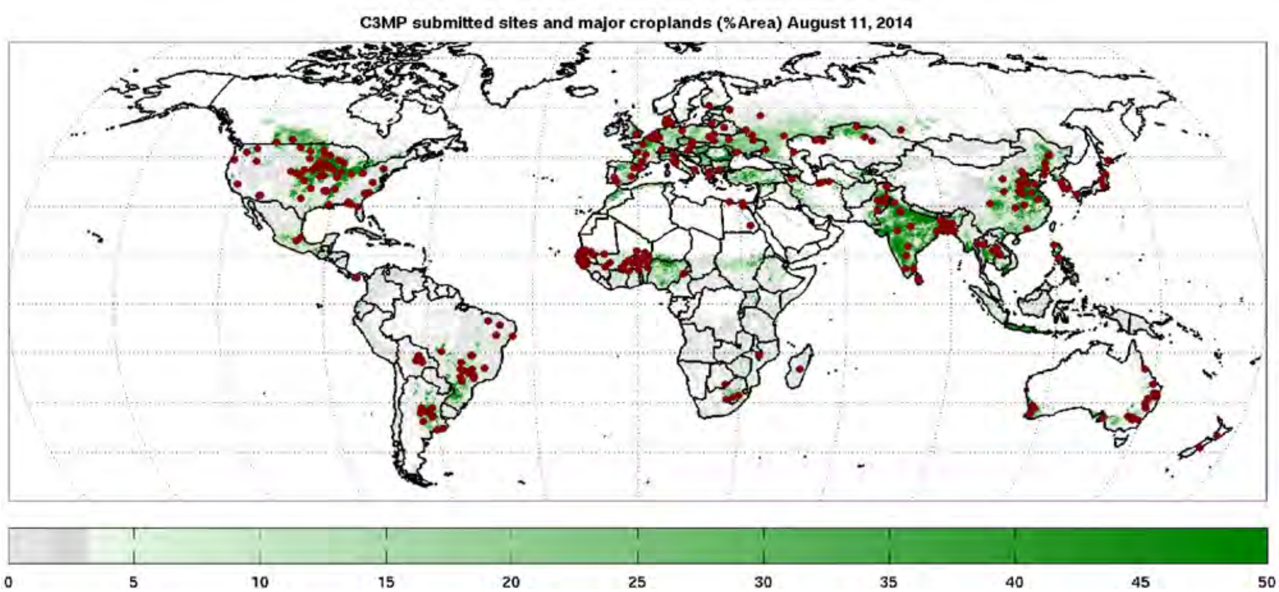

Figure 10: C3MP model sites (dots) and major croplands (% area; green shading) as of August 1, 2014. From McDermid et al., 2014.

and regional leaders (**Figure 12**). AgMIP's Science Integration and Coordination Office in the US spearheads interactions with national agricultural ministries, international development agencies, and research teams, which in turn lead to interactions with stakeholders and decision-makers across scales.

8. Impact

For the first time, decision makers will have access to information that can be used to evaluate and prioritize climate change adaptation strategies for small-holder agricultural households in regions of SSA and SA. This information will be based on rigorous new data and methods for climate impact and adaptation assessment at 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 clear examples of decision-maker uptake and improved the scientific capacity in SSA and SA.

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 vast majority of previous studies that simulated a representative field with little recognition of heterogeneity and economic responses, AgMIP results offer a much 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 small-holder 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 Eastern

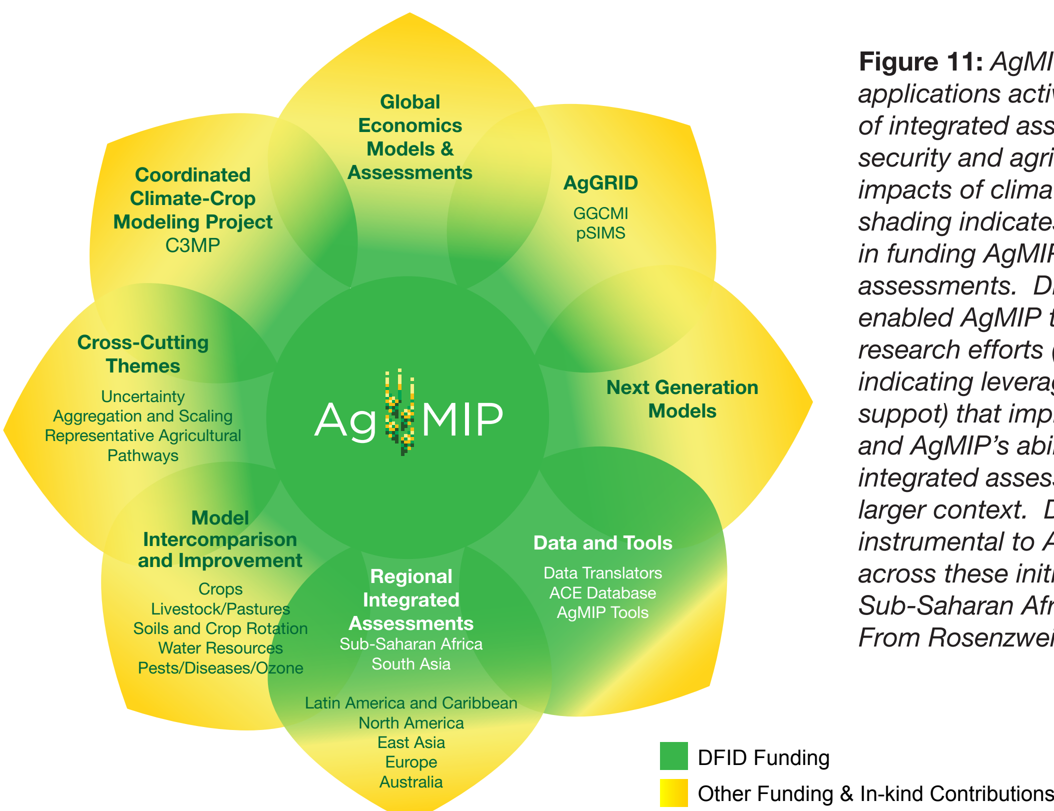

Figure 11: *AgMIP research and applications activities in support of integrated assessment of food security and agricultural sector impacts of climate change. Green shading indicates DFID's central role in funding AgMIP's regional integrated assessments. DFID resources also enabled AgMIP to lead additional research efforts (yellow shading indicating leveraged and/or in-kind suppot) that improved the scientific rigor and AgMIP's ability to place regional integrated assessment results in their larger context. DFID has thus been instrumental to AgMIP's successes across these initiatives even outside of Sub-Saharan Africa and South Asia. From Rosenzweig et al., 2015*

Africa, although increases in rainfall are projected for eastern West Africa and all of South Asia. Climate changes lead to yield decreases in all study regions except Southern India and areas in central Kenya, as detrimental temperature effects overcome the positive effects of CO_2 and most regions where rainfall increases. Projections indicate improved production for livestock in Zimbabwe. 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's stakeholder engagement process has led to a clear pathway to development impact. It has empowered the AgMIP Pathway to Development Impact, through its targeted stakeholder engagement process. This process includes focused engagement with global to regional levels of the value chain of stakeholders. AgMIP stakeholders at the regional and national levels now are now asking for additional simulations to test additional adaptations and policies (an emphasis of AgMIP's proposed second phase). AgMIP results are informing adaptation planning in 16 countries. **Pakistan recently launched a high-profile national initiative to use AgMIP approaches for adaptation planning.**

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. AgMIP has documented enhanced capacity in these regions.

At the global scale, AgMIP has emerged as an international leader in the use of agricultural models

Figure 12: AgMIP regional programs (shaded; dark green indicates DFID-funded regions) and crop model intercomparison sites from Phase 1. From Rosenzweig et al. 2015.

for assessment of climate impacts on crop production, food security, economic development, and adaptation strategies. The Global Gridded Crop Model Initiative has found that global average yields begin to decline immediately and are more widespread than previously projected. These results show areas of model agreement for the first time, in a manner similar to IPCC climate projections. Key results include that yields decline most in tropics, with maize and wheat yield declines larger than those of rice and soybean.

With DFID and USDA support, AgMIP has grown to include important new activities and partners. These include C3MP – the Coordinated Climate and Crop Modeling Project, and GGCMI – Global Gridded Crop Model Improvement, Global Economics, and Crop Model Intercomparison and Improvement Teams (Wheat, Maize, Rice, Sugarcane, Soybean, Sorghum/Millet, Potato, and Groundnut). In addition, the AgMIP successes have led to a number of countries organizing AgMIP projects in their own regions (e.g., Argentina, Brazil, Colombia, Peru, China, Korea, Pakistan, and Turkey).

AgMIP communications include a central website (*www.agmip.org*) designed as a resource for both the lay public and scientific experts, as well as a list-serve to keep participants informed and involved in crucial research efforts. AgMIP's website includes videos and blog posts explaining the challenges our society will face as climate change impacts food security, as well as news items and activity pages that help disseminate important findings, publicize key results, and organize important workshops.

AgMIP has built a network of researchers across Sub-Saharan Africa and South Asia who are capable of conducting 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. AgMIP researchers are also comfortable with the AgMIP methods published on *www.agmip.org*. Capacity gains included increased modeling experience for more than 200 participants, training of more than a dozen agronomists in a second crop model, vast improvements in regional economic modeling capacity, increased interactions with vital stakeholder communities, new capabilities for climate scenario generation utilizing the freely-available R programming language, and increased collaboration between scientists from different disciplines, countries, institutions, universities, genders, and seniority levels. **Participating researchers are under high demand to apply this increased capacity in additional projects.**

Figure 13: *Screenshot of AgMIP website* (www.agmip.org).

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Annex 1: Publications

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AgMIP's 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.

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