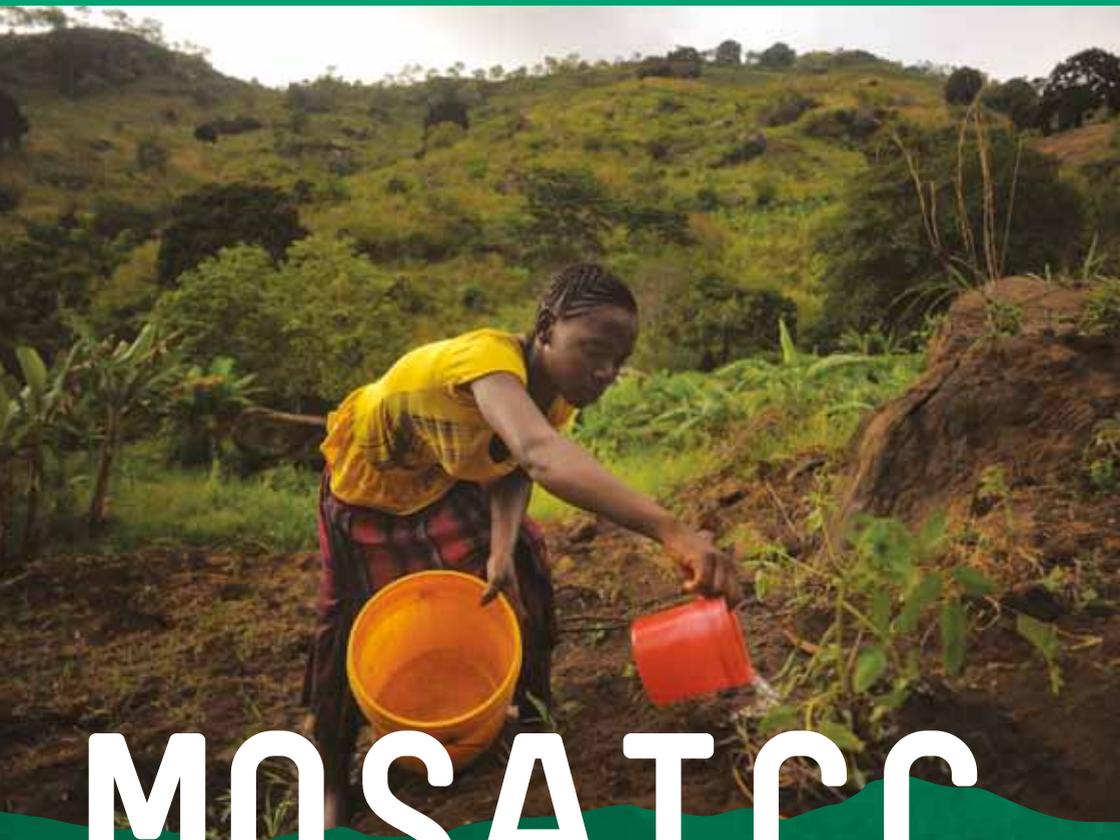




Food and Agriculture
Organization of the
United Nations



MOSAICCC

*A modelling system for the assessment of
the agricultural impacts of climate change*

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MOSAICC

*A modelling system for the assessment of
the agricultural impacts of climate change*

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List of acronyms

AMICAF	Analysis and Mapping of Impacts under Climate Change for Adaptation and Food Security
AURELHY	Analysis Using the Relief for Hydrometeorology
DCGE	Dynamic Computable General Equilibrium
DMN	National Direction of Meteorology (Morocco)
DRPE	Direction of Research and Water Planning (Morocco)
DSS-MAPM	Strategy and Statistics Directorate, Ministry of Agriculture and Fisheries (Morocco)
ENFI	National School of Forestry Engineering (Morocco)
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GCM	Global Climate Model
GIS	Geographic Information System
HCEFLCD	High Commissariat of Water and Forest and Fight Against Desertification (Morocco)
IFPRI	International Food Policy Research Institute
INRA	National Institute for Agricultural Research (Morocco)
LANDIS	Landscape Disturbance and Succession
MAPM	Ministry of Agriculture and Marine Fisheries (Morocco)
MOSAICC	Modelling System for Agricultural Impacts of Climate Change
NEDA	National Economic and Development Authority (the Philippines)
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PhilRice	Philippine Rice Research Institute
RCP	Representative Concentration Pathway
SAM	Social Accounting Matrix
SENAMHI	National Service for Meteorology and Hydrology (Peru)
STREAM	Spatial Tools for River Basins and Environment and Analysis of Management Options
UNFCCC	United Nations Framework Convention on Climate Change
UPNIGS	University of the Philippines - National Institute of Geological Sciences

1/ Background

Climate change poses great challenges to agricultural production systems. Changing climate conditions are projected to affect food security from the local to the global level. New evidence-based policies and strategic development plans are required to address the emerging challenges of improving food security.

Information on the impacts of climate change is a primary resource for policy makers trying to cope with climate change. In recent years, scientists have developed a range of different models to monitor, evaluate and predict the effects of climate change. However, this information is often scattered, incomplete or focused exclusively on one scientific domain. An innovative, multidisciplinary approach combining knowledge from different domains would therefore constitute an ideal tool to evaluate the sustainability of agricultural systems. The Food and Agriculture Organization of the United Nations (FAO), in partnership with European research institutes, has developed an integrated package of models to assess the impacts of climate change on agriculture (including

forestry), water resources and the national economy. This package is called MOSAICC or "Modelling System for Agricultural Impacts of Climate Change".

MOSAICC is developed within the framework of the EU/FAO "Improved Global Governance for Hunger Reduction" programme. It assesses crop production systems, water and forest resources and the national economy under changing climatic conditions. This innovative system has been developed to be transferred to interested countries, with training towards independent use by national experts provided. The climate impact assessments at country level constitute a pertinent response to the UNFCCC Least Developed Countries Expert Group's request for country-specific climate information.

The MOSAICC country studies provide an opportunity to assess the threats and opportunities presented by climate change to agricultural systems and food security, and develop ways to adapt agricultural systems to the impacts of climate change. The discussions with policy makers, local experts and researchers therefore address not only the findings of the studies, but also the importance of agriculture, with

a particular focus on adaptation. These topics are central to achieving sound and evidence-based national adaptation plans, projects or programmes.

The negative impacts of climate change are threatening the food security of the world's poorest and most vulnerable, almost 80 percent of which live in rural areas. These populations, including family farmers, pastoralists, fisherfolk and community foresters, are highly dependent on natural resources and are the first to suffer from weather-related shocks. Mr Graziano da Silva, Director-General of FAO, highlights: "Agriculture can and must play a central role in addressing climate change and FAO supports more productive, inclusive and resilient agricultural development. This can enhance incomes and food security for the world's poorest, which remains our main priority."

FAO is working to raise awareness on these issues, emphasizing the Organization's position that adaptation needs to be encouraged in order to overcome the challenges presented by climate change. The Director-General urges all countries to work together to "promote a paradigm shift towards an agriculture and food systems that are more productive and more inclusive, and more adapted to climate change."

2/ Presentation of the MOSAICC platform

2.1/ Overview

MOSAICC is a complex but powerful modelling system which allows users from various disciplines, including climatology, agronomy, hydrology, forestry and economics, to assess the impacts of climate change. It integrates a powerful data management system which allows users to upload data, as well as a flexible and configurable system to run multiple models. Its web-based interface is user-friendly. Users do not need to install any software on their computers, as data and results are shared on a centralized server, acting as web server, data server and processing workstation.

The results from simulations by MOSAICC can be used by experts from national partner institutions but also by a wider audience of policymakers, scientists, students and members of the civil society, to raise awareness of the potential impacts of climate change and the need for adaptation.

The distribution of MOSAICC's results allows for the integration of scientific information in the design of agricultural development projects and, more generally, in economic decision-making and policy development.

Climate impact assessment studies based on the MOSAICC system are being carried out in several countries, including Morocco, Peru and the Philippines, and will soon be implemented in Malawi, Zambia and Indonesia.

2.2/ Strengths of the MOSAICC platform

MOSAICC is a powerful tool for simulation, and is unique in that it combines several models in a single modelling system. The main advantage of such a system consists in the exchange of data between different models, which enables researchers to consistently assess different aspects of climate change impacts. The data exchange is easy, effective and transparent. The processing time required to perform simulations is reduced. A web interface is used to communicate information to users. Users may consult the results of the climate change impact studies or use the system to produce customized simulations.

Beyond impact studies, the possible applications of the system are numerous. They include: assessing climate changes at the local level; monitoring the impacts of climate change on water resources, crops and food security; vulnerability analysis; simulating agricultural policy measures etc.

2.3/ Technical aspects of the MOSAICC platform

2.3.1/ Introduction

MOSAICC models and tools all run on a central server to which users have access via web interfaces. All models are connected to a single spatial database, which facilitates the exchange of data, guarantees data coherence and allows users to run simulations that can generate data for other experiments or use the results of other model executions.

The user interface of MOSAICC is based on the WEB-GIS technology, which requires open source tools and libraries. It is a multi-user system which allows users to share data and results (i.e. other data generated from the models).

2.3.2/ The architecture of MOSAICC

The architecture of MOSAICC is based on the open source Linux distribution called CentOS. CentOS aims to provide a free, enterprise-class, community-supported computing platform which is functionally compatible with its upstream source, Red Hat Enterprise Linux (RHEL). CentOS is one of the most popular Linux distributions in the hosting industry.

The suggested server configuration for Linux installation is:

- **CPU:** Intel®Core™ 2 Quad CPU Q9550 @ 2.83 GHz (i.e. 8 CPUs)
- **RAM:** 8 GB
- **Disk:** 2 TB in RAID 1
- **CentOS 6.x, 64-bits**

The platform-independent software includes:

- **Programming languages:** C/C++, Fortran, Pascal, Basic, Python and R
- **GIS libraries:** GDAL, Proj.4, GEOS
- **DBMS:** PostgreSQL with PostGIS extension
- **Web-GIS:** Apache 2.x web-server with PHP support and MapServer
- **CMS:** Drupal 6.x or 7.x

3/ Components of the MOSAICC platform

3.1/ Overview

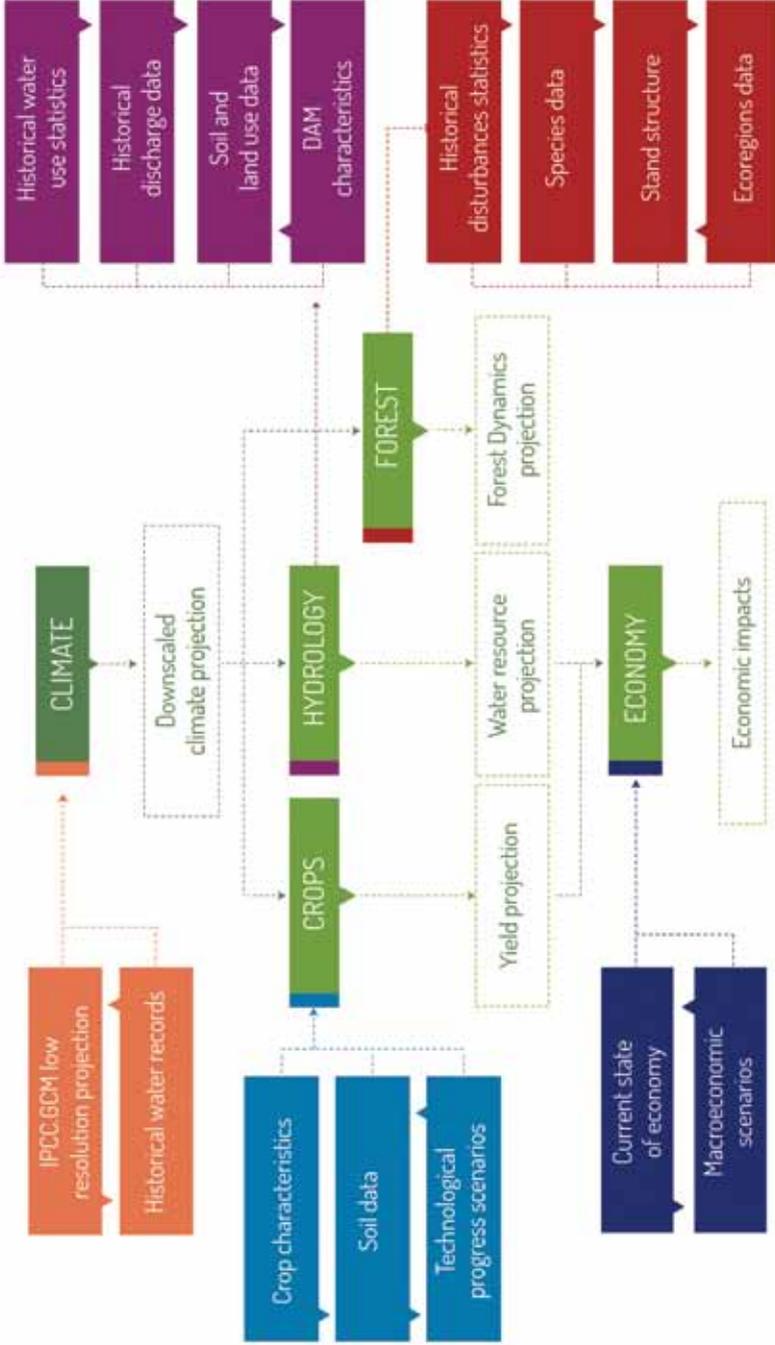
The models integrated in the MOSAICC platform are categorized into five main components:

- Climate data processing tools: statistical downscaling and spatial interpolation tools aimed at preparing the data for the crop, hydrology, and forestry models;
- Crop models: simulate crop growth under climate change scenarios, using the data produced by the climate data processing tools;
- Hydrological model: model the hydrology of river basins under climate change scenarios, using the data produced by the climate data processing tools;
- Economic model: simulate the impact of yield variations due to climate change on national economies;
- Forest model: assess the impacts of climate change on forest dynamics.

The five components of the MOSAICC platform are discussed in the following sections.

Figure 1/ Overview of the MOSAICC platform with its five components (green boxes), inputs (orange and blue boxes) and data generated (purple and red boxes)

1/ Components



3.2/ The climate component

The climate component of MOSAICC includes tools to generate time series of localized climatic variables:

- minimum and maximum temperatures
- precipitation
- reference evapotranspiration
- growing season onset
- length of the growing season

The climate component integrates a statistical downscaling tool based on the portal developed by the Santander Meteorology Group of the University of Cantabria. This tool is designed to perform the statistical downscaling of climate data generated by Global Climate Models (GCMs) to the weather station level. Several statistical downscaling methods to maintain spatial and inter-variable consistency are available, including regression methods.

A second tool was developed to interpolate station-level climate data in the study domain using the AURELHY method ("Analysis

Using the Relief for Hydrometeorology"), a spatial interpolation algorithm for meteorological and hydrological data based on the analysis of the topography. A specific utility was developed to directly calculate the reference evapotranspiration from interpolated minimum and maximum temperatures.

Finally, the climate component also comprises a tool to estimate the onset of the growing season and the length of the growth cycle.

Two GHG greenhouse gas concentration scenarios are usually customarily used for climate projections. A first scenario is called "Representative Concentration Pathway (RCP) 4.5", based on the assumption that greenhouse gas emissions stabilize by 2050, while a pessimistic scenario, is RCP 8.5, which assumes that greenhouse gas emissions continue to rise until 2100. The climate projections from several global climate models are chosen for downscaling to weather station levels, and the results are presented in various temporal resolutions: daily, the decade (ten days), monthly, and annually.

3.3/ The agronomic component

For the agronomic component, two models are available to produce crop yield projections, both chosen for their simplicity and consistency, although their level of sophistication is different. The first model is a crop specific water balance model developed by FAO, called WABAL, designed to simulate soil water balance based on each crop for individual crops using:

- climatic data (precipitation, reference evapotranspiration and the starting date and length of the growing season);
- soil data (soil water retention capacity);
- crop parameters (factors and the length of each crop growth stage).

The results consist in the values of crop water balance variables (such as evapotranspiration, water deficit, water satisfaction index) for the growing season and the different growth stages. Based on the simulated water balance variables and weather variables, regression models are built to predict crop yields. Localized future climate

conditions from the climate component are used together with the calibrated models to produce projections of crop yields.

The second model is called AQUACROP and was also developed at FAO. This model simulates crop response to water in a more sophisticated way than WABAL, and may be applied at a smaller scale simulation. AQUACROP distinguishes between soil evaporation and crop transpiration; simulates root development, canopy cover expansion and water stress; and provides biomass production and yield estimates. The effect of the CO₂ concentration in the atmosphere is also taken into account. Applications of AQUACROP include:

- Developing wheat cultivation techniques adapted to the conditions of a region;
- Quantifying water volumes provided at plot level for various irrigation systems (rate and duration of irrigation);
- Simulating soil moisture at different depths on the basis of the gravimetric method;
- Determining the physicochemical and hydrodynamic parameters of the soil.

3.4/ The hydrological component

MOSAICC includes a hydrological model based on a new version of STREAM ("Spatial Tools for River Basins and Environment and Analysis of Management Options"), a gridded rainfall runoff model simulating flow rates in major water catchment areas. This tool was developed by the Free University of Amsterdam and Water Insight, and has been applied in several basins around the world, such as the Rhine, the Ganges-Brahmaputra, the Yangtze and the Zambezi river basins. The new version of STREAM offers more flexibility in terms of input and incorporates dams in the water cycle. A calibration module has also been incorporated. The hydrological model can have several applications for climate change impact studies in the agricultural sector. At the scale of a watershed, STREAM can be used to estimate the water availability for irrigation schemes under different climate change scenarios. At country level, the model can be used to assess total actual renewable water resources.

The hydrological data for the calibration of the STREAM model are:

- Monthly water flows observed in the hydrological stations of the watershed;
- Monthly water flows at the entrance and exit of the main dam for the same period;

- The total capacity of the main dams, degree of filling, the average amount of water extracted;
- Station and dam coordinates.

The main output of the hydrology component is simulated volumes of monthly stream flows in the future driven by localized climate projections.

3.5/ The economic component

MOSAICC includes a dynamic computable general equilibrium (DCGE) model, which simulates the evolution of the economy of a given country and the changes induced by crop yields variations projected under several climate change scenarios.

This model, developed in partnership with the Free University of Amsterdam, is inspired by the IFPRI DCGE model. The model allows the user to define a number of activities, each producing a commodity to account for different cultures and differentiated variations in crop yields across the country. The effect of variations in crop yields is simulated using multipliers in the activity production functions. The model requires the construction of a Social Accounting Matrix (SAM), is developed based on a country's data and statistics. The model

provides estimates for all endogenous variables (commodity prices, imports, taxes, household income and savings etc.). The main output of the economic component is national GDP changes in response to changes in climatic conditions and agricultural productivity.

3.6/ The forestry component

The forestry component of MOSAICC has been developed in accordance with interests at the national and regional levels concerning the impacts of climate change on forest dynamics. The forest model integrated in MOSAICC, LANDIS-II, is a forest landscape simulation model. It simulates the effects of ecological processes (including succession, seed dispersal, disturbances and climate change) on forested landscapes over time. The version of the LANDIS-II model integrated in MOSAICC is a process-based model. It uses direct cause-and-effect relationships to link forest dynamics to fundamental climate drivers (temperature, precipitation and CO₂ concentration), and can produce robust predictions under novel conditions. The main output of the forestry component is changes in biomass and the distribution of tree species distributions in response to climate change.

The forestry component is a useful tool to:

- Assess forest productivity and its influence on the economy under changing climatic conditions.
- Assess the establishment of tree species under novel conditions.
- Assess the impacts of disturbances such as fire or wind on forest production and on the economy.

4/ Case Studies

4.1/ Morocco

Starting in 2009, the Moroccan Ministry of Agriculture and Marine Fisheries (MAPM) has undertaken, with technical support from FAO, quantitative analyses of the impact of climate change on the productivity of major crops in the country. These analyses were carried out in partnership with the National Institute for Agricultural Research (INRA) and the National Direction of Meteorology (DMN). Based on the methodologies and tools developed in the framework of these initial studies, and in collaboration with the Moroccan institutions involved and with the EU, FAO has developed a pilot study using MOSAICC, aimed at assessing the economic impact of climate change on Moroccan agriculture. This experimental assessment was carried out using four model components (climatic, agricultural, hydrological and economic). In 2014, the forestry component was also introduced. The Moroccan experience constitutes the first complete implementation of MOSAICC at country level. This pilot project has allowed researchers to test the functioning of the platform and make the necessary adjustments.

Several national institutions contributed towards the development of the MOSAICC platform, including:

- The National Institute for Agricultural Research (INRA);
- The National Direction of Meteorology (DMN);
- The Strategy and Statistics Directorate, Ministry of Agriculture and Fisheries (DSS-MAPM);
- The Direction of Research and Water Planning (DRPE);
- The seven agencies of the hydraulic river basins of the Oum Er-ria, Loukkos, Sebu, Moulouya, Tensift, Souss-Massa-Drâa and Bouregreg-Chaouia areas;
- The High Commissariat of Water and Forest and Fight Against Desertification (HCEFLCD);
- The National School of Forestry Engineering (ENFI).

Around 50 to 60 managers and experts in Moroccan partner institutions have received tailored training on the various components of the MOSAICC system, related to their area of expertise. The training focused on the administration of the system, troubleshooting, the spatial interpolation and statistical downscaling of climate data and hydrological, agronomic, economic and forestry modelling. The training sessions were given by experts involved in the development of the system. After the training sessions, continuous support and guidance are offered to carry out the modelling work, present the results and interpret the analysis and findings. An assessment of the training modules shows that the majority of survey respondents were satisfied with the training received, which was perceived as a good preparation for independent use of the system and its components.

4.2/ The Philippines and Peru

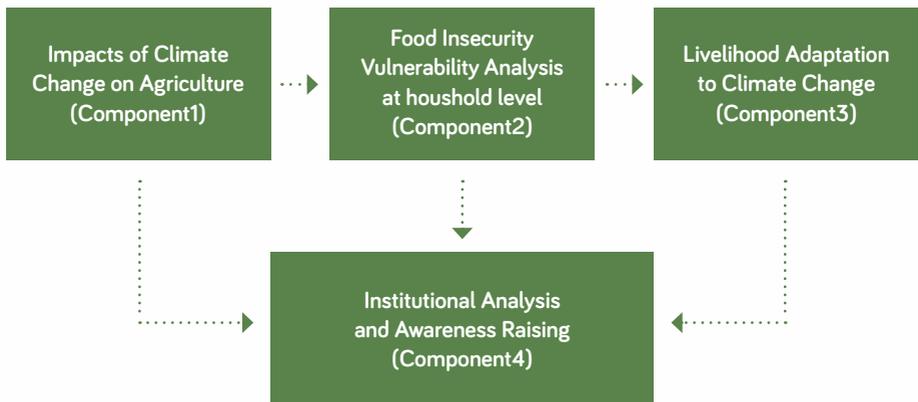
Often, climate change impact studies by academic researchers are disconnected from stakeholders' decision making processes. Moreover, many climate change adaptation projects and programmes in developing countries lack a solid base of evidence on current and future climate impacts and vulnerabilities at different levels. In order to fill this information gap, FAO has implemented, from 2012 to 2015, a project named "Analysis and Mapping of Impacts under Climate Change for Adaptation and Food Security" (AMICAF) in the Philippines and Peru.

The project adopted a multi-disciplinary assessment approach. It consisted of four components [Figure 2]:

1. Assessment of the impacts of climate change on agriculture;
2. Analysis and mapping of food insecurity vulnerability at household level;

3. Community-based livelihood adaptation to climate change;
4. Institutional analysis and awareness raising, to support the other three components.

Figure 2/ The four components of the AMICAF project in the Philippines and Peru



Over the course of this project, national experts used MOSAICC to generate spatially downscaled climate change scenarios and a robust assessment of the impacts of climate change on agricultural crops, water resources and the economy for component 1 of the project. The following partners contributed towards component 1:

for the Philippines:

- The Department of Agriculture
- The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)

- The Philippine Rice Research Institute (PhilRice)
- National Economic and Development Authority (NEDA)
- University of the Philippines - National Institute of Geological Sciences (UPNIGS)

Examples of the output of project component 1 are illustrated below. Figure 3 shows precipitation projections on 10 km grids in the Philippines after downscaling of coarse resolution global climate model outputs and spatial interpolation. Precipitation changes are expected to show seasonal as well as regional differences within the country.

for Peru:

- The Ministry of Agriculture and Irrigation
- The Peruvian National Service for Meteorology and Hydrology (SENAMHI)
- The National Agrarian University in La Molina

Figure 3/ Percentage (%) change in precipitation in the Philippines (A1B, BCM2 model) from 1971–1999 to 2011–2040)

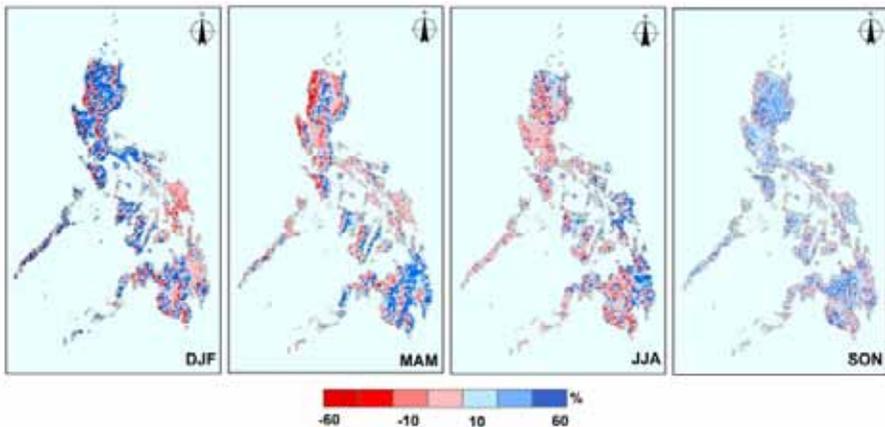


Figure 4 shows that Peru will experience a wetter climate in the future, particularly in the northern part of the country. Because of the complex topography of the country, the size and direction of the projected changes show a high degree of spatial heterogeneity.

Figure 4 // Percentage (%) change in precipitation in Peru (MPI-ESM-MR model) from 1971–2000 to 2036–2065 at various weather stations

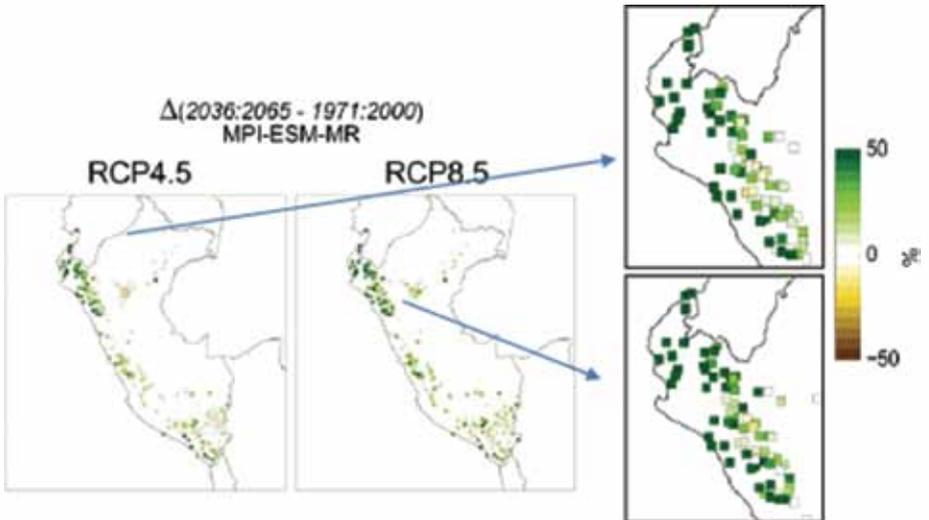
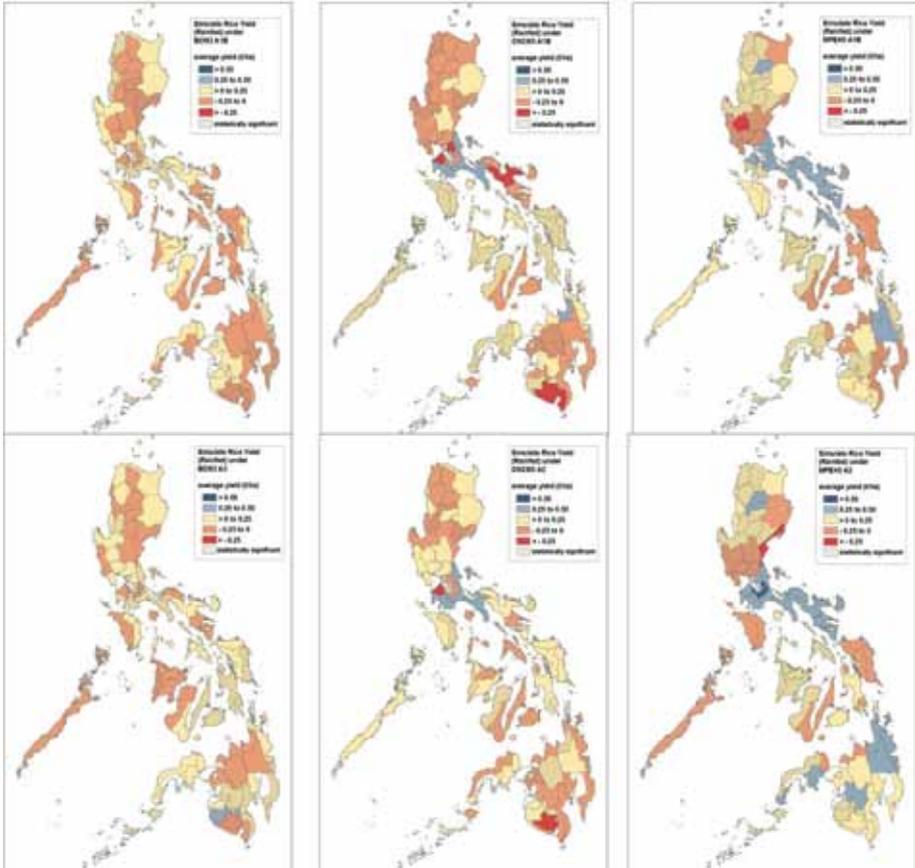


Figure 5 shows projected yield changes of rainfed rice in the Philippines. The six panels indicate the range of uncertainties from different climate projections simulated by three global climate models and two emission scenarios. Many provinces are expected to experience increases in yields under future climate conditions.

Figure 5/ Projected rainfed rice yield changes (tonnes/ha) from 1971–2000 to 2011–2040 in the Philippines



On the other hand, potato productivity in Peru is projected to decrease under changing climatic conditions, as illustrated in Figure 6.

Figure 7 shows the simulation results of the hydrological study in the Philippines. Overall, an increased amount of river water will be available in the majority of the 24 basins, as a result of the increase in precipitation.

The increase in stream flow will be accompanied by an increase in maximum peak flow, which presents challenges to water resources management.

Figure 8 shows seasonal changes in one of the 16 Peruvian basins simulated for the project. The model suggests increases in stream flow in response to precipitation increases, and a shift in seasonal peaks of river flows. This may have significant implications for farmers trying to adapt to climate changes in the basin.

Figure 6/ Projected potato yield change (kg/ha) from 1971–2000 to 2036–2065 in Peru.

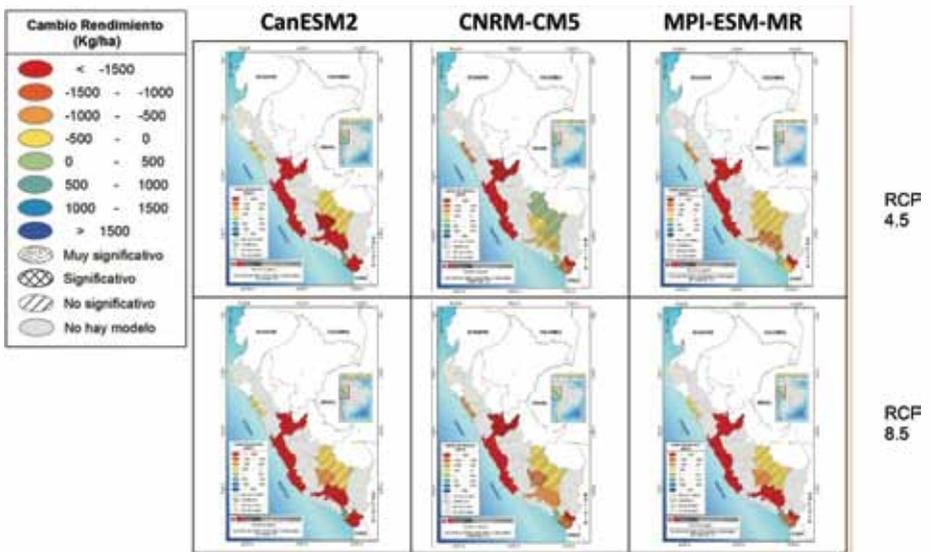


Figure 7/ Projected changes in water balance (precipitation minus potential evapotranspiration) (maps) and projected changes in stream flow for 24 basins (box plots) in the Philippines. Changes from 1971-2000 to 2011-2040 for both maps and box plots.

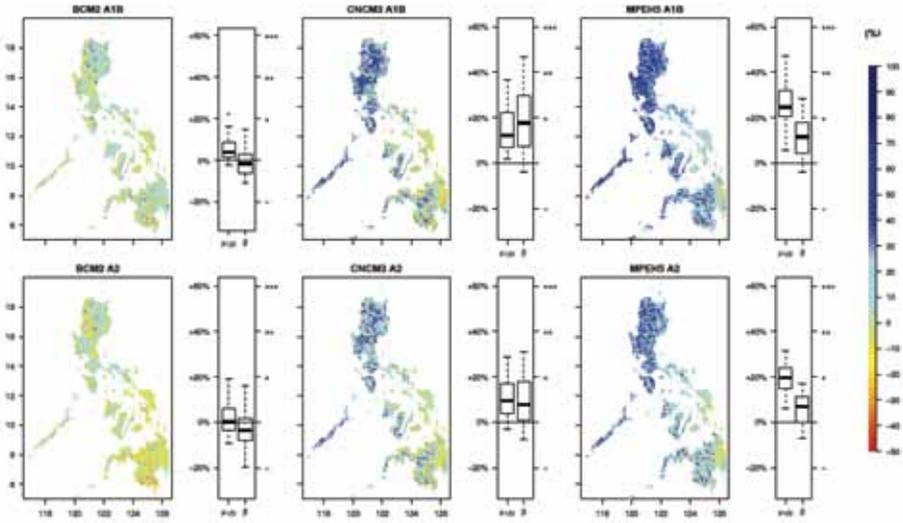
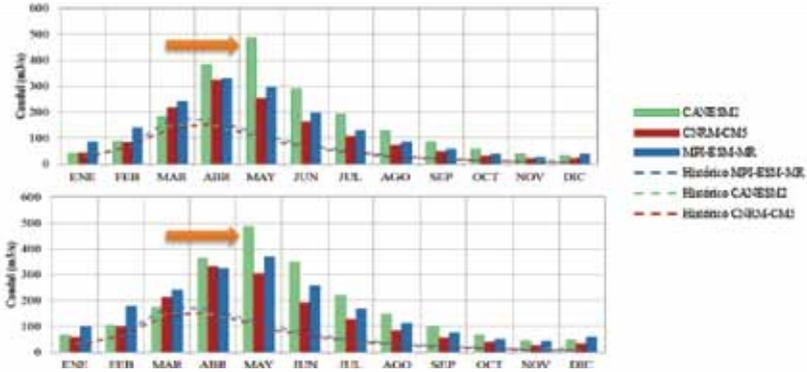


Figure 8/ Monthly simulated stream flows in the Piura basin in Peru, 1971–2000 and 2031–2065.



5/ Improving the MOSAICC platform

One of MOSAICC's main strengths is its participatory approach, allowing multiple entities to work within a single framework agreement. All actors involved in the implementation of MOSAICC agree on the need to strengthen the consortium(s) created and guarantee the necessary coordination between different institutions and stakeholders.

MOSAICC is a work in process, open to improvement, and thus requires human and financial resources to ensure its continuity. Improvements can be made, for example, by adding new models that address different aspects of climate change, agriculture and food security issues (fisheries and aquaculture, nutrition, livestock, pests and diseases, etc).

There are plans to promote the use of MOSAICC in various climate change projects (climate-smart agriculture, national adaptation plans in the agricultural sector, agricultural investment planning, etc.) in many more countries. It is expected that more ideas for the improvement of MOSAICC will emerge through these future projects.

6/ Conclusions

MOSAICC is an easily accessible web-based platform which allows for the quantification of the impacts of climate change on agricultural production. As such, MOSAICC supports strategic development and adaptation planning and allows national experts to carry out studies using the country's own data.

MOSAICC provides information regarding the impacts of climate change at the subnational level, identifying the most vulnerable areas.

MOSAICC is a decision support tool for decision-makers pressed to provide answers to the challenges posed by changing climatic conditions. They can rely on the information, knowledge and experience derived from the climate impact assessment studies carried out at the national level to formulate sound and comprehensive policies and "resilient adaptation" plans at the local and national levels to contend with the dynamic nature of climate change.

MOSAICC also constitutes a powerful tool for the simulation of the impacts of climate change by researchers and students in the fields of climatology, agronomy, hydrology, forestry or economics. Given its various components and its many possible uses, MOSAICC deserves a greater recognition by development organizations, governmental and non-governmental institutions and the general public. In this perspective, new national and international partnerships must be explored.

MOSAICC

A modelling system for the assessment of the agricultural impacts of climate change

MOSAICC is a system of models and utilities designed to carry out inter-disciplinary climate change impact assessment on agriculture, water resources, forestry, economy through simulations at national level. It uses an innovative approach that integrates five components to assess the impact of climate change and comprises documentation on methods and tools, as well as user manual and sample data. The system is typically deployed in national institutions (ministries, research institutes, universities) and delivered with training sessions, under the framework of an inter-institutional agreement and trust fund sources.

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