Chapter 6

Integrated Assessments of the Impact of Climate Change on Agriculture: An Overview of AgMIP Regional Research in South Asia

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Introduction

South Asia encompasses a wide and highly varied geographic region, and includes climate zones ranging from the mountainous Himalayan territory to the tropical lowland and coastal zones along alluvial floodplains. The region's climate is dominated by a monsoonal circulation that heralds the arrival of seasonal rainfall, upon which much of the regional agriculture relies (Mall *et al.*, 2006). The spatial and temporal distribution of this rainfall is, however, not uniform over the region. Northern South Asia, central India, and the west coast receive much of their rainfall during the southwest monsoon season, between June and September. These rains partly result from the moisture transport accompanying the monsoonal winds, which move in the southwesterly direction from the equatorial Indian Ocean. Regions further south, such as south/southeast India and Sri Lanka, may receive rains both from the southwest monsoon, and also during the northeast monsoon season between October and December (with northeasterly monsoonal wind flow and moisture flux), which results in a bi- or multi-modal rainfall distribution. In addition, rainfall across South Asia displays a large amount of intraseasonal and interannual variability (Fig. 1). Interannual variability is influenced by many drivers, both natural (e.g., El Niño Southern Oscillation; ENSO) and man-made (e.g., rising temperatures due to increasing greenhouse gas concentrations), and it is challenging to obtaining accurate time-series of annual rainfall, even amongst various observed data products, which display inconsistencies amongst themselves (exemplified in Fig. 1). These climatic and rainfall variations can further complicate South Asia's agricultural and water management.

Agriculture employs at least 65% of the workforce in most South Asian countries, and nearly 80% of South Asia's poor inhabit rural areas. Understanding the response of current agricultural production to climate variability and future climate change is of utmost importance in securing food and livelihoods for South Asia's growing population. In order to assess the future of food and livelihood security across South Asia, the Agricultural Model Intercomparison and Improvement Project (AgMIP) has undertaken integrated climate-crop-economic assessments of the impact of climate change on food security and poverty in South Asia, encompassing Bangladesh, India, Nepal, Pakistan, and Sri Lanka (Rosenzweig *et al.*, 2013). AgMIP has funded, on a competitive basis, four South Asian regional research teams (RRTs) and one South Asian coordination team (CT) to undertake climate-crop-economic integrated assessments of food security for many districts in each of these countries, with the goal of characterizing the state of food security and poverty across the region, and projecting how these are subject to change under future climate conditions.

Understanding the historical production trends and the impact of observed farming practices in South Asia are crucial to successfully plan for, and adapt, food production under future climate conditions. South Asia benefitted from a boom in food grain productivity in the 1970s as a result of "green revolution" technologies and high-yielding seed varieties (Hazel *et al.*, 2008). However, as the population has continued to rise, and as other non-agricultural sectors have developed, South Asia is at risk of not being able to provide sustained food and nutrition security in the future. In fact, some studies point to a seeming "plateau" of food grain production in various areas that suggest current technology trends may not be sustainable without

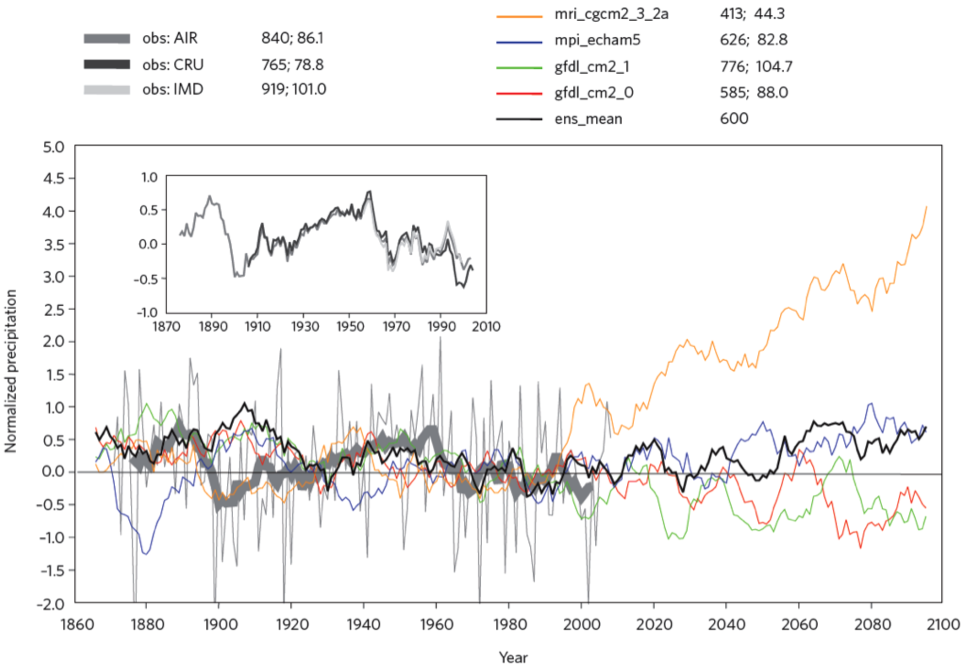

Fig. 1. Historical and SRES A1B projection of South Asian monsoon rainfall (Turner and Annamalai, 2012). Time-series of mean summer (June to September) rainfall averaged over the South Asian domain from 1861–2100. Four climate models are shown (colored lines), along with gauge information from the 1871–2008 AIR index (shown in the thick gray line in the main plot). The inset shows the AIR index compared to the 1951–2004 IMD daily gridded data and 1901–2009 monthly gridded CRU data. All curves are normalized by their mean and standard deviation, measured over the 1961–1999 period and are passed through an 11-year moving window. Reprinted by permission from Macmillan Publishers Ltd: *Nature Climate Change*, Turner, A. G., Annamalai, M., Climate change and the South Asian Summer Monsoon, **2**(8), copyright 2012.

substantial improvements in seed, management, and agricultural planning into the future (Grassini *et al.*, 2013). Furthermore, green revolution practices contributed to the over-utilization of fertilizers, pesticides, and resources, while diminishing soil quality and biodiversity. Poverty and malnutrition also persist, even in the face of increased grain production and stores.

In particular, these production increases over the 20th century have also encouraged the increasing use of groundwater stores, which has resulted in the over-exploitation of important ground aquifers. These aquifers are in jeopardy of running dry in what are now some of the most productive areas in South Asia, particularly in Pakistan and northwest India (Rodell *et al.*, 2009). The concurrent land-use transition, deforestation, loss of soil health, and the flight of the agricultural workforce to urban areas are also compounding factors that must be considered when planning for future agriculture and resource policies.

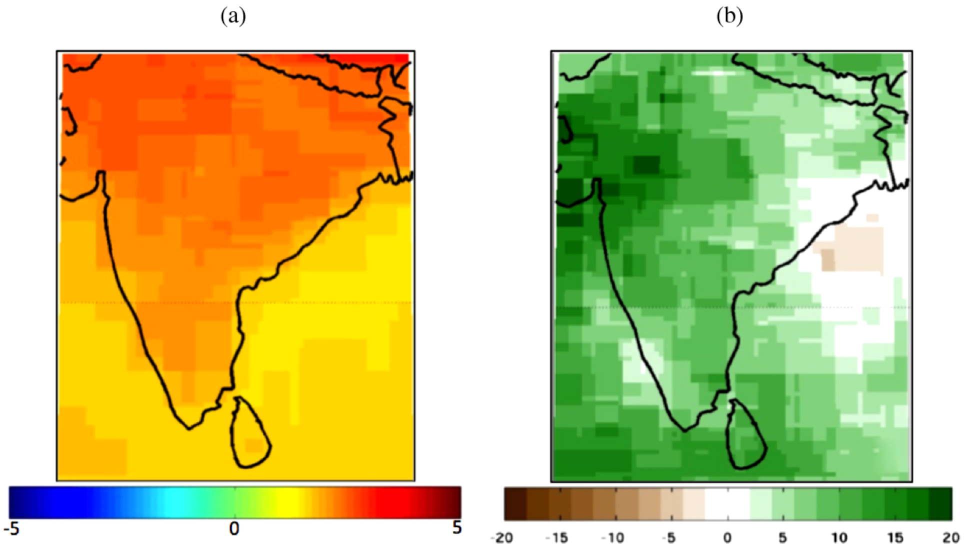

Fig. 2. Temperature (a, °C) and precipitation (b, %) changes under RCP8.5 mid-century climate projections from 20 CMIP5-coupled global-climate models, compared to baseline conditions. Courtesy of Alexander Ruane and CMIP5.

Potential Climate Change Impacts in South Asia

Further compounding these concerns are the changes expected to occur with rising global carbon emissions as the 21st century progresses. Climate change is expected to raise baseline mean, minimum, and maximum temperatures, bringing a moderate-to-large warming across the entire region by mid-century (Kirtman *et al.*, 2013), and also raise sea levels in vulnerable coastal territories. In addition, climate change may impact the strength of the regional monsoon circulation and the timing, frequency, and spatial distribution of seasonal rainfall, although large uncertainties exist in quantifying these changes (Turner and Annamalai, 2012). Figure 2 shows the IPCC climate models' projections of future interannual rainfall up to 2100, and there are substantial differences in both the interannual variability and the amount of rainfall projected. Bracketing this uncertainty will be critical for assessing impacts to future agricultural production. In addition to this, some other prime concerns amongst stakeholders in South Asia include potential increases in extreme events, more variability in rainfall, pronounced dry periods, inadequate or limited rainfall during the monsoon onset, and rising minimum and wintertime temperatures (Mall *et al.*, 2006).

AgMIP has attempted to characterize climate change and vulnerability in geographically varied South Asian subregions, challenging areas in which to project climate changes as climate models have historically had difficulty resolving fine-scale geographic features and dynamical processes. A major objective of the AgMIP

South Asia regional assessments studies is to assess how important crops respond to climatic changes in temperature, rainfall, and humidity variables, and to project what the future impact might be to crop yields, prices, poverty levels, and overall farmer livelihoods under a range of future climate and economic scenarios.

Regional Contrasts

South Asia's climate can be generally characterized by a monsoonal regime, in which the main rains occur during either the southwest or the northeast phases of the monsoon (for South India and Sri Lanka). However, the region is highly varied in terms of topography (Fig. 3), hydrology, and soils which make for diverse agricultural systems, and climate impacts. These regional distinctions will be further characterized in the following chapters with depictions of the farming systems being modeled.

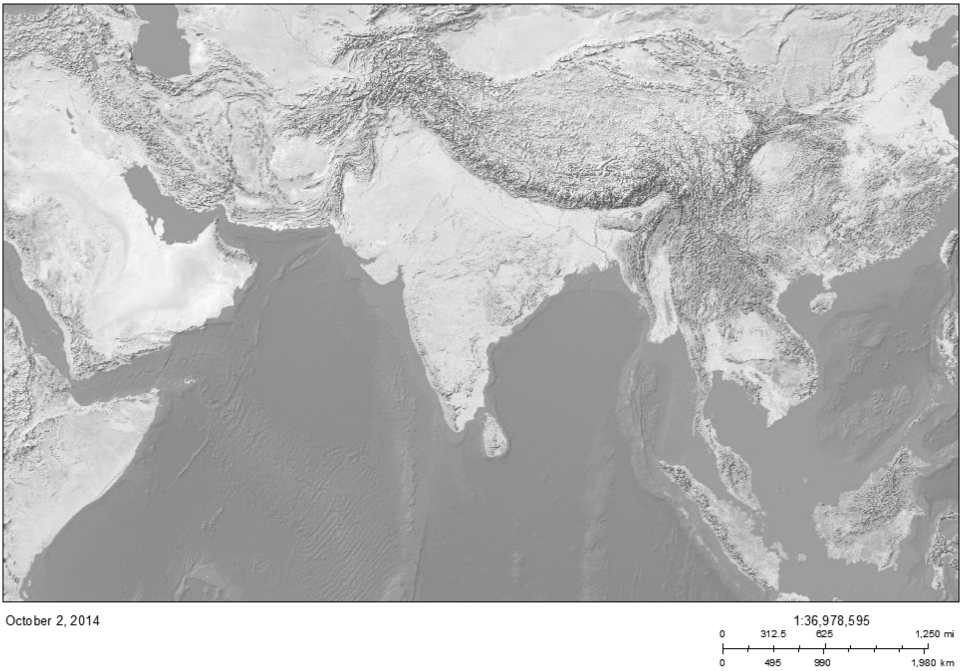

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Fig. 3. The topography and geography of the South Asian region. The monsoon rains bring the sub-Himalayan and northwest regions the majority of their rainfall, largely distributed from June to September. South India and Sri Lanka also benefit from the second phase of the monsoon (the northeast monsoon), which is prevalent from October to November.

Pakistan

Pakistan's climate spans from subtropical arid to semi-arid, temperate to alpine, and rainfall totals across the country can span 100 to 2000 mm, and the majority of which occurs from June to September (Franken, 2012; Kahlown and Majeed, 2002). Nearly 40% of the population of Pakistan participates in the agricultural sector, in which the dominant crops are wheat, rice, and cotton (GOP, 2011, 2012). Within Pakistan, these crops are grown in different agroecological zones, each comprising a diversity of soil, hydrological, climatic, and even social, conditions. The Punjab region dominates the agricultural production such that much of the country's agricultural regions are more homogeneous than the wider country. There are two primary growing seasons in Pakistan, and rainfed agriculture is heavily dependent on the southwest monsoon, which has historically been subject to a large amount of variability in the timing and amount of rainfall (Ringler and Anwar, 2013). Additionally, significant pressure has been applied to water management and resources due to the increasing prevalence of cash crops, population growth, urban growth, and other competing sectors.

The Indo-Gangetic Basin (India, Nepal, Bangladesh)

The Indo-Gangetic Basin (IGB) has historically seen high variability in monsoon rainfall and extreme events across the region, due to the east–west movement of low-pressure centers along the trough that overlies the subregion (Turner and Annamalai, 2012). Additionally, the continuation of glacial melt may eventually result in decreases in river flow, which is a primary irrigation resource, particularly in east IGB. The west IGB is characterized by having a more developed irrigation infrastructure and relies heavily on the extraction of groundwater for crop irrigation. While this may currently insulate western IGB farmers from the irregularities of the southwest monsoonal rainfall, the over-exploitation of these groundwater resources may result in eventual decreases in wheat and rice production as water stores run low (Rodell *et al.*, 2009). Additionally, other indirect climate change effects may compound impacts on agriculture. A comprehensive study by Ruane *et al.* (2013) investigated climate-related rises in temperature and CO_2 concentrations, changes in rainfall, impacts of river flooding, and sea-level rise on agricultural production in Bangladesh. The study identified key vulnerabilities of Bangladesh's agricultural system, and in particular rice production, under future changes in rainfall, sea-level rise, which can inundate and salinate coastal agricultural lands, and river flooding.

South India

The South India AgMIP region encompasses the Indian states of Andhra Pradesh and Tamil Nadu. Although considered one region in the AgMIP assessments, these two states have distinctive rainfall seasons, topography, soils, etc. Andhra Pradesh receives most of its rainfall during the southwest monsoon season, while Tamil Nadu receives rainfall during both the southwest monsoon and northeast monsoon (although most of the rainfall occurs during the northeast monsoon). Though uncertainty exists, climate projections indicate that seasonal rainfall totals may increase across south India (Turner and Annamalai, 2012). In Andhra Pradesh, agriculture provides a livelihood for nearly 65% of the population, and nearly half of the cultivated land in Andhra Pradesh is irrigated, while half is rainfed. Approximately half of Tamil Nadu's geographical area is devoted to agriculture, while nearly two thirds of the population is employed in the agricultural sector. Both Andhra Pradesh and Tamil Nadu have long coastlines to enable export, and have the capability to further develop their agricultural sector. Maize and rice are among the most important crops in both Andhra Pradesh and Tamil Nadu, and will be a focus of AgMIP integrated assessments.

Sri Lanka

Sri Lanka is characterized by high subregional annual rainfall totals, and low temperature variability, which can enable a relatively high state of food security, despite internal variability in the timing and active/break periods of rainfall during the rainy seasons. A majority of the rainfall occurs during the Yala and Maha seasons, which correspond to the southwest and northeast monsoons. Agriculture accounts for nearly one third of the labor force, and rice is among the most important food crops planted in a variety of regions. Sri Lanka's rice, and overall agricultural production, is susceptible to climate shocks, which has implications for domestic food prices (Yahiya *et al.*, 2011; Zubair, 2002, 2005). Global climate models generally indicate wetter conditions over Sri Lanka, but there is uncertainty in the projections of extreme rainfall events and temperature variability, particularly at the district level (Turner and Annamalai, 2012). Additionally, sea-level rise could impact coastal rice growing communities.

Integrated Assessments of Food Security in South Asia

Sustainable agricultural production must focus not just on productivity of food grains, but must also consider the natural resource management, market externalities, inclusion of high-value crops and livestock options, agroforestry, agricultural intensification on existing lands, and other more broad socio-economic problems (micro-nutrient fortification and pro-rural policies; Hazel *et al.*, 2008). Such considerations must and can be included through the use of interdisciplinary, integrated assessments of the impact of global environmental and socio-economic change on

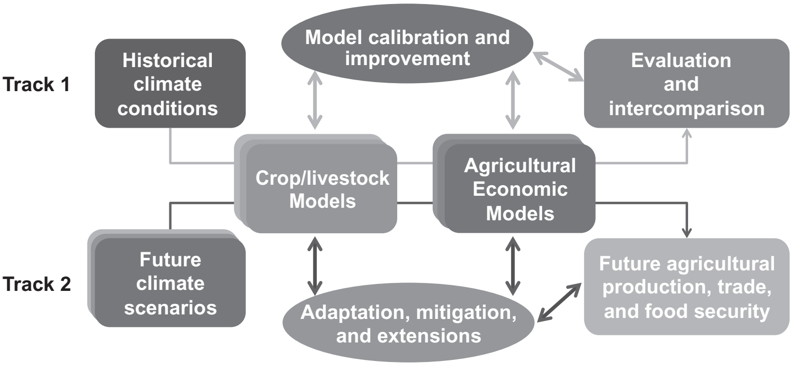

Fig. 4. The AgMIP framework for integrated assessments of the impact of climate change on agriculture. Reprinted from Rosenzweig *et al.* (2013) with permission from Elsevier.

regional agriculture. Though there have been many assessments of future agricultural production in various South Asian states (e.g., Knox *et al.*, 2012, and references therein), there is much scope for a comprehensive climate-crop-economic assessment that investigates the impact of climate change on overall food security, farmer income, and poverty. AgMIP presents a unique approach in integrated assessment by combining multi-model intercomparisons with interdisciplinary (climate-crop-economic) interactions that facilitate such a comprehensive investigation of the impact of climate change on agriculture. Additionally, AgMIP has involved a range of stakeholders at various local and regional levels to inform these integrated assessments, and have worked with South Asian RRTs to develop and test the efficacy of various adaptation strategies, given different scenarios of climatic and socio-economic change.

The AgMIP framework (Fig. 4) utilizes a two-track approach to understand and attribute historical fluctuations in agricultural production, intercompare and improve the crop and economic models, evaluate future impacts to food security, and develop and test adaptation strategies (Rosenzweig *et al.*, 2013). Additionally, AgMIP has a range of cross-cutting initiatives, particularly to evaluate the uncertainty in these assessments for informing stakeholders and decision-makers. The climate models utilized are represented in the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) (Kirtman *et al.*, 2013). There are four AgMIP RRTs in South Asia comprised of climate scientists, crop scientists, agroeconomists, and information technology experts. These teams are tasked with carrying out integrated assessments of food security utilizing the AgMIP Protocols (Rosenzweig *et al.*, 2013) in specified districts across the region (black dots, Fig. 5), and their researchers hail from Pakistan, India, Nepal, Bangladesh, and Sri Lanka. These teams mainly conduct their crop simulations with the Decision Support System for

Fig. 5. AgMIP focus regions in South Asia (courtesy of AgMIP).

Agrotechnology Transfer (DSSAT; Jones *et al.*, 2003; Hoogenboom *et al.*, 2012), the Agricultural Production Systems Simulator (APSIM; Keating *et al.*, 2003), and Infocrop (Aggarwal, 2006). All the RRTs utilize the Tradeoff Analysis Minimum Data Model (TOA-MD; Antle *et al.*, 2011) for their agroeconomic assessments of climate impacts and economic effects across a representative population of farmers in each South Asian focus region.

Identifying and integrating stakeholder concerns

Given the variety of concerns facing South Asian agriculture in the 21st Century, the AgMIP RRTs' climate-crop-economic integrated assessments can help to identify the most critical parameters for assessing agricultural production, bracket the uncertainty in future climate changes, and aid in developing adaptation strategies that target South Asia's diversity of agricultural districts, while serving to promote food security across the region. The South Asian RRTs have engaged a range of stakeholders, from the federal ministry level to district-level extension specialists, and even farmers. Each stakeholder meeting conducted by the RRTs has had a multi-fold objective: To communicate the results and findings from the integrated assessments, and to work with the various stakeholders to frame the outstanding challenges to agriculture which can be targeted through the AgMIP framework. In this way, the stakeholders have become important participants in the AgMIP process, particularly with respect to development of future agricultural trajectories, classified as "representative agricultural pathways", described below. In order to best address stakeholder concerns and consider the future of agricultural systems in these regions, AgMIP regional research focuses on answering three core questions:

(1) What is the sensitivity of current agricultural production systems to climate change?
(2) What is the impact of climate change on future agricultural production systems?
(3) What are the benefits of climate change adaptations?

Representative agricultural pathways (*RAPs*)

The future state of regional food security can be influenced by multiple drivers of change: Climatic, socio-economic, and geo-political. Although there are uncertainties in the future trajectories of these drivers, their inclusion in AgMIP integrated assessments is critical in order to develop regionally tailored adaptation strategies. Therefore, the AgMIP RRTs have engaged stakeholders at multiple levels (representing farmers, districts, states, and federal entities) to jointly develop representative agricultural pathways (RAPs). These RAPs will provide agricultural development scenarios in the joint context of the representative concentration pathways of carbon emissions and the shared socio-economic pathways of international development (Rosenzweig *et al.*, 2013). Additionally, the regional teams will devise adaptation strategies through consultation with stakeholders, and these will be incorporated into the future RAPs to inform the integrated assessments. Many adaptation strategies in the subregions will focus on diversifying farm income strategies, involving multiple or alternative crops, incorporating livestock, or improving water saving, storage and service techniques. These have been recommended as suitable strategies to pursue in these regions (Morton, 2007).

The RAPs are informed through AgMIP global economic initiatives and incorporate important drivers of global food and agricultural input markets and prices. This is done by incorporating trajectories based upon assumptions such as "business as usual". Since RAPs are statements about the likely evolution of variables such as soil fertility, farm size, and regulatory policies, their development requires interactions with informed stakeholders to make them regionally representative. All the South

Asian RRTs have conducted a number of RAP development workshops with stakeholders, the results of which are detailed in Part 2, Chapters 7–10 in this volume. In addition to aiding the RAP development workshops, facilitating and enhancing the communication and presentation of AgMIP data and findings to major stakeholders has been a key priority for the regional coordination team (CT). The AgMIP South Asia CT activities are detailed below.

Information-Sharing and Stakeholder Engagement

In this first phase of the AgMIP RRT assessments, the South Asia CT contributions have facilitated (1) enhanced capacities through training of the South Asian RRTs, as well as national agriculture and natural resource management agencies; (2) outreach and dissemination of key RRT findings through engagement and coordination of stakeholders. The CT team encourages the continued development of knowledge-sharing platforms to enable learning exchanges among and across the various AgMIP regional teams of South Asia, national research programs, and other stakeholders who utilize AgMIP research results.

Training

The CT was responsible for coordination and facilitation of region-wide workshops and training sessions, in collaboration with the AgMIP leadership team. This included the multiple crop model training workshop, which provided experienced crop modelers with training on a second crop model for use in the AgMIP regional integrated assessments (see also Part 2, Chapter 13 and Appendix 1 in this volume). Plenary sessions of workshop proceedings were recorded by video for sharing with researchers elsewhere. The sessions document RRT experiences in adoption of a second crop model, uses of AgMIP IT tools, and methods for assessing and interpreting the multiple crop model simulations.

The CT also organized virtual training experiences, including AgMIP climate, crop, and economic output analysis and interpretation webinars. Six virtual meetings were conducted by utilizing KSIConnect, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)'s virtual knowledge platform. A section of the platform was dedicated to serve AgMIP and its RRTs. This allowed collaborative virtual experiences and sharing of research results. The webinars made possible through these virtual interactions helped the RRT members to interpret their data better and to draw valuable conclusions, which are discussed in other chapters of this volume.

The CT also created innovative demonstration "knowledge products" to stimulate interactivity, to motivate further collaboration across existing RRT initiatives, and to broaden engagement to include other researchers and stakeholders in the region. Demonstration products of the CT included the below prototypes:

- Data repositories with well-defined metadata features to store, back-up, and share data and statistical analyses of those data by incorporation of open-source statistical software. The repository encourages researchers to store data in a secured online location by providing useful tools for quick investigations of data attributes, trends, or distributions without installing statistical software on their respective desktops.
- Online cloud-based tool for data aggregation, analysis, and visualization, including features to help researchers to share results with others.
- Web GIS platform for map generations and to aid spatial data interpretation. The prototype was developed in collaboration with the East Africa RRT and demonstrates how users could jointly access high-quality figures, images of AgMIP integrated assessment results, and characterizations of the distribution of climate impacts in the South Asian subregions. The CT also explored spatial integration with Google Maps for inclusion of auxiliary project information, research results/analysis, outputs, lessons learned, and impact videos and photo galleries.

Stakeholder engagement

The South Asia CT also played an important role in facilitating stakeholder interactions. At the farm level, they coordinated discussions with district farmers, in which the RRTs sought to better understand farmers' views on current climate variability and future climate agricultural impacts. At the institute level, multi-disciplinary meetings with research scientists were held, which focused on understanding the priority climate risks raised by the farmers and devising tailored adaptation strategies. At the district level, stakeholder workshops were conducted, in which representatives of district agricultural development agencies, universities, progressive farmers, and researchers of organizations participated.

Through these discussions, it was generally found that stakeholders were interested in testing the efficacy of various technologies that can help farmers to adapt to the extreme weather events, and they expressed an interest in quantifying and anticipating changes to climate and monsoonal variability. The CT found that a top stakeholder priority is improving the reliability of climate forecasting, as this would aid farmers directly in managing their farm activities. More "near-term" time-scales of prediction, from the present to 2030, are also a priority for state- and federal-level stakeholders in order to implement and assess the efficacy of various agroeconomic policies that aid in adaptation and buffer against monsoon and climate variability.

Current AgMIP assessments have focused on the "mid-century" time-frame (2040–2069) because it was an intermediate time-frame closer to stakeholder decisions, but also late enough that the climate change signal begins to emerge from climatic variability. However, it is within the scope of near-future AgMIP activities to evaluate the impacts of climate change on regional agriculture and rural livelihood in the near-term, mid-century, and end-of-century time-frames to facilitate a range of decision-making, from short-lived subsidies and agroeconomic policies to long-term infrastructure projects, which are further detailed in each RRT's RAPs (Rosenzweig *et al.*, 2013).

Future Directions

Extended monsoon scenarios

The South Asian regional climate is dominated by a monsoonal regime, which is characterized as a fully coupled sea-land-atmosphere system, which is also subject to orographic influences (Turner and Annamalai, 2012). As such, there are many complex processes, from poleward moisture transport to low-pressure centers that traverse the region along the IGB and incite monsoonal rainfall, and the region is subject to a large amount of intraseasonal and interannual rainfall variability. Thus far, the AgMIP approach has utilized a "delta" method of imposing monthly mean climate changes (as projected by global climate models) on important agroclimate variables in a 30-year 1980–2010 climate/weather series for each modeled location. This important method aids researchers in understanding and anticipating how the mean climate will change in future periods from baseline conditions.

In continuing phases of AgMIP, the RRTs, with the help of the AgMIP leadership, will further develop tailored South Asian future climate scenarios to incorporate potential changes not just to the mean monsoon, but also in intraseasonal and interannual monsoon variability. This will entail evaluating changes to active and break periods within the monsoon to evaluate both the amount and frequency of rainfall during the growing season. Other parameters to evaluate are the monsoon onset period, withdrawal period, frequency and strength of monsoon depressions, and future influences of influential modes of climate variability, like ENSO, Indian Ocean modes of variability, and the anthropogenic warming of the Indian Ocean surface (Gadgil and Rupa Kumar, 2006; Turner and Annamalai, 2012, and references therein).

More work is needed to evaluate important agroclimatic variables in correlating with crop yields over the baseline period, with the goal of identifying parameters that can aid in future crop response to climate change. Identifying trends in the baseline monsoon circulation also proves challenging as the evaluation of different time-periods/decades, and evaluations of different monsoon metrics, yields much uncertainty in establishing an overall response to 20th century forcings (Turner and Annamalai, 2012). A baseline agroclimatic analysis is currently being undertaken by several of the South Asian RRTs to better understand and bracket uncertainty in climate crop response.

Data management and additional regional representation

The AgMIP RRTs are generating a wealth of climate scenario information and crop and agroeconomic model results that can greatly inform regional adaptation decision-making, and agricultural and resource policy. One of the major hurdles in utilizing scientific information in policymaking is the organization, comprehensibility, and accessibility of that information. AgMIP is currently working on building a comprehensive, searchable database that contains all results from both the South Asian and Sub-Saharan African RRTs. Such a database will facilitate easy access and interpretation of the RRT's findings for particular districts and across the South Asian region, and can help to inform a wide range of agricultural development policies into the future.

Furthermore, the regional distribution of not just the modeled results, but also the AgMIP methodology, may encourage additional participation from South Asian districts and subregions that require more representation, such those from Nepal, Bangladesh, central India, and south Pakistan. Regions that display highly varying topography or large geographic gradients in temperature and rainfall (such as Sri Lanka) may also require additional sites to understand the contribution of these varying environments to spatial yield and production distributions better.

Capacity building

The continuation of AgMIP activities in South Asia will be benefited by more extensive and intensive training sessions in the areas of climate, crop, and economic modeling. The CT has contributed to the organization of "training the trainer" activities led by AgMIP in its initial phase to build capacity for the regional integrated assessments (see also Part 2, Chapter 13 in this volume). As South Asia moves to expand these assessments and methodologies, more in-region trainers will be required to help additional teams to build their modeling and analysis capacities.

Likewise, the CT envisions a number of similar training activities for those scientists that have preliminary familiarity with the tools, conducted through major coordinating institutions in each of the subregions (including ICRISAT). Such training courses would provide a certificate of completion, and allow each subregion to access analysis aid and expertise easily through their representative trainers. These trainers would also be able to travel to various South Asian subregions to educate participants in best practices for implementing AgMIP methodologies (as per the AgMIP Protocols). These trainers will also be in a prime position to build upon and improve the AgMIP Protocols, tailoring them for unique conditions in each South Asian subregion.

The CT encourages broader consideration of student scholarship programs as a means for advancing capacity in each of the AgMIP South Asian subregions. The involvement of students in the AgMIP research process helps meet the demand for researchers who are able to contribute to integrated assessments. The CT supported undergraduate and graduate students to work alongside AgMIP researchers, in South India and Sri Lanka (Vellingiri and Zubair, 2013).

Conclusions

Agricultural production across South Asia is subject to much variability, due to natural climate fluctuations, socio-economic policies, and global shocks, and is also potentially at risk under future climate change conditions. Furthermore, a significant portion of agricultural productivity relies on natural resources, such as groundwater stores, that are fast becoming over-exploited in critical subregions (Rodell *et al.*, 2009).

AgMIP has mobilized interdisciplinary scientists across South Asia to participate in a coordinated investigation of the impact of climate change on food security (Rosenzweig *et al.*, 2013). The CT has helped scientists from highly varied and disparate subregions across South Asia, representing Bangladesh, India, Nepal, Pakistan, and Sri Lanka convene, learn new methodologies, and engage with their decision-making communities in the process of undertaking integrated assessments. The regionally tailored RAPs, which have been developed in conjunction with representative stakeholders, demonstrate the future trajectories of agricultural development and global drivers of change that are being anticipated and considered for planning and policy. The results, presented in chapters of this volume, serve as a comprehensive investigation of the important drivers of change in agricultural productivity across select districts in these countries, and they also provide a first assessment of some of the uncertainties that must be examined in order to interpret and utilize these results accurately in policy applications.

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