CLIMATE RISKS AND VULNERABILITY ASSESSMENT TOOLS IN SUPPORT OF POLICY PLANNING AND CLIMATE SMART AGRICULTURE

Hideki Kanamaru[1] and Mariko Fujisawa[2]

[1]Food and Agriculture Organization of the United Nations (FAO), Regional Office for Asia and the Pacific, Bangkok, Thailand
[2]FAO, Rome, Italy

E-mail: hideki.kanamaru@fao.org

ABSTRACT

Climate change will pose considerable risks to agriculture and food security in Asia and the Pacific Region. Strengthening resilience and enhancing carbon sinks are key priorities for agriculture. It is recognized that incremental adaptation will not be enough and transformational adaptation will be required in some agro-ecosystems — a transition to more resilient society, beyond a typical rural development project and one-time investment, with innovations made available to smallholder farmers. An important element to support transformational changes is building robust evidence about past and future climate risks and vulnerabilities, and identification and appraisal of adaptation practices. Climate change adaptation is a long-term iterative process from the farm to national levels, and it requires a robust evidence base to design investments and interventions. However, beyond assessments of the impacts of historical trends in climate variables and projected climate change on the yield of key crops, understanding of climate change risks for agriculture and food security in the Region is weak. Critical knowledge gaps that need to be addressed to craft effective responses, at various scales, to risks posed by climate change to agricultural systems in the Region are highlighted. Insufficient capacities of many countries and their experts to produce evidence are gaps to be addressed. There is a need for climate change risks and vulnerability assessment tools that can fill both knowledge and capacity gaps. FAO developed Modelling System for Agricultural Impacts of Climate Change (MOSAICC) for this purpose. It packages multiple models from different disciplines into one system where researchers can work in collaborative manner to assess climate change impacts in agriculture. MOSAICC is transferred to countries together with extensive training programs. It was successfully implemented in the

Philippines, Indonesia, Morocco, Peru, Paraguay, Uruguay, Malawi, and Zambia. In all these countries, an interdisciplinary technical working group was established where modelers, data providers, and policy makers together design the assessment study, run simulations, interpret results, and produce policy briefs. Efforts are made to link evidence from MOSAICC with major policy processes such as National Adaptation Plan by engaging relevant stakeholders early in the process and fostering enabling environment. There are high expectations for science community to translate research models and methodologies into practical risk and vulnerability assessment tools for decision making at the national and sub-national levels. There are opportunities for further strengthening collaboration between the academia and the development community.

Keywords: Climate change, impacts, vulnerability, risks, adaptation, agriculture, food security

INTRODUCTION

Climate change is affecting agriculture particularly in low latitudes. Around 2.5 billion small-scale farmers in developing countries are most vulnerable to climate change and their food security is at risk. According to the latest UN report, the number of food insecure people in the world has declined from 945 million in 2005 to 784 million in 2014. However the declining trend reversed since 2014, and the number of undernourished people reached an estimated 821 million in 2017 (FAO, 2018).

Climate affects all dimensions of food security: food availability, food access, food utilization and food safety. Most researches focus on the relationship between climate and food availability — how much productivity is reduced (crop yields), how much cropping areas are changed, or how the number of crops grown within a year (cropping intensity) change, due to climate change. Food access may be impaired through food price increase and volatility, and income loss (due to reduced food production), following extreme weather events. Food utilization and food safety may be affected as climatic conditions can change the pattern of pests and diseases, or affect food storage and crop contamination.

Climate variability and extremes are identified as one of the major causes behind the recent rise in global hunger. Among various climatic hazards, floods, droughts, storms, and extreme heat affect food production the most. Drought is estimated to be responsible for more than 80% of the total damage and losses in agriculture, particularly for livestock and crops. Impacts on fisheries are mostly from storms, while forestry impacts are mainly caused by floods and storms. Thirty-six percent of the countries with a rise in undernourishment since 2005 experienced severe agricultural drought. There is also a strong link between drought and stunting (i.e. short height for age) in children. For example, droughts in Bangladesh are correlated with a higher stunting rate around five and nine months after the beginning of the drought event. In Zimbabwe, one to two year olds under drought effects have lower growth velocity than those with average rainfall.

GLOBAL AGENDAS

World leaders established major global agendas that frame the issue of climate change and agriculture over the past few years. The Sustainable Development Goals (SDGs), agreed in 2015 at the United Nations General Assembly, is a set of 17 global goals by 2030 towards achieving a better and more sustainable future for the world. SDG-2 aims to achieve zero hunger, and one of the indicators (2.4.1[1]) under this second goal highlights climate change as an underlying challenge[2]. SDG-13 is about taking urgent action to combat climate change and its impacts, and it aims at strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. One of the indicators (13.2.1[3]) tracks the progress in integrating climate change measures into national policies, strategies and planning, “in a manner that does not threaten food production”. Both food security and climate change goals recognize the interlinked nature of the challenges.

The Sendai Framework for Disaster Risk Reduction is a 15-year agreement (2015-2030) where the countries try to reduce disaster risk, with seven targets and four priorities for action. The primary objective is to substantially reduce "disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries". Its target C aims to reduce direct disaster economic loss in relation to global GDP by 2030, and C2 particularly monitors direct agricultural loss attributed to disasters.

On the longer-term climate change timescale, the Paris Agreement in 2015 aims to strengthen the world's commitment to reducing greenhouse gas

[1]Proportion of agricultural area under productive and sustainable agriculture.

[2]Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

[3]Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other).

emission to keep a global temperature increase below 2°C above pre-industrial levels, with an effort to limit it further to 1.5°C, and to strengthen the ability of countries to adapt to climate change "in a manner that does not threaten food production". Here, safeguarding food security is regarded as the fundamental priority, and "the particular vulnerabilities of food production systems to the adverse impacts of climate change" is recognized. All countries submitted (intended) nationally determined conditions (NDCs) where their climate actions to reduce national emissions and adapt to the impacts of climate change are defined. On the other hand, the National Adaptation Plan (NAP) processes, established in 2010 under the UNFCCC, are domestic planning processes where countries identify, address and review adaptation needs in order to adapt to climate change through medium- to long-term planning.

FOCUS ON ADAPTATION

There are many challenges for climate actions to materialize in the agriculture sector. Climate-smart agriculture is a concept that promotes mitigation and adaptation in the sector in support of achieving food security for all. A number of farm- to community-scale projects have already demonstrated farming practices that are better suited to changing climate conditions. It is imperative to scale up those climate-smart actions from project to regional and national level actions, while recognizing best climate-smart practices in one area may not be directly applicable to a neighboring area or larger surrounding areas due to their location- and context-specificity. In order to support scaling-up of climate-smart agriculture, climate finance should be made available, which meets the needs of a broad range of agricultural value chain actors that are involved from the farm to the final consumer. Climate-smart agriculture needs to be promoted while meeting transparency requirements for monitoring and verification. A mechanism for reporting progress in GHG reduction and sequestration and in adaptation, in a transparent manner, will be crucial for ensuring national and international climate goals are met.

Food and Agriculture Organization of the United Nations has been supporting countries with tackling climate change both for mitigation and adaptation. In FAO's analysis of NDCs, it was evident that strengthening resilience and enhancing carbon sinks are key priorities for agriculture in Asia-Pacific countries. Although not required, most countries chose to include an adaptation component in their NDC in addition to mitigation commitments. Most developing countries' share of greenhouse gas emissions is not significant but climate change affects everyone, regardless of emission levels, prompting timely adaptation actions.

It is recognized that incremental adaptation will not be enough and transformational adaptation will be required in some agro-ecosystems (Jones and Thornton, 2009; Kates *et al.*, 2012). Incremental adaptation maintains the essence and integrity of a system or process at a given scale, while transformational adaptation changes the fundamental attributes of a system in anticipation of climate change and its impacts (IPCC, 2014). In the agriculture sector, improvements to crops (e.g. drought or flood tolerant variety) or on-farm management practices (e.g. irrigation timing and quantity, fertilizers, adjusting cropping calendars, use of weather forecast, seasonal climate forecast and agrometeorological advisories) can be considered as incremental adaptation. Transformational adaptation takes a variety of forms — switching crop types, shifting locations for producing certain crops and livestock, shifting farming systems new to an area, exploring alternative livelihood strategies, etc. (Rippke *et al.* 2016). Major climate finance mechanisms such as Green Climate Fund intend to support a paradigm shift to low-emission and climate-resilient development by promoting innovations that are catalytic to transformational changes. Transformational adaptation carries a long-term perspective, beyond typical time frame of disaster risk reduction in face of currently prevalent extreme weather events. Investments should have a multiplying effect of an initial financing, setting a path for climate-resilient and low-emission pathways. Innovative technologies need to be made accessible for smallholder farmers while improving food security.

There are several important elements that are necessary for supporting transformational adaptation, and are highly relevant to agrometeorological research. Designing transformational adaptation requires a robust climate rationale – information on climate risks and vulnerabilities of the agro-ecosystem. The climate rationale (evidence) at the local scale justifies the choice of adaptation options, and investments on adaptation interventions at the project level. Evidence at a larger spatial scale (sub-national to national) forms the basis for adaptation planning and policies at the national level. Climate change adaptation is a long-term iterative process — learning from lessons after projects and revising subsequent strategies to adapt better. Countries need to have capacities in the full cycle of the process, from producing evidence, planning policies, developing and implementing projects, and monitoring and evaluating the progress. Most of the evidence can be highly scientific but they need to be well linked with policy making process. Research agendas should be formulated in response to emerging policy-relevant questions, and the research results need to be channeled into decision making. These essential elements needed for transformational adaptation, with an emphasis on evidence and capacities, will be discussed in the following sections with examples from countries we worked in.

EVIDECE-BASED ADAPTATION

We identify five main types of evidence that facilitate evidence-based adaptation planning and decision making. The first is about what happened in the past — historical climate trends, including extreme weather events, and their impacts on agriculture. The second type of evidence is similar but for the future — projection of climate and its impacts on agriculture. Characterized risks and vulnerability to climate change and social and environmental factors is the third type of evidence. The fourth type of evidence is identification and appraisal of potential adaptation practices. They include on-farm trials, and desktop studies such as cost-benefit analysis and biophysical assessments. Lastly, implemented adaptation practices need to be monitored and evaluated to assess their effectiveness for the next iteration in the adaptation pathway.

The complex nature of food security and climate change challenges complicates the process of producing these types of evidence. Sub-sectors of agriculture — crops, livestock, fisheries, aquaculture, and forest — are interlinked with each other in an agro-ecosystem. Much attention is paid to the production dimension of food security, but access to food, utilization and safety of food, and stability of food systems are equally important to ensure food security. The temporal scale for evidence varies from days (weather and agronomic practice), monthly, seasonal, yearly, decades, to a century (long-term climate projections). The spatial scale of relevance also varies from farm to national level.

Looking at currently existing evidence, large knowledge gaps are apparent in Asia and the Pacific. FAO assessed papers cited in Chapter 7 (Food security and food production systems) of Working Group II contribution to the fifth assessment report of the IPCC (Porter *et al.* 2014), which deals mainly with the first three types of evidence. The majority of papers in the chapter about developing countries in the Region are for India and China, and the literature is scarce for the rest of the Region. Papers about crops are abundant but literature on other sub-sectors are noticeably lacking.

Capacities of countries and their experts in producing evidence are insufficient, particularly in least developed countries. Even in middle income countries such as Indonesia and the Philippines, a lot of research are conducted by international scientists with only minimal involvement of local researchers.

Most of climate risk assessment tools for producing evidence are developed as research tools to answer academic questions in their own discipline, and they are not designed for use by other researchers and for answering policy questions. There is a need for more climate risks and vulnerability assessment tools that address both gaps — knowledge (evidence) and capacities.

MOSAICC

Objectives of the modelling system

FAO developed a capacity development tool, Modelling System for Agricultural Impacts of Climate Change (MOSAICC), in an attempt to fill these gaps. It packages multiple models from different disciplines into one system where researchers can work in a collaborative manner to assess climate change impacts in agriculture. MOSAICC is transferred to countries together with extensive training programs. An innovative software design of MOSAICC supports participatory and integrated modelling environment in an interdisciplinary working group.

MOSAICC addresses common climate impacts on agriculture in an integrated way and in a modular system. Currently it combines five different components from diverse academic disciplines: statistical downscaling of climate change projections, yield simulation of crops, surface hydrology simulation, forest landscape model, and macroeconomic model.

All components of MOSAICC run on a server and exchange data through a central geospatial database. This system design brings together very different models that are usually run independently by separate groups of researchers. MOSAICC facilitates and fosters collaboration of researchers from different disciplines who tend to work only in their own domains.

System design

MOSAICC's basic design was determined to meet the requirements elaborated in a series of consultations with international scientists and economists, and government officials.

The five main components of the models (Fig. 1) are:

- Statistical methods for downscaling climate projections from General Circulation Models (GCMs)
- Crop growth models to simulate future crop yields
- A hydrological model for estimating river water resources
- A forest model to simulate biomass and tree species distributions
- A CGE (Computable General Equilibrium) model to assess the effect of changing yields and water availability on national economies

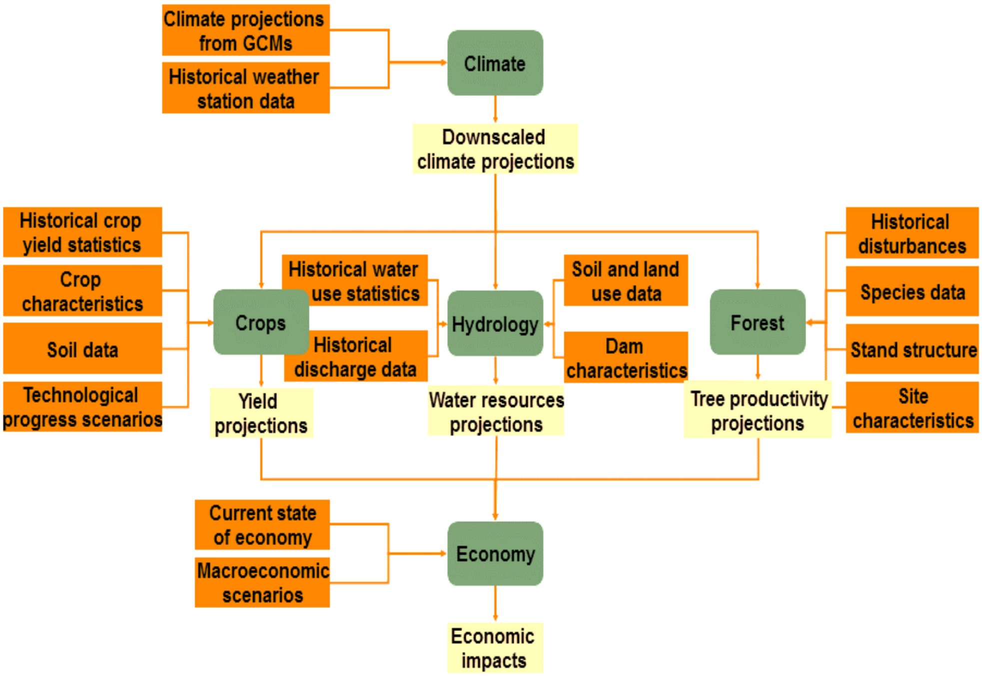

Fig. 1. MOSAICC components.

Each component provides one or more models. There are also cross-component tools, such as spatial interpolation, grid area analysis, and cell statistics. The models chosen to be integrated into MOSAICC are relatively simple and robust, and can run with input data of limited quality and availability in different ecosystems. The participating models and tools are open source. As a result, MOSAICC is free and highly transferable to many different countries in diverse agroecological zones.

Climatologists first upload weather station locations and weather time series data, perform downscaling, perform spatial interpolation of the results, and share them with other users. The downscaling process is external to MOSAICC because it requires huge computation resources, but MOSAICC provides an interface to interact with it efficiently. There are several statistical methods available for climate downscaling (Gutiérrez *et al.*, 2012).

The spatial interpolation operation addresses the problem of limited number and coverage of weather stations in developing countries. The optimized AURELHY (Analyse Utilisant le RELief pour les besoins de l'Hydrométéorologie) algorithm (Bénichou and Le Breton, 1987) facilitates subsequent model simulations by gridding climate data (and aggregating to administrative levels, as necessary).

Agronomists have several models and tools: the planting dekad model

(PLD) (Franquin, 1973), the water balance model (WABAL) (Frère and Popov, 1986), and the crop water productivity model (AQUACROP) (Steduto *et al.,* 2009). AQUACROP simulates crop yield and is used usually in specific locations because it requires a number of data collected in the field. WABAL is a simpler model with limited requirements of input data and produces crop-specific water balance variables as outputs. The variables are used to construct statistical models to simulate crop yield. The WABAL approach is more suitable for assessments at larger spatial scale. Many different crops can be simulated as long as necessary data are available.

Hydrologists work with a model called STREAM (Spatial Tools for River Basins and Environment and Analysis of Management Options) (Aerts *et al.*, 1999). It is a rainfall-runoff model that simulates discharges in river basins. The water availability is calculated at sub-basin level, depending on data availability.

For foresters, MOSAICC provides LANDIS (Landscape Disturbance and Succession) (Scheller and Mladenoff, 2004), which simulates forest succession, disturbance (including fire, wind, harvesting, insects), and seed dispersal across large landscapes. LANDIS requires a huge number of parameters. MOSAICC provides an interface to deal with all the details and re-arranges the information in required files. The results are post-processed to generate key variables: forest biomass, tree species distributions, biodiversity, establishments, forestry evolution, Leaf Area Index (LAI), and non-wood products.

Economists have the DCGE (Dynamic Computable General Equilibrium) model (Lofgren *et al*., 2002) to work with. It simulates the current and future economy under different climate projections. The model distinguishes the national economy and that of the rest of the world, between which goods and services are exchanged. The model uses crop yields and water availability generated by agronomists and hydrologists as shocks to the national economy. The main outputs are macro indicators (GDP), domestic market variables, external trade variables, and prices.

Key outputs of MOSAICC simulations are future projected values of these different variables simulated by each model. All the models can use the data generated from other models through a central geospatial database. The user works on MOSAICC with a web browser to connect to the MOSAICC server over the Internet. Data, models and results are all on the server. Nothing is required on the user’s computer. The systems installed in countries can be easily upgraded remotely by MOSAICC developers.

IMPLEMENTATION OF MOSAICC IN COUNTRIES

Information needs and capacity assessments

MOSAICC was successfully implemented in the Philippines, Indonesia, Morocco, Peru, Paraguay, Uruguay, Malawi, and Zambia. In order to ensure that local researchers use MOSAICC to produce information that are useful for stakeholders, we emphasize a country-driven process for implementing MOSAICC. A typical implementation of MOSAICC in a new country starts with a stocktaking exercise of existing information in the country about climate change impacts on agriculture. Once gaps in information availability become clear, national ministries are consulted as main stakeholders. They provide their views about needs for information about climate impacts in the sector for adaptation policies and programmes. In many cases, ministry of agriculture and its climate change office are the main stakeholders. They have responsibility for developing climate change adaptation policies and programmes. Information on potential climate change impacts support their work. For example, in Peru, the Ministry of Agriculture and Irrigation (MINAGRI) was identified as the main stakeholder and its Vice-minister chaired the steering committee of the project that implemented MOSAICC. Other ministries such as the Ministry of Environment were also consulted.

In parallel with information needs assessment, country's technical and institutional capacities in filling the gaps are assessed, across national research institutes and universities. In Peru, the National Meteorological and Hydrological Services, the National Agrarian University in La Molina, the Office of Economic and Statistical Studies in MINAGRI, were found to possess relevant knowledge and skills.

Interdisciplinary technical working group

If MOSAICC appears to address country's information and capacity gaps, we start forming an interdisciplinary technical working group that is composed typically of ministries, national research institutes, and universities, and the group is supervised by the project steering committee. The main members of the group are subject experts that will be responsible for running simulations with each component of MOSAICC. Climatologists in national weather service often take responsibility for climate component. National agricultural research institutes may take on crop simulations. The group also includes policy makers as a main stakeholder. They guide a climate change study as a member of the working group from study design to communication of the results. Other technical offices of the government can also provide necessary data and expertise as a member of the group. The agencies mentioned in the previous section constituted the Peruvian technical working group. In the Philippines, the Department of Agriculture, Philippine Atmospheric, Geophysical and Astronomical Services Administration, Philippine Rice Research Institute, University of the Philippines – National Institute of Geological Sciences were the main members of the technical working group.

Data collection is a time-consuming process. MOSAICC requires relatively small amount of data as inputs to models, but data are often scattered across different offices, and not in a format suitable for computer processing. We also make sure that the data providers agree on sharing the data with all members of the technical working group so that a truly collaborative research is possible. Digital elevation model (DEM), land use, soil properties, weather data, hydrological data, crop yield statistics, and crop parameters are examples of data that are necessary for MOSAICC simulations.

As a next step, the technical working group agrees on the study objectives, study design (including time periods, target crops, study areas, basins, etc.), taking account of stakeholder needs and data availability. In the process, the group members have an opportunity to reflect on country's context, and to build a common understanding about what would constitute a successful adaptation to climate change in the agriculture sector, and what kind of information MOSAICC should produce in support of achieving the goal.

The Philippines decided to examine climate change impacts up to mid-21st century. The climate statistical downscaling work is considered to complement dynamical downscaling work conducted in the past, and to provide up-to-date information with a new set of climate projections (CMIP5). Their MOSAICC crop and hydrology work were designed to highlight differentiated impacts of climate change in different locations across the whole country with a focus on rice and corn at the province level, and 24 river basins. Peru was interested in extending the projections up to the end of the 21st century, with a set of 29 crops at the region level, and 16 river basins that represent different agroecological systems.

Usually at least two Representative Concentration Pathways are examined (e.g. RCP 4.5 and RCP 8.5). Also at least three climatic models are evaluated in order to account for uncertainties from GCMs. The spatial scale for simulations is flexible, but MOSAICC's system design and model choices are most appropriate for national-level studies with sub-national disaggregation. MOSAICC primarily deals with medium- to long-term climate change time scale, beyond 10 years. The downscaled climate projections are daily data so aggregation to any temporal scales (10-day, month, season, year, etc.) is possible, and changes in frequency and intensity of extreme events, for example, can also be studied.

Capacity development and simulations

Capacity development is another important focus in our MOSAICC implementation strategy. Climate change adaptation planning is a long and iterative process that should be periodically reviewed with new evidence, science, and outcomes from adaptation interventions. The capacities of country experts to carry out science work that forms an evidence-base about climate impacts and adaptation are key to a sustainable policy planning process. We provide extensive training programs to the identified local experts for use of each component of MOSAICC. At least one week of training per component is usually provided. The sustainability of strengthened technical capacities of individual experts is ensured by commitment of all stakeholders represented in the interdisciplinary technical working group.

The idea is that country experts can perform simulations using their country's own data in support of national planning. The trainers, who are original developers of participating MOSAICC models, continue to provide technical support to make sure the experts can accomplish simulation studies, after training. It takes about three months (per component) for experts to perform simulations provided dedicated researchers are assigned to the task.

Communication of results

Running simulations is only part of climate impact studies. The simulation results need to be analysed, interpreted, and visualized for stakeholders. They would inform policy makers of which areas / sub-sectors / crops / basins / forest species are more vulnerable than others are. The information would strengthen evidence-bases that support adaptation planning and allow strategic resource allocations, investment programmes, research and development, and prioritization of adaptation interventions.

The technical working group is tasked to make sure that the modellers can communicate the implications of model outputs to aid policy processes. Communication of the results can take a number of other forms: presentation in conferences, paper and electronic publications, and web site. MOSAICC is designed to publish results from the simulation server in a seamless manner as graphs/maps to the web server.

The work in the Philippines was presented in a national project conference hosted by the Department of Agriculture, with wide participation from other Departments, Climate Change Commission, research institutes, universities, international development agencies, NGOs, and media. The nation-wide assessment work was highly appreciated and forms a basis for National

Adaptation Plans in the agriculture sector, Philippine Development Plan, National Climate Change Action Plan, and other policy processes.

In the following section, we provide two case studies. The Paraguay case focuses more on scientific results while the Malawi case examines the country-driven implementation process.

CASE STUDIES

Paraguay

Climate change impact assessment in the agriculture sector in Paraguay was conducted as part of the Analysis and Mapping of Impacts under Climate Change for Adaptation and Food Security (AMICAF) project. Climate downscaling in Paraguay was based on the historical meteorological information from 12 meteorological stations for the entire country. The historical reference time considered was 1981 to 2010. The models under analysis showed that a reduction in precipitation is expected for both time periods up to 2070, while temperatures (maximum and minimum) are expected to increase. The models showed a range of possible decrease in precipitation from 2.40% to 10.24% under RCP4.5 while a possible decrease in precipitation for RCP8.5 was 3.27 % to 15.92 %. Projected temperature increases are from 1.8 to 2.7°C (TMax) and 1.8 to 3.3°C (TMin) under the RCP4.5 and from 2.3 to 3.3°C (TMax) from 2.18 to 4°C (TMin) under the RCP8.5.

The impact assessment of climate change on crops included the analysis of historic yields and projected trends for the future. 8 crops were selected for this analysis: sugarcane, common beans, cassava, corn, wheat, soybean, irrigated rice and non-irrigated rice. The results showed great heterogeneity in terms of future impacts on the yield of crops at the department level due to climate change, with both increasing and decreasing projections for different departments/crops. For several crops, no significant differences between historical and expected future yields were reported, or different GCM projections lead to inconsistent results. Fig. 2. shows the result for cassava ("mandioca"). This crop, which is strongly associated with family small-scale agriculture, could significantly increase its yield in Alto Paraguay, Amambay, Canindeyú, Caazapá and Concepción departments. The yield increase was consistent in both scenarios (RCP4.5 and RCP8.5). Results for soybean were mostly heterogeneous, with significant decrease on future yields projected in Misiones (MPI model, RCP4.5), Alto Parana and Amambay departments (CANES model, RCP4.5 and RCP8.5). Upland and irrigated rice yields show a different behavior: the most affected by climate change is expected to be upland rice, with significant reduction in yields in the departments of Itapua

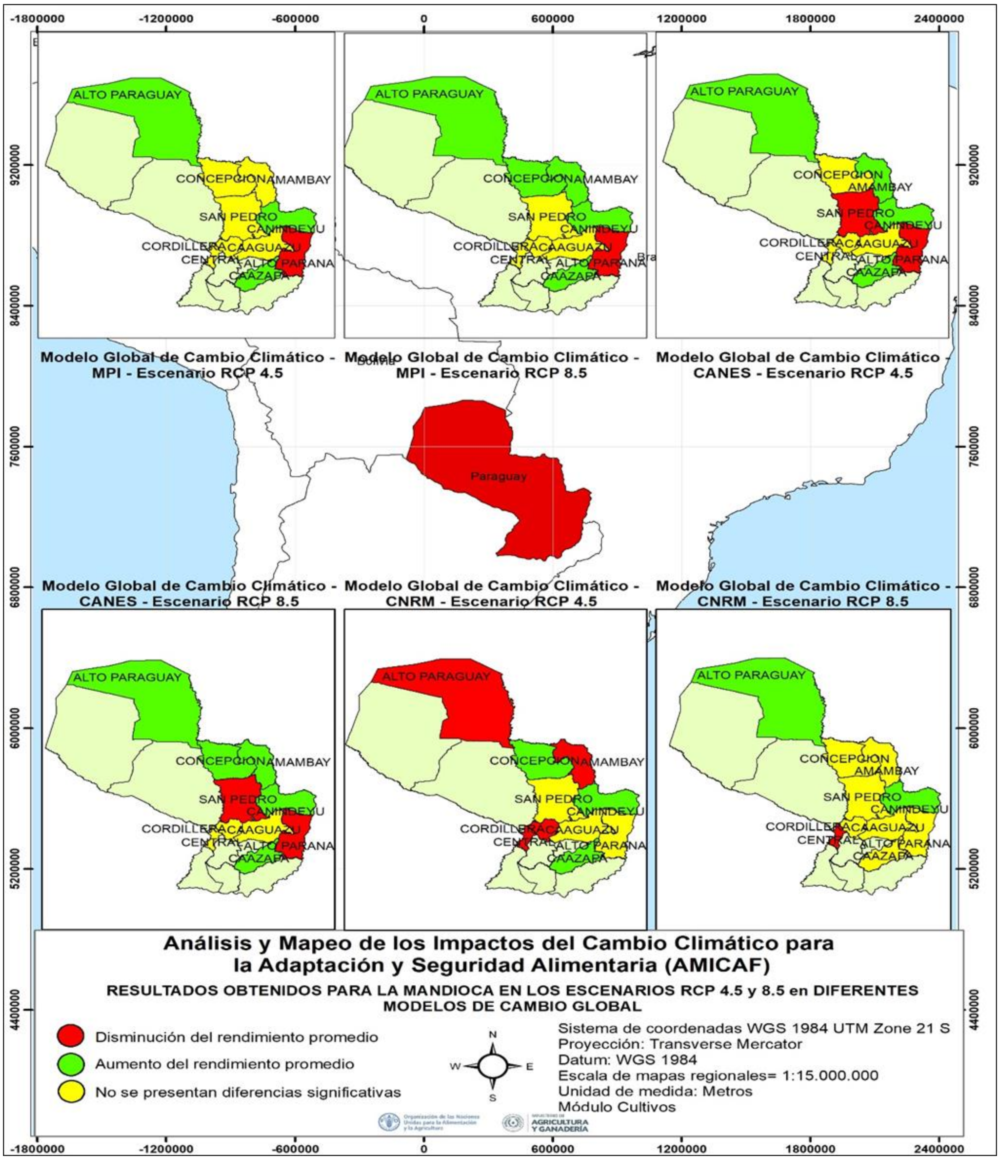

Fig. 2. Projected Cassava yield changes under RCP 4.5 and 8.5 for different GCMs.
(red – decrease; green – increase; yellow – no significant changes)

and Canindeyú. Irrigated rice shows instead positive changes in yields in the departments of Cordillera and Misiones, and negative for Paraguarí.

In summary, negative impacts of climate change are expected for sugarcane (in five departments), soybeans in three departments, and upland rice in two departments. Interestingly, cassava shows a positive impact of climate change on yields for approximately the same region for which negative impact is observed for sugarcane. Common bean yields are expected to increase in three departments, and decrease in three other departments. We can conclude that higher climate change risks concern sugarcane, soybeans and upland rice, while wheat, maize and common beans show no significant changes, or both positive and negative changes. We can consider these crops as the most resilient, while cassava yields appear to mainly benefit from climate change effects. These Paraguay results are a good example of evidence that facilitates transformational adaptation planning with potential options such as shifting cultivating areas of key crops within a country.

Malawi

The Government of Malawi is committed to taking action to tackle food security and climate change challenges. Over the last two decades, Malawi has scaled up its efforts to identify vulnerabilities and related adaptation priorities, and to mainstream climate change adaptation into development and sectoral planning. The National Adaptation Plan process was launched in 2014 to provide medium- to long-term options for Malawi to address adaptation needs. In 2017, Malawi Growth and Development Strategy (MGDS) III was established to move the country to a sustainable development growth path. MDGS III recognizes that climate change has adverse impacts on the agriculture sector.

FAO began supporting the integration of the agriculture sectors into the Malawi NAP process in 2015. FAO is also a member of the NAP Core Team – the formal coordinating mechanism at national level, driving this process and reporting to the National Climate Change Technical Committee (NCCTP). A stocktaking exercise found that decisions at ministry level are reached without the backing of data and evidence, which make it difficult to monitor policies for success or failure. FAO supported the use of MOSAICC by domestic experts with the objective to incorporate a strong evidence base in policy making. In the 2015-2016 rainfall season Malawi was hit by a prolonged dry spell, and agriculture was severely affected by the drought. It was estimated that this season saw 12.4% decline from the 2014/15 season in overall food production, which was already down by about 30% (due to 2015 floods) compared to the 2013/14 season (Government of Malawi, 2016). These two extreme weather events together became a strong drive within the country to assess the impacts of climate change on agriculture.

Key national stakeholders are engaged at every stage in the MOSAICC process to ensure that the outputs exemplify local expertise and national priorities. By bringing together national experts from across institutions, participants in the process can prioritize activities taking the various perspectives and objectives into consideration. Stakeholder engagement also ensures long-term sustainability and capacity development. Upon completion of the MOSAICC process, local experts have the capacity to repeat the exercises if new information (e.g. emission scenarios, updated data) becomes available or national adaptation goals change. Also the Parties to the UNFCCC are required to update National Communication every four years, which include the types of evidence that MOSIACC produces. In Malawi, key stakeholders involved are the Lilongwe University of Agriculture and Natural Resources, the Department of Climate Change and Meteorological Services, and the Departments of Agriculture Research Services, Agriculture Planning Services, and Irrigation and Water Development. MOSAICC is also used in the University as a training tool for students, who will be contributing to the relevant work in academia or in the ministries in the future.

Country ownership is prioritized in the implementation of MOSAICC. The process starts with the collection of data (meteorological, crop yield, etc.), a process that also acts as a stocktaking exercise to identify potential data gaps within the country. One of the issues encountered at this stage was that some of the meteorological data are not in digital format, and records on paper had to be digitized and manually entered into a database. Another issue was the lack of systematic recoding of crop planting dates, which required capacity and time to harmonize for use in any data processing activity.

Capacity building is a core element of MOSAICC and ensures that lessons learned in establishing a climate information system are sustainable. A computer server was provided to the country on which MOSAICC is installed. Trainings on each module of MOSAICC, IT maintenance, climate and crop were carried out. The trained experts were supported by FAO experts until the completion of simulations using MOSAICC and report writing. The final outputs of MOSAICC in Malawi include long-term climate projections downscaled to local level, and projected crop yields, for five major crops across eight districts up to 2070. The responsibility, management, and ownership of the data, tools and results remain in the country. The final results were presented to stakeholders in the final technical workshop. This workshop served as the opportunity for validation of the results by stakeholders, and the results were treated as the material to start discussion within and across the ministries. The stakeholders were mostly convinced of the results of the analysis, while they disagreed with some of the outputs. It was pointed out that several key management practices such as irrigation were not well considered, which resulted in misleading projections of crop productions in the future. The Department of Agriculture Irrigation and Water Development particularly showed a great interest in the simulation outputs, as the results may directly affect their plan for selecting the location of new irrigation systems in the very near future.

Currently Malawian team is in the process to finalize the technical report and disseminate their results to relevant stakeholders including several ministries, reflecting the discussion at the final technical workshop. With various degree of agreement due to spatial aggregation and future projections range, they were able to identify consistency in climate projections in specific areas, crops particularly sensitive (or insensitive) to this change, or areas particularly impacted for most of the crops, for instance. The nation-wide information, directly related to policy relevant administrative boundaries, provides a new basis for improving adaptation measures (e.g. new crops of relevance, irrigation option) for the government.

Several important lessons were learned in the implementation process. Participating experts referred to the lack of human resources within the ministries as a limiting factor in maintaining momentum to complete the MOSAICC process. Strong encouragement of the team leader and senior management of the ministries to push the process forward is necessary to successfully coordinate the various components and to keep the experts engaged throughout. The final objectives and key milestones should be clearly laid out to incentivize the work. The utility of learning these models and the transferability of the skills gained should be clear to the experts as additional motivations to be involved in MOSAICC exercises.

CONCLUSION

Agriculture is widely recognized as one of the most vulnerable sectors to climate change, and it requires urgent action, from the farm to global level. Global agendas that frame the challenges are in place – Sustainable Development Goals, Sendai Framework for Disaster Risk Reduction, and Paris Agreement. Scaling up measures for climate-smart agriculture, and particularly adaptation actions are important in the agriculture sector for many developing countries. In view of promoting transformational adaptation, critical knowledge and capacity gaps have been identified in Asia-Pacific countries – lack of policy-relevant information on evidence about climate risks and vulnerability in agriculture (and its sub-sectors) at the right spatial and temporal scales; and limited capacities to produce evidence in the country and to link them with policies.

Modelling System for Agricultural Impacts of Climate Change (MOSAICC) has been developed and transferred to countries to address the gaps. This in-country, simple, robust and modular nature of the platform makes it a useful and accessible tool for nation-wide, nation-relevant, collaborative and integrated assessment. This approach contributes to building more sustainable institutional capacities within countries, hence improving ownership, relevance and uptake of the assessment. The trained national experts can further promote the agricultural planning and policy based on the evidence-base. It also enables national actors to periodically and independently revisit climate change information in response to new science and evidence. The locally developed evidence that is relevant to national context supports policy discussions at the national level. The assessment, conducted by the national experts, serves as a basis and a trigger for inter-ministerial discussions. This brings relevant ministries to the same table, and through stakeholder and expert validations, the outputs of the analysis are reviewed and reflected in adaptation planning.

The involvement of the governmental people brings another benefit: promotion of evidence-based adaptation within the community of practice. They attend regional and international workshops on climate change adaptation frequently, and exchange information with other countries. A successful experience of a country in implementing agricultural policies based on robust evidence motivates other countries to do so in their own country too. South-south cooperation has also been facilitated by FAO between Philippines and Indonesia, and Peru and Paraguay, where the lessons learned in one country are communicated to the other, resulting in successful implementation.

Although not discussed in this paper, FAO is also developing a tool to analyze daily weather observation data, from agronomic point of view, in terms of intensity and frequency of extreme weather events, with dozens of indices defined for crop-specific agronomic seasons. The tool facilitates visualization of the trends in the weather indices with ability to set user-defined thresholds for extremes. The philosophy for the agronomic weather indices is the same as MOSAICC — easy-to-use, policy-relevant, decision-making and capacity development tool, in support of adaptation planning.

There are high expectations for science community to contribute to the climate change and agriculture agenda by making scientific information available to national policy making process, and by making tools more accessible to the global community of adaptation practitioners. Models and methodologies originally developed for research can be translated into practical tools for decision making. More application-oriented research can be designed which may influence national and sub-national policies and actions. The adaptation community, with un-biased assistance from scientists, will be able to make an informed decision about how to produce evidence — choice of tools and requirement of data. A guidance on selection of tools is particularly important because any tool is developed for specific purposes and for answering certain types of questions, and there is no one single best tool. However it is difficult for practitioners to understand the differences in characteristics of tools. A neutral forum where scientists and adaptation community can exchange information for advancing climate change risks and vulnerability assessment will be highly useful. There are opportunities for further strengthening collaboration between the academia and the development community in the work of climate risks, vulnerability and adaptation assessment.

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