Tortillas on the Roaster

(ToR)

Central American Maize-Bean Systems and the Changing Climate

Full Technical Report

Main Authors: Axel Schmidt, Anton Eitzinger, Kai Sonder & Gustavo Sain

CIAT

CIMMYT

CRS CATHOLIC RELIEF SERVICES

October 2012

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FULL TECHNICAL REPORT

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1 Foreword

We would like to express our gratitude to the Howard G. Buffett Foundation (HGBF) for its vision in initiating and funding such a rigorous and much needed study. HGBF has been proactive in asking the difficult questions in pursuit of global food security, and then taking the risk to test solutions in the field. We also want to highlight our appreciation to Dr. Axel Schmidt, who helped design the TOR study and then led it with professionalism and integrity, immersing himself in every facet of research, analysis, and writing.

We believe that TOR is excellent example of applied research, where cutting edge science, led by CIAT and CIMMYT, meet on-the-ground needs of smallholder farmers and their communities that CRS seeks to serve. It has been an honor to work with and learn from both these institutions.

All of us involved in TOR approached this theme with curiosity and objectivity. We sought to better understand the impacts of climate change on beans and maize, and we wanted to produce a study that would be useful for us, for the wider development community, and most of all for farmers. We hope and expect that this study will generate some controversy and push development actors, governments, and most of all farmers to wrestle with and challenge the results and recommendations of this study. But most of all, we hope this study is a call to action. Through this study, and many others, we now know enough to act and make vital changes. We hope the main messages are clear: (a) there is an urgency to use this information wisely and immediately, and (b) there is much we can do now to manage the impacts of climate change on maize and beans with the right tools and knowledge.

For CRS, the results and recommendations from TOR have contributed to our broader development strategy for Central America. Specifically, there are three points we draw from the study:

First, we need to manage the resources we already have in Central America, specifically soil and water, much more effectively. TOR shows that soil degradation is both the key factor in vulnerability and critical to climate change adaptation; it is urgent that we focus on rebuilding and protecting soils. Similarly, water is a tremendous natural resource that Central America has in abundance. So much can be done to adapt to climate change by using this resource wisely, by harvesting rainwater and using it efficiently for producing food, while conserving watersheds, wetlands, and the other ecosystems that we rely on for our well-being and survival.

Second, we need to put "farmers first". This idea, expressed so eloquently by Robert Chambers, Miguel Altieri, and others more than twenty years ago, remains fundamental. Farmers want to produce food for their families and earn income to afford education and health services for their children. They can succeed when provided the right skills, knowledge, and opportunities. Small farmers have been neglected in Central America over the past two decades, to the detriment of society and nature. All of us in the development community need to focus more effort and resources to support farmers to for mitigate and adapt to climate change.

Third, success requires the leadership of government. Governments in Central America need to commit to climate-smart agricultural development. Extension services and academic training need to be funded and reinvigorated with a focus on small farmers, who produce most of the food for this region. NGOs, research institutions, and donors can be part of the solution, but governments are the only ones with the power and ability to make a real difference through their leadership and courage in setting new policy priorities and ensuring immediate action and long-term commitment.

Paul Hicks
Regional Coordinator
Global Water Initiative - Central America
Catholic Relief Services

2 Abstract

In order to be able to adapt to climate change, maize and bean producing smallholders in Central America have to know which type of changes and to which extent and ranges these changes will occur. Adaptation is only possible if global climate predictions are broken down on local levels, to give farmers a direction on what to adapt to, but also to provide detailed information about the extent of climate change impact and the exact location of the affected population to local, national, and regional governments and authorities, and the international cooperation/donors in order to coordinate and focus their interventions

This technical report seeks to assess the expected impact of climate change on maize and bean production in four countries in Central America. We downscaled GCM (Global Climate Models) to a local scale, predicted future maize and bean production using the dynamic crop model DSSAT (Decision Support for Agro-technology Transfer), we identified based on the DSSAT-results 3 types of focus areas where impact is predicted to be significant and run DSSAT again with the full range of available GCMs to address uncertainty of model predictions. Outputs of downscaled climate data show that temperature is predicted to increase in the future, while precipitation will slightly reduce. Crop modeling shows that bean yields will decrease high along the dry belt in Central America and revealed a significant influence of soil fertility and soil water retention capacity especially on maize yield which will be drastically affected by climate change under such poor soil conditions. Furthermore, we identified hot-spots with more than 50% yield reduction as well as area with favorable growth conditions in the future.

The conducted vulnerability analysis shows the low adaptive capacity at household level and the low availability of human and social capital across the region for climate change adaptation. Central America is highly vulnerable to climate change. Based on the results we finally made recommendations for adaptation- and mitigation strategies such as eco-efficient and sustainable intensification of the production system combing soil and fertility management with water harvesting schemes, marketed-oriented high value plant production and plant genetic improvement for heat- and drought stress. The findings of the present study should enable decision makers on local, national and regional levels to take appropriate action in the right locations and provide an adequate policy framework for successful implementation of adaptation strategies in the rural sector of Central America.

3 Introduction

In the Central American countries of El Salvador, Guatemala, Honduras, and Nicaragua more than 1 million smallholder farm families depend on the cultivation of maize and/or beans for their subsistence. The maize-beans production system is the most important agricultural production system in the region, which dates back to the pre-Columbian period. It builds the foundation of the Central American diet and is integral to the regional culture. The annual consumption of maize is as much as 170 kg/person, and for beans it is more than 25 kg/person (CEPAL 2005).

The production system comprises 2.4 million ha—1.8 million ha of maize and around 600,000 ha of beans—with an overall output of 3 million t of maize and 475,000 t of beans annually. The annual gross values of maize-beans production are greater than US$700 million and US$400 million, respectively. Nicaragua produces more than 30% of the regional harvest and exports to neighbor countries. Farming is conducted mostly by smallholder families on farms averaging 3.5 ha. Productivity is low by global standards, averaging 1.5 t/ha for maize and 0.7 t/ha for beans. Smallholders invest over 120 million working days per season in producing maize and beans (IICA 2007).

Most of the maize-beans production in Central America can be found on sloping terrain (e.g. 80% in Honduras). Soils, albeit mostly of volcanic origin, are shallow and erosion prone on sloping lands. Combined with the traditional slash and burn management soil degradation is becoming a major constraint for production (Oldeman et al. 1991). For smallholders dependent on agriculture for their livelihoods, degradation of natural resources and low maize-beans production are intimately related to major determinants of poverty, including: geographic isolation; lack of access to services and infrastructure, credit, and input and output markets; low education levels; and dependency on family labor. Labor migration within countries and the region, or to the United States, is common. And, within this already precarious scenario, the food security of millions of people is often at risk because smallholders are highly vulnerable to climate variability, including droughts and severe storms.

Climate change will intensify the already existing challenges for smallholder farmers in Central America. The added impacts of climate change, in the form of higher temperatures and less precipitation, will significantly affect crop viability or prevent production altogether However, predictions of possible extent of climate change impacts are for the most part of general nature and the current outputs of global climate prediction models are too coarse to allow effective decision making and strategy implementation at municipal or smallholder farm level. There is an urgent need by smallholder farmers and decision makers, both nationally and regionally, for sufficiently detailed information on both the extent of climate change and the specifics on where, when and how to focus their decisions, policy, coordination, and interventions for climate change adaptation and mitigation of the maize-beans production system in Central America. Adaptation is possible only if predictions of global climate impacts are known at local levels, so that smallholders know what to adapt to.

The present study was carried out to provide specific and actionable information on the projected impacts of climate change on maize-beans and to provide decision makers and smallholder farmers with recommendations for adaptation. With funding from the Howard G. Buffett Foundation (HGBF), Catholic Relief Services collaborated with the International Center for Tropical Agriculture (CIAT) and the International Center for Improvement of Maize and Wheat (CIMMYT) to conduct the study from March

2011 to April 2012. The study became familiarly known as Tortillas on the Roaster (TOR), alluding to both the cultural significance of maize and beans to Central Americans and climate change.

4 Project goals and objectives

The project “Tortillas on the Roaster” seeks to predict site-specific changes in maize-bean production systems in order to inform and enable vulnerable farmers in Nicaragua, Honduras, El Salvador and Guatemala to act and respond to ongoing climate change through specific adaptation measures and increased capacity. In order to achieve this ambitious goal we worked along two main activity lines: (i) the analysis of climate change impact and (ii) the targeting of future interventions (Figure 1). While the first activity line included the collection and compilation of all necessary field data and ground proofing of climate and crop models, the downscaling of climate models to local levels, and the predictions of future climate conditions, crop production, and socio-economic impacts, the second activity line targeted the identification of hot spots/focus areas for different adaptation scenarios across four countries in Central America.

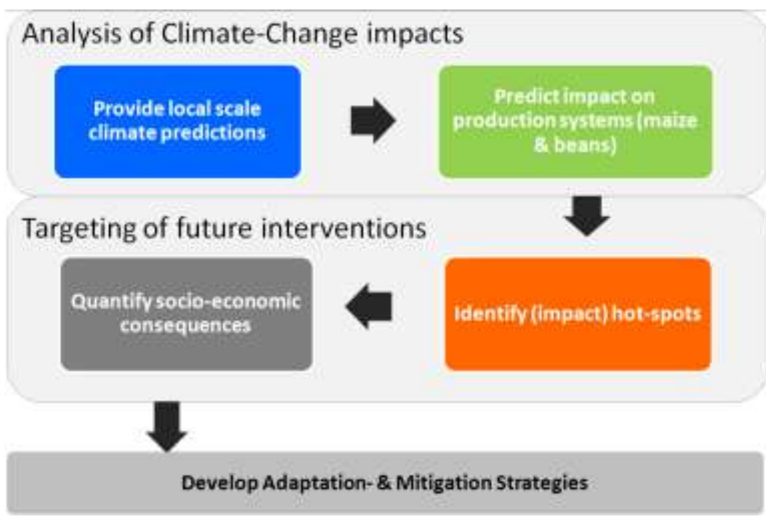


Figure 1: Activity lines and main objectives

4.1 Analysis of climate change impact

The aim of the analysis was to systematically address the magnitude of long term climate change impact regarding farmers’ maize and beans production systems in Central America. Generally, the region is highly vulnerable to extreme events and unfavorable future climate conditions. Several studies based on historical climate, register that hurricanes and extreme weather events are increasing in frequency and intensity in Central America (Magrin et al. 2007; Tucker et al. 2009). A climate disaster often leads to crop failure and harms farmers’ resilience and their food security. Farmers already experienced unforeseen climate variability in the past and need to cope with these uncertainties every day for their agricultural production. With climate change they have to face additional long-term shifts of climate patterns as shown by global climate predictions. Long-term changes in temperature and rainfall patterns require strategies for adapting agriculture and food systems and also new ways of managing risks. This project and the climate data we used focus on a long-term changing climate and will not take into account climate variability. Data and methodologies used for the climate change impact assessment are described in this report.

4.2 Targeting of future interventions

In order to be able to adapt to climate change, smallholders have to know which type of changes and to which extent and ranges these changes will occur and the respective specific impacts on their livelihood, from effects on plant growth to market conditions and value chains. Adaptation is only possible if global climate predictions are broken down to local levels, to give farmers a direction on what to adapt to, but also to provide detailed information about the extent of climate change impact and the exact location of the affected population to local, national, and regional governments and authorities and the international cooperation/donors in order to coordinate and focus their interventions in the future. There will be people who will be more affected by climate change than others; some might have to leave the agricultural sector while others will have to change their whole operation. But there will be also new opportunities for those who will adapt quickly making them winners of changes in climate.

5 Methodology

In the block diagram (Figure 2) we show methods and elements we used throughout the process.

5.1 Current climate

We used historical climate data from the www.worldclim.org database (Hijmans et al. 2005a) as the current (baseline) climate. WorldClim data are generated by interpolating average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1-km" resolution). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 bioclimatic variables (Hijmans et al. 2005a) derived from the initial variables that are often used in crop niche modeling.

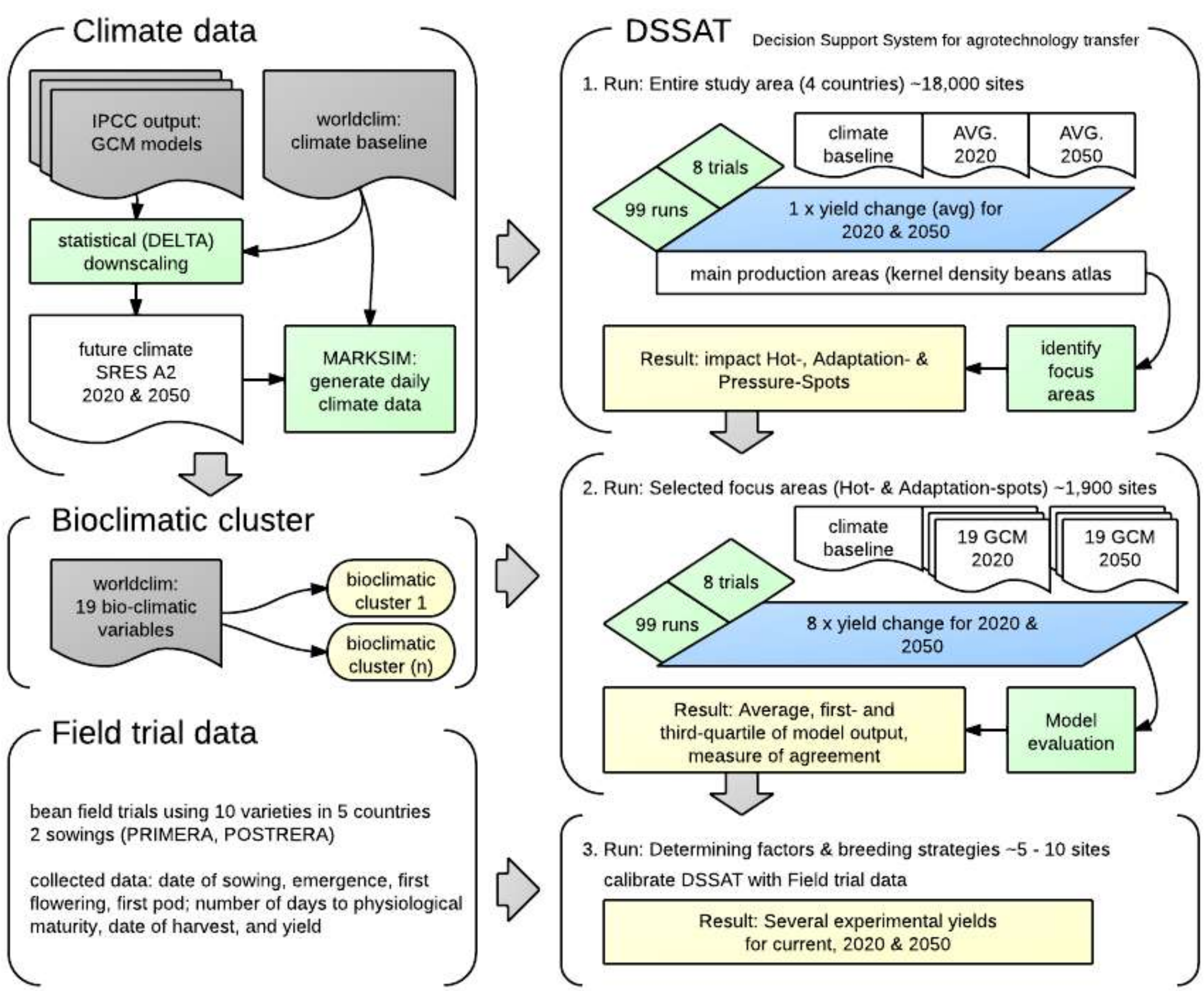


Figure 2: Block diagram of the used methods

In the WorldClim database, climate layers were interpolated using:

- Major climate databases compiled by the Global Historical Climatology Network (GHCN), the Food and Agriculture Organization (FAO), the World Meteorological Organization (WMO), the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru and Bolivia, amongst others.
- The SRTM elevation database (aggregated to 30 arc-seconds, "1 km").
- The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multivariate data using thin plate smoothing splines. We used latitude, longitude and elevation as independent variables.

For stations for which there were records for multiple years, the averages were calculated for the 1960-90 period. Only records for which there were at least 10 years of data were used. In some cases, the time period was extended to the 1950-2000 period to include records from areas for which there were few recent records available or predominantly recent records.

After removing stations with errors, the database consisted globally of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

Table 1: Meteorological stations on which WorldClim is based in the study area

Country	Precipitation stations	Mean temperature stations	Minimum temperature stations	Maximum temperature stations
Nicaragua	225	220	2	2
Honduras	49	70	52	56
El Salvador	131	127	19	19
Guatemala	303	292	91	102

5.2 Future climate

A global climate model (GCM) is a computer-based model that calculates and predicts what climate patterns will look like in the future. GCMs use equations of motion as a numerical weather prediction (NWP) model, with the purpose of numerically simulating changes in the climate as a result of slow changes in some boundary conditions (such as the solar constant) or physical parameters (such as the concentration of greenhouse gases). The model focuses on each grid cell and the transfer of energy between grid cells. Once the simulation is calculated, a number of climate patterns can be determined; from ocean and wind currents to patterns in precipitation and evaporation rates that affect, for example, lake levels and crop plant growth. The GCMs are run in a number of specialized computer laboratories around the world. We used data from these laboratories in our analyses (Randall et al. 2007).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report was based on the results of 21 global climate models (GCMs), data which are available through an IPCC interface, or directly from the institutions that developed each individual model. The spatial resolution of the GCM results is inappropriate for analyzing the impacts on agriculture as in almost all cases the grid cells measure more than 100 km a side. This is especially a problem in heterogeneous landscapes such as those of the Andes, where, in some places, one cell can cover the entire width of the range.

5.2.1 Downscaling of global climate models to local level

The spatial resolution of the GCM results is inappropriate for analyzing the impacts on agriculture. Downscaling is therefore needed to provide higher-resolution surfaces of expected future climates if the likely impacts of climate change on agriculture are to be forecasted. We used a simple downscaling method (named delta method), based on the sum of interpolated anomalies to high resolution monthly climate surfaces from WorldClim (Hijmans et al. 2005a). The method, basically, produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate (from WorldClim), taking into account the possible bias due to the difference in baselines. The method assumes that changes in climates are only relevant at coarse scales, and that relationships between variables are maintained towards the future (Jarvis and Ramirez 2010).

CIAT downloaded the data from the Earth System Grid (ESG) data portal and applied the downscaling method on over 19 GCMs from the IPCC Fourth Assessment Report (Solomon et al. 2007) for the emission scenario SRES-A2 and for 2 different 30 year running mean periods (i.e. 2010-2039 [2020s/2020], 2040-2069 [2050s/2050]). Each dataset (SRES scenario – GCM – time slice) comprises 4 variables at a monthly time-step (mean, maximum, minimum temperature, and total precipitation), on a spatial resolution of 30 arc-seconds and 2.5 arc-minutes (Jarvis and Ramirez 2010). We produced datasets for Nicaragua, Honduras, El Salvador and Guatemala.

5.2.2 Prediction of future climate (2020s and 2050s)

After downscaling the global climate models to the local level we generated 19 bioclimatic variables from current and future (2020s, 2050s) climate data and extracted climate characteristics for the entire study area and for selected sample sites for the vulnerability analysis. The extraction includes a general description of the current and future distribution of rainfall and temperature patterns, parameters for extreme conditions and climate seasonality. In order to address uncertainty of Global Climate Models (GCM) we used the full ensemble of available models from IPCC Fourth Assessment Report and calculated variability between models.

5.3 Ground-proofing and sampling design

To understand maize and beans production areas in Nicaragua, Honduras, El Salvador and Guatemala, we started with data compilation and a literature review on crop bio-physical information, geographical base layers (topography, elevation models, land-use, infrastructure), abiotic components such as soil and historical climate data, agricultural production data (harvesting areas, yields) and previous studies conducted in Nicaragua, Honduras, El Salvador and Guatemala. These data were used to establish ground proofing of current crop production areas and were also used to calibrate crop models.

Table 2: From the literature compiled data for Nicaragua

Nicaragua	Data description
MAGFOR (Ministerio Agropecuario y Forestal), INTA (Instituto Nicaragüense de Tecnología) Agropecuaria).2004. Cultivando frijol con menos riesgos. Managua, NI. 43 p.	Agronomic management
IICA, Proyecto Red SICTA. 2008. Guía de identificación y manejo integrado de enfermedades de frijol de Centro América. Managua, NI. 38 p.	Pest and disease management
IICA, Proyecto Red SICTA. 2010. Guía técnica para la producción artesanal de semilla de frijol. Estelí, NI. 32 p.	Agronomic management
NICAEXPORT (Centro de Promoción de Exportaciones).2007. Estudio de Inteligencia de mercados. Managua, NI. 88 p.	Markets for exportation
INTA (Instituto Nicaragüense de Tecnología Agropecuaria). Informe anual 2001. Resultados de generación y validaciones de la región de las Segovias. Nicaragua. [on line] http://www.funica.org.ni/docs/gran_basic_14.pdf	Improved variety
IICA, Proyecto Red SICTA. 2009. Guía técnica para el cultivo de frijol. Managua, NI. 28 p.	Agronomic management
SRTM - International Center for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.	Elevation model (30 arc-seconds resolution) for Nicaragua
MAGFOR (Ministerio Agropecuario y Forestal), INETER (Instituto Nicaragüense de Recursos Territoriales). 2010. Compendio de mapas: uso potencial de la tierra. Managua, NI.	Soils, protected areas, forest areas Land-use data map-scale 1:50.000
Global Land Cover 2000 database. European Commission, Joint Research Centre, 2003. http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php	Global land cover for Nicaragua
Common Beans Atlas for Nicaragua online: https://www.msu.edu/~bernsten/beanatlas/Country%20Pages--withGIS/Nicaragua/1.Nicaragua.Index.Page.htm	Bean Growing Environments (GIS-based dot maps)

Table 3: From the literature compiled data for Honduras

Honduras	Data description
SAG (Secretaría de Agricultura y Ganadería), FHIA (Fundación Hondureña de investigación Agrícola). 2006. Condiciones de fertilización de suelo en zonas productoras de granos básicos de Honduras y recomendaciones de fertilidad. Cortés, HU. 50 p.	Agronomic management
SAG (Secretaría de Agricultura y Ganadería), DICTA. 2004. Manual técnico para uso de empresas privadas, consultores individuales y productores. Matagalpa, HU. 37 p.	Agronomic management
SRTM - International Center for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.	Elevation model (30 arc-seconds resolution) for Honduras
Global Land Cover 2000 database. European Commission, Joint Research Centre, 2003. http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php	Global land cover for Honduras
Common Beans Atlas for Honduras online: https://www.msu.edu/~bernsten/beanatlas/Country%20Pages--withGIS/Honduras/1.Honduras.Index.Page.htm	Bean Growing Environments (GIS-based dot maps)

Table 4: From the literature compiled data for El Salvador

El Salvador	Data description
MAG (Ministerio de Agricultura y Ganadería), CENTA (Centro Nacional de Tecnología Agropecuaria y Forestal). 2002. Boletín Informático No.2. CENTA 2000, variedad de frijol. San Salvador. SS. 21 p.	Improved variety
MAG (Ministerio de agricultura y Ganadería, CENTA (Centro Nacional de Tecnología Agropecuaria y Forestal). 2002. Guía técnica para el manejo de variedades de frijol. San Salvador. SS. 24 p.	Agronomic management
SRTM - International Center for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.	Elevation model (30 arc-seconds resolution) for El Salvador
Global Land Cover 2000 database. European Commission, Joint Research Centre, 2003. http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php	Global land cover for El Salvador
Common Beans Atlas for El Salvador online: https://www.msu.edu/~bernsten/beanatlas/Country%20Pages--withGIS/El%20Salvador/1.ElSalvador.Index.Page.htm	Bean Growing Environments (GIS-based dot maps)

Table 5: From the literature compiled data for Guatemala

Guatemala	Data description
IICA, Proyecto Red SICTA. 2008. Guía de exportación de frijol negro a Guatemala. Managua, NI. 19 p.	Markets for exportation
IICA, Proyecto Red SICTA. ICTA. 2010. Guía de exportación de frijol negro a Guatemala. Chiquimula, GU. 9 p.	Markets for exportation
IICA, Proyecto Red SICTA. 2008. Guía de identificación y manejo integrado de enfermedades de frijol de Centro América. Managua, NI. 38 p.	Pest and disease management
Universidad del Valle de Guatemala. 2010. Mapas de uso de la tierra. Guatemala, GU.	Land use data
SRTM - International Center for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.	Elevation model (30 arc-seconds resolution) for Guatemala
Global Land Cover 2000 database. European Commission, Joint Research Centre, 2003. http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php	Global land cover for Guatemala
Common Beans Atlas for Guatemala online: **https://www.msu.edu/~bernsten/beanatlas/Country%20Pages--withGIS/Guatemala/1.Guatemala.Index.Page.htm**	Bean Growing Environments (GIS-based dot maps)

5.3.1 Climate cluster

To evaluate the distribution of similar climate patterns within the study area, we used statistical cluster analysis to assess a set of objects (bioclimatic variables on a 5- kilometer point-raster) into groups (called clusters) so that objects in the same cluster are more similar to each other than to those in other clusters. For the cluster-analysis, we used bioclimatic variables (Bios), as initially derived from monthly temperature and rainfall values of current climate, in order to generate more biologically meaningful variables. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters) (Hijmans et al. 2005a). See Table 6 for a complete list of variables used.

In order to carry out a cluster-analysis with 19 bioclimatic variables, we conducted the following steps: (1) we performed a Principal Component Analysis (PCA) to reduce the dimensionality of the original data (Bio1 – Bio19) to a small number of dimensions (new variables) while losing as little information as possible. The new variables (called principal components or factors), which are independent of each other, are a linear combination of the original variables and retain those characteristics of the original data set that contribute most to its variance. As there is no definite rule on the number of principal components that must be retained, we used a number of variables that explains at least 90% of the original total variance to ensure the cumulative proportion. (2) Each selected PCA component was then weighted by the value of the portion of variance explained by each component to reflect the importance of the new calculated values. (3) Based on the values obtained in the previous step, we performed a cluster analysis to generate groups with as much similarity as possible using the Euclidean distance as a measure of similarity. (4) To determine the number of selected groups, we used the statistical method Calinski-Harabasz-pseudo-F-index.

Table 6: Bioclimatic variables used for the cluster analysis

ID	Variable name	Unit
Bio1	Annual mean temperature	°C
Bio2	Mean diurnal temperature range	°C
Bio3	Isothermality N/A	N/A
Bio4	Temperature seasonality (standard deviation)	°C
Bio5	Maximum temperature of warmest month	°C
Bio6	Minimum temperature of coldest month	°C
Bio7	Temperature annual range	°C
Bio8	Mean temperature of wettest quarter	°C
Bio9	Mean temperature of driest quarter	°C
Bio10	Mean temperature of warmest quarter	°C
Bio11	Mean temperature of coldest quarter	°C
Bio12	Annual precipitation	mm
Bio13	Precipitation of wettest month	mm
Bio14	Precipitation of driest month	mm
Bio15	Precipitation seasonality (coefficient of variation)	%
Bio16	Precipitation of wettest quarter	mm
Bio17	Precipitation of driest quarter	mm
Bio18	Precipitation of warmest quarter	mm
Bio19	Precipitation of coldest quarter	mm

In the Köppen climate classification map (Peel et al. 2007) Central America is characterized by three main climate zones (Figure 3).

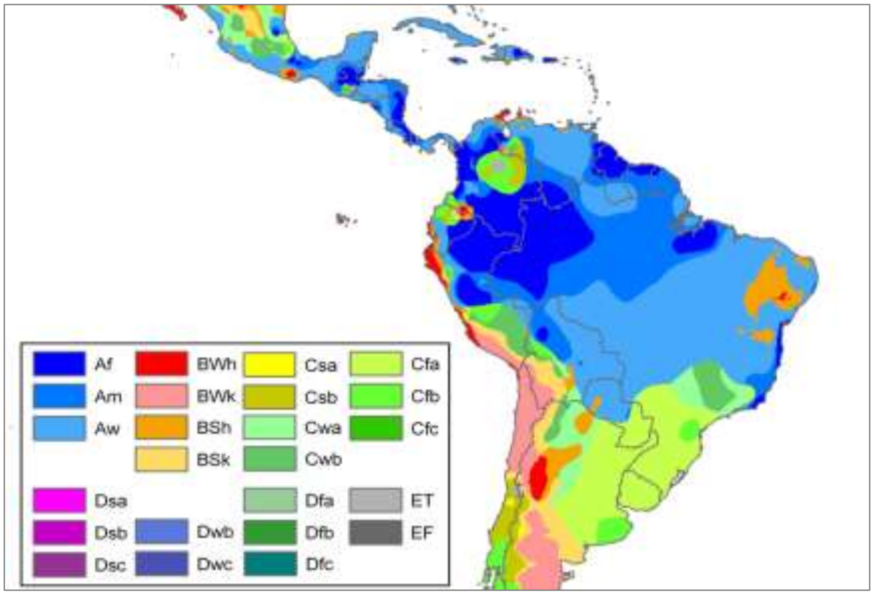


Figure 3: Köppen climate classification map for Central and South America (Köppen 1936, Source: Peel et al. 2007)

The tropical rainforest climate (Af) does not have a dry season, and all months have mean precipitation of at least 60 mm. It is typically hot and wet throughout the year, and rainfall is both heavy and frequent. The tropical monsoon climate (Am) has temperatures above 18°C in every month, and feature wet and dry season. A pronounced dry season is followed by a sustained period of extraordinary rainfall: up to 1,000 mm of precipitation is observed per month for two or more consecutive months. Third, the tropical savanna climate (Aw) features distinct wet and dry seasons of relatively equal duration. Most of the region's annual rainfall is experienced during the wet season and very little precipitation falls during the dry season. Furthermore for Guatemala also a humid subtropical climate (Cwa) and a dry (arid and semiarid) climate (Bw) was characterized by Köppen. The Cwa climate zone is characterized by hot, humid summers and generally mild to cool winters and the Bw climate has less annual precipitation and is also classified as desert climate.

5.3.2 EcoCrop model

To determine potential suitable areas for beans within the study area, we used a spatial model based on the FAO-EcoCrop database (FAO 2000). The basic mechanistic model (EcoCrop) uses environmental ranges as inputs to determine the main niche of a crop and then produces a suitability index (0-100) as output. The model was originally developed by Hijmans et al. (2001) and named EcoCrop. Later the model was implemented in Diva-GIS software (Hijmans et al. 2005b). The model predicts crop climate-suitability where no prior knowledge or data are available. EcoCrop uses minimum, maximum, and mean monthly temperatures, total monthly rainfall, and length of growth period (see EcoCrop model in Figure 4). We calibrated the crop parameters by statistically finding the correct ecological parameters following the method of Ramirez-Villegas et al. (2011) in the FAO database with expert knowledge (maize and bean breeders) gathered from the compiled literature. Based on this information, we generated random evidence sample points to recalculate the environmental factors by dividing them into discrete constant-value ranges, and predict current crop climate-suitability based on the current crop distribution.

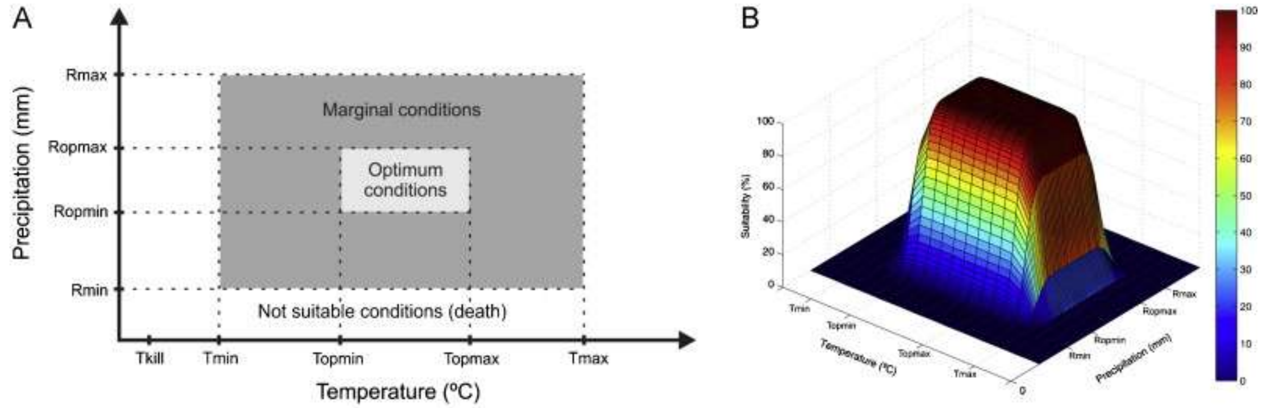


Figure 4: Functional principle of the EcoCrop model

5.4 Prediction of future crop growth and production

To predict changes in crop physiology and changes in yields caused by climate change, we used the Decision Support for Agro-technology Transfer (DSSAT) as cropping system model. DSSAT is a widely-tested series of simulation models that incorporates detailed understanding of crop physiology, biochemistry, agronomy, and soil science to simulate performance of the main food crops, as well as pastures and fallows (Jones and Thornton 1993, Jones et al. 2003). Besides other parameters, DSSAT requires daily weather data for the crop development cycle. MarkSim was selected and used to simulate daily weather data for the study area (Hartkamp et al. 2003).

5.4.1 DSSAT - Decision Support System for Agro-technology Transfer

In order to predict future crop growth and production, the DSSAT model uses the detailed understanding of crop biochemistry, physiology and agronomy to simulate crop water balance, photosynthesis, growth and development on a daily time step. It requires input of the soil water characteristics and genetic coefficients of the crop cultivar, plus any relevant agronomic inputs such as fertilizer and irrigation, together with the daily maximum and minimum temperature, rainfall and solar radiation (see DSSAT Scheme in Figure 5).

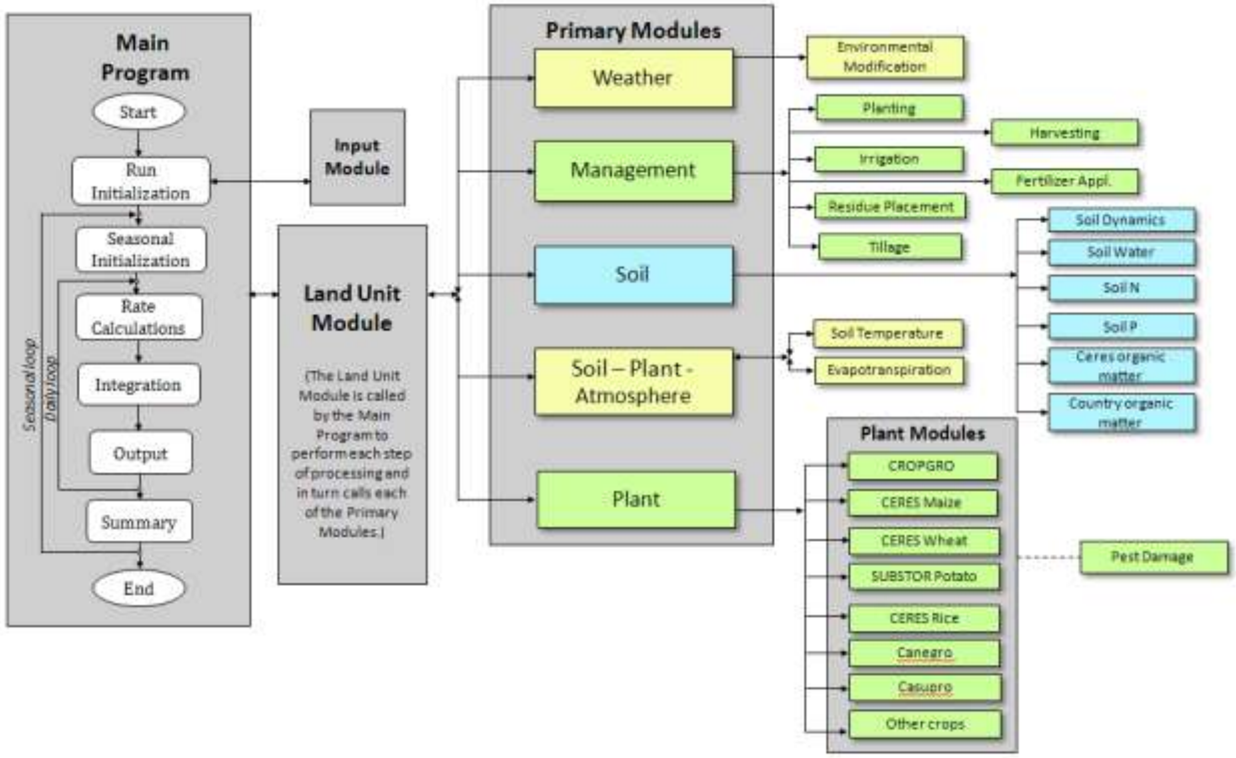


Figure 5: Overview of the components and modular structure of DSSAT

In the tropics there is a lack of good daily weather data. Weather stations are rare and far apart, and the length and reliability of the record is sometimes not as required. Interpolated monthly mean climate surfaces are of great use to some other applications but fall short where daily weather is required, as in DSSAT. Also, future predictions as output of Global Climate Models (GCM) are only available as monthly mean at the moment.

MarkSim (Jones and Thornton, 1993) is a third-order Markov daily weather generator that obtains parameters from climate clusters of interpolated surfaces. This generator was specifically developed to generate precipitation data for tropical regions. MarkSim is designed to fill the gap by simulating daily rainfall from monthly climate surfaces. The weather generator MarkSim interpolates a multi-dimensional weather surface based on observed data from 9,200 stations in the tropics and subtropics. The routine uses these data in a third-order Markov model to generate daily data of maximum and minimum temperatures, rainfall and solar radiation for as many years as the user requires.

In order to process the high amount of daily weather data necessary for the study area (99 x daily weather data for current, 2*19 models (2020s, 2050s) for each pixel (5- km resolution) in 4 countries, we needed to automate this step by batch-processing. We therefore modified the code of MarkSim 1.0 to MarkSim 1.2 as a compiled executable file. The code has been changed to remove the annoyance of MarkSim 1.0 producing occasional data with tmax=tmin. When this occurs, MarkSim 1.2 substitutes the values tmax and tmin with the mean maximum and the mean minimum for the month within which the day in question occurs (see Figure 6).

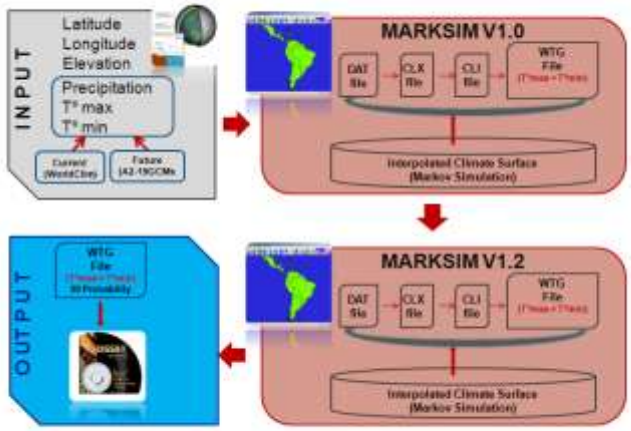


Figure 6: Changed MarkSim workflow to make it executable in a batch-processing

Considering that for the 5- km resolution (2.5 arc-minutes) we would have to generate 99 MarkSim samples for 17,800 points within the study area and then run DSSAT for 8 trials for each point with climate input data for current climate, 19 GCMs for 2020 and 19 for 2050, in total 39 climate inputs for MarkSIM results in more than 549 billion DSSAT simulations. Taking into account that an average processor takes one and a half minutes for each batch-processed simulation, it would still take a lot more time as available in this project. We therefore decided to use average climate from 19 GCM ensembles as input data to MarkSim in a first step and run the model again after selecting areas for vulnerability analysis (identified through socio-economic analysis of focus areas).

We took into consideration to run the entire modelling on available server-clusters with a modified DSSAT application for an open-source environment, but could only achieve the goal partially by running maize with previous processed daily climate data by using the modified MarkSim batch-processing.

For future large area simulations, we would recommend transact DSSAT on a server-cluster, possibly using cloud-computing, to gain more flexibility on trial-runs, resolution and the possibility to use GCM ensembles for various climate scenarios.

5.4.2 Uncertainty using GCM for future yield prediction with DSSAT

Availability of high-quality and less uncertain climate predictions is less likely at the current state of science. GCMs do not provide realistic representations of climate conditions in a particular site, but rather provide estimated conditions for a large scale. Ramirez-Villegas and Challinor (2012) state that climate model outputs cannot be inputted directly into plot-scale agriculture models, but support the idea that higher resolution climate modelling largely improves results and can be adequately used if: (1) scales between models are matched, (2) skill of models is assessed and ways to create robust model ensembles are defined, (3) uncertainty and models spread are quantified in a robust way, and (4) decision-making in the context of uncertainty is fully understood (Ramirez-Villegas and Challinor 2012).

Therefore it is very important to address the uncertainty of climate prediction models used. Jarvis et al. (2012) state that impact assessment methods are sensitive to uncertainties and assessing the climate-inherent uncertainty in climate change impact assessment projects explicitly entails the usage of different GCMs.

To consider climate-inherent uncertainty, we used 19 different GCMs in our study in a second run of the DSSAT model (as mentioned above). In this run, we expanded a 15- km buffer around municipalities where we conducted the participatory workshops for socio-economic impact assessment during the field work and used the same (downscaled) 5- km resolution for each model. To account for uncertainty, we plotted standard deviation, and the individual GCM predicted changes we used as input data for DSSAT (via MarkSim). Producing 19 yield predictions for the future with DSSAT (for the 2020s and 2050s), we calculated the change of yield (compared to current yield results using climate baseline WorldClim) for each GCM. As final maps to show uncertainty of DSSAT modelling using future climate predictions, we produced, on pixel basis: (i) the change of the ensemble mean, (ii) the percentile rank using first quartile (25^{th} percentile) and third quartile (75^{th} percentile), and (iii) the agreement among 19 DSSAT models calculated as percentage of models predicting changes in the same direction as the average of all models at a given location.

5.4.3 Beans field trials to calibrate DSSAT model

In addition, field trials (see example site in Figure 7) with recently introduced bean varieties showing higher drought tolerance were conducted in order to obtain calibration data sets for more precise predictions in a second run of DSSAT. In the field trials we established 10 varieties in 5 countries (Nicaragua, Guatemala, Honduras, El Salvador and Costa Rica) in order to obtain physiological information of each of the varieties to calibrate the DSSAT software. The calibrated varieties were run for the sites relevant to the project. The used varieties and their origin are “INTA Fuerte Sequia”, “INTA Rojo”, and “Tío Canela 75” originating from Nicaragua; “ICTA Ostua” and “ICTA Ligero” originating from Guatemala; “BAT 304” originating from Costa Rica; and “SER 16”, SEN 56”, “NCB 226”, and “SXB 412” originating from CIAT, Colombia. In every country the trials were conducted depending on the available time and resources. All trials were organized as homogeneous as possible to minimize information bias

Figure 7: Example of a field trial (Estelí, Nicaragua)

3.4.4 Predict maize yields with DSSAT

The maize DSSAT model runs were performed at the High Performance Cluster (HPC) of the Global Futures (GF) project hosted at the International Livestock Research Institute (ILRI) in Nairobi. The hardware had been purchased for modeling work for the Global Futures (GF) project, which is dedicated to estimating global impact of climate change on the most important food commodities. Due to the high relevance of the TOR project for the goals of the GF project, access to hardware and input from experts was given. The HP cluster can run 48 parallel DSSAT sessions on 12 computing nodes each having a quad core processor. After the climate data on current conditions and future predictions (ensembles of 19 models for emission scenario A2 for 2020 and 2050) for the four countries had been generated by CIAT in DSSAT format, they were transferred via ftp to the cluster, and a member of the GF project at IFPRI performed the runs. Results were then shared and utilized for the country-wide and focus area analyses.

For the model runs themselves the same two generic soil types selected and utilized by CIAT to represent good (good case scenario) and poor soil (worst case scenario) conditions were utilized, as well as an adjusted improved maize variety from the DSSAT database which had been utilized previously in the project region.

5.5 Identification of impact focus areas

To characterize the different adaptation strategies needed, we used the quantified impact on maize and beans production yields analyzed by DSSAT and identified focus areas for different adaptation scenarios across countries.

5.5.1 Areas where maize-bean systems are no longer an option – Hot-Spots

Areas where current production volume is declining by more than 50% in 2020 or 2050 (for maize or beans), farmers need a focus on diversification of their livelihoods. The actual grown crop might not be economically feasible anymore for this area in the future and strategies need to take into account diversification to other crops as currently produced, increased off-farm income and exit from the agriculture sector

5.5.2 Areas where maize-bean systems can be adapted – Adaptation Areas

In these areas yield loss for the future is between 25% and up to 50% of current yields (kg/ha) of at least one of the crops (maize or beans). Farmers in these areas will face decreasing production predicted for 2020 and on a long-term even more drastic until 2050. Through technical and agronomic management adjustments the crop can still be grown in these areas. Furthermore, through early adaptation strategies there might be even an opportunity for certain sites to gain from climate change on a short-term by achieving a competitive advantage on fast implementation of measures. But they need concrete adaptation strategies for their existing maize and beans production systems to start today with the implementation of measures to ensure food- and income security for the future. Further future climate change impacts can be alleviated by starting on mitigation measures as well

5.5.3 Areas where maize-bean systems will be established – Pressure Areas

So-called "pressure areas" are locations with conditions favorable for maize or beans production in the future. These sites are under threat through possible migration and mostly located in forest areas and natural reserves, and are close to the current agriculture frontier. The identification of pressure areas is highly important for national and regional decision makers to protect these areas. Pressure areas were not shown to farmers in field workshops to avoid misuse of information.

We followed the below described steps to identify hot-spots-, adaptation- and pressure areas in the four countries:

- We used the complied information on beans and maize as basic information where both crops in each country are produced. We then calculated the Kernel density (Silverman 1986) for these sites to obtain most important production areas as polygons with high density of registered production sites.
- Land use is an indicator for availability of land for agricultural production. To conserve forest from future agriculture migration different land-use categories need to be set as restrictions for land-use change. We used different land-use layers for each country depending on available data resources from data compilation. In some countries we could obtain national land-use layers, e.g. in 1:50,000 map-scales, in others we used the Global land cover with 30 seconds grid (around 1km) resolution (Global land cover 2000 database).
- We verified outcomes of both crop models (EcoCrop and DSSAT) for compliance of results.
- Next we mapped absolute (kg/ha loss) and relative yield (% yield loss) change within potential productions areas
- And detected patterns of adjoining (5 kilometer) pixels with the same magnitude of impact
- Finally resulting hot-spots were classified as polygons in the 3 categories

5.6 Prediction of socio-economic impacts and focus area vulnerability analyses

In order to gather the necessary information to estimate the vulnerability index at the selected hot-spot level field interventions were developed in two stages. The first stage implemented Focal Group assessments at each focus area with the main objective of collecting information on four general aspects of the focus area: main agriculture activities and trends, main sources of food and income, stock of types of capital and a general perception of communal future strengths and threats. The information was used to characterize the focus areas and to adjust the questionnaire to be used in the survey. The second stage comprised a survey at farm level which was carried out to collect more detailed information on the household level in each focus area.

Both instruments were carried out during October 2011 and February 2012 once the focus areas for beans and maize were identified through the bio-physical models of potential impacts on productivity. All the activities were carried out by the CIMMYT and CIAT socio-economic teams with the support of national collaborators in each of the four countries. Table 7 present the chronogram of field activities as well as the name and institution of the national collaborator

Table 7: Chronogram of field activities and national collaborators

Activity	Country/Focus areas	Date	National Collaborator Name/Institution
Focal Groups (3 in Nicaragua and 4 in El Salvador and Honduras)	Nicaragua: La Hormiga, San Dionisio y Totogalpa	December 13th – 16th 2011	Edwin Vásquez (INTA) Félix Miranda (CRS) Edwin Lopez (Alcaldía de Totogalpa)
	Honduras: Alauca, Jamastran, Orica y Yorito.	November 25th - December 6th 2011	Danilo Escoto (DICTA)
	El Salvador: Candelaria, Las Mesas, San Felipe y San Rafael	November 28th – 30th 2011	Aldemaro Clara (CENTA)
Survey test	Nicaragua	November 12th-17th(*)	
Field survey / questionnaire (120 in each country)	Nicaragua: La Hormiga, San Dionisio y Totogalpa	February 21th - March 15th 2012	Edwin Vásquez (INTA) Félix Miranda (CRS) Edwin López (Alcaldía de Totogalpa)
	Honduras: Alauca, Jamastran, Orica.	February 15th – March 12th 2012	Danilo Escoto (DICTA)
	El Salvador: Candelaria, San Felipe y San Rafael	February 8th – March 10th 2012	Aldemaro Clara (CENTA)
	Guatemala: Ipala San Manuel de Chaparron Patzicia	February 26th – March 20th 2012	Julio Cesar Villa Toro (ICTA)

As a first step in assessing vulnerability, we estimated the impact of climate change on maize and bean productivity. This was done at the aggregate level (at the department [the equivalent of a state in Central America] and country level), and at a disaggregate level (focus area and/or household level)

5.6.1 Impact on yield distribution at the aggregate level

Assuming a normal distribution for maize and beans productivity (Just and Weninger 1999), we estimated the yield distribution for the base year (2000) and for the target years (2020s) at the country level as the weighted average of the yields at the department level with the weights being the importance of the area cropped with beans and maize in the department:

$$Y_i = \sum_j \alpha_{ij} * Y_{ij}$$

Where Y_{ij} is a random variable normally distributed representing maize-beans yield at the department j; α_{ij} is the relative importance of the maize-beans area cropped in department j; and Y_i, is a random variable representing maize-beans yield at the country level.

Potential yield loss was estimated using

$$YL_i = \left(Y_{i20} - Y_{i00}\right) / Y_{i00}$$

where YL_i, represents the change in maize-beans productivity by 2020 relative to 2000.

To estimate yield distribution and potential yield loss, a Monte Carlo simulation was run using the @Risk v. 5.7 software program (Palisade).

5.6.2 Impact at the disaggregate level

Out of four focus areas selected in each country for the implementation of the Focal Groups, three of them were selected for the implementation of surveys at farm level. The selection was made taking into account representativeness in terms of production of maize or beans, as well as the availability of resources and logistical support. The implementation of surveys was coordinated by the CIMMYT-CIAT team and its implementation in the field was conducted by national teams previously trained for this purpose. A head of national teams was in charge of the data compilation.

Surveys were applied to 40 producers of maize or beans in a semi-random approach for a total of 480 observations. Semi-random means that data collector went to villages within the focus areas and questioned producers as they found them. Table 7 presents a list of focus areas where the surveys were conducted in each country as well as the name of the Coordinator of the national team and the institution to which it belongs.

The survey information is primarily aimed at the estimation of the vulnerability index of the household, which is composed of three composite indices: 1) the level of exposure of the maize-beans cropping system to changes caused by climate change, 2) The level of sensitivity of the household to the change in maize-beans production, and 3) the resilience or adaptive capacity of the household. Once estimated the different components and the vulnerability index of the household “i” belonging to the focus area “j” (Vij = high, medium, low), each focus area “j” was characterized by the frequency of occurrence of household within the different classes of vulnerability.

5.7 Development of local adaptation strategies

During the field interventions, especially during focal group discussions, we tried to generate ideas from participants as to which degree adaptation would be possible and how this adaptation activities would look like. Ideas where collected and incorporated into our overall strategy for the project region.

6 Results

6.1 Downscaled global and regional climate models

After downscaling of global climate models to local level we extracted 19 bioclimatic variables from current and future (2020s, 2050s) climate data and generated a general climate change description for each country in the study area. As we can see in Figure 8, Figure 9, Figure 10, and Figure 11, precipitation (bars in the chart) will be low or even lower in the first 4 months of the year which is the typical dry season in the region. For the month of May (planting time) we predict no significant changes in precipitation although there is a tendency towards reduction in all 4 countries. For the important month of June (establishment and early development of maize) we see a reduction of rainfall followed by a more severe and extended dry spell, the so called “canicula” in July and August into September putting the first planting season “la primera” under serious threat. For the second planting season “la postrera”, which is the more important season for beans, there will be less precipitation for the planting month September. Together with the deficit from the prolonged canicula climate conditions might be very unfavorable for the establishment of beans especially in areas with sandy soils. During the month of October and November there is a risk of increased rainfall causing flooding similar to the ones experienced in 2011 with huge damages on agricultural production and infrastructure in Central America. The water deficit is further increased through the increase of the minimum, mean and maximum temperature (see lines in charts). Higher temperatures cause higher evapotranspiration rates of plants triggering soil water deficits and heat stresses. High temperature stresses especially high night time temperatures (> 18 °C) and drought conditions have substantial effects on biomass production and reproductive stages of maize and bean plants. We can resume that in the future there will be higher mean temperatures (around +1°C by 2020 and + 2°C by 2050), higher minimum and maximum temperatures and an increasing water deficit due to less precipitation and higher evapotranspiration. Since a statistical test (Tukey 1977) for downscaled climate data for the region detected 2 models significantly different from others (“bccr_bcm2_0” and “ncar_pcm1” for 2020 and “ncar_pcm1” for 2050 data), the respective models were not included in results of climate characteristics and first DSSAT-analysis-run.

6.2 Climate characteristics and predicted future changes

6.2.1 Nicaragua

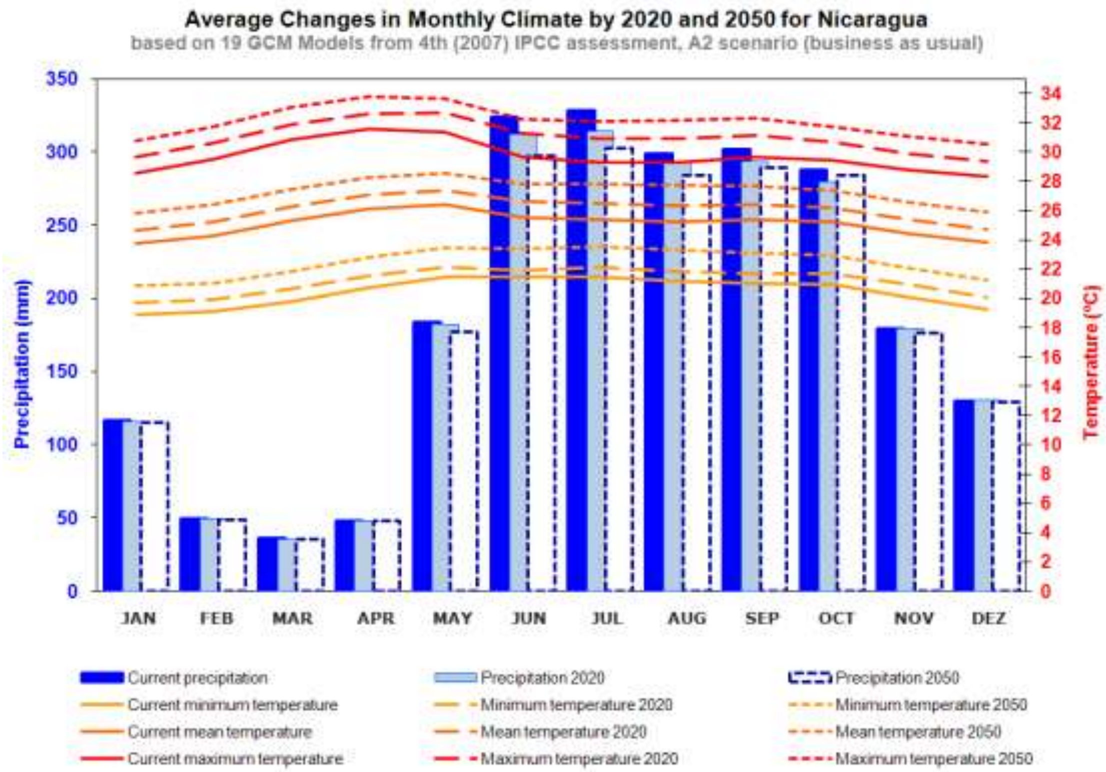


Figure 8: Climate change predictions for Nicaragua

General climatic characteristics

- Rainfall decreases from 2283 to 2186 mm in 2050, passing through 2234 mm in 2020
- Temperatures increase and the average increase is 2.2 ºC, passing through an increment of 1 ºC in 2020
- The mean daily temperature range increases from 9.2 ºC to 9.6 ºC in 2050
- The maximum number of cumulative dry months keeps constant in 4 months

Extreme conditions

- The maximum temperature of the year increases from 31.7 ºC to 34.1 ºC, while the warmest quarter gets hotter by 2.2 ºC in 2050
- The minimum temperature of the year increases from 18.9 ºC to 20.8 ºC, while the coldest quarter gets hotter by 2.1 ºC in 2050
- The wettest month gets drier, with 371 mm instead of 382 mm of rain, while the wettest quarter gets drier by 47 mm in 2050
- The driest month gets drier, with 34 mm instead of 35 mm, while the driest quarter gets drier by 1 mm in 2050

Climate seasonality

- Overall this climate becomes more seasonal in terms of variability through the year in temperature and more seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 2.5%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 7.9%
- Precipitation predictions were uniform between models and thus no outliers were detected

6.2.2 Honduras

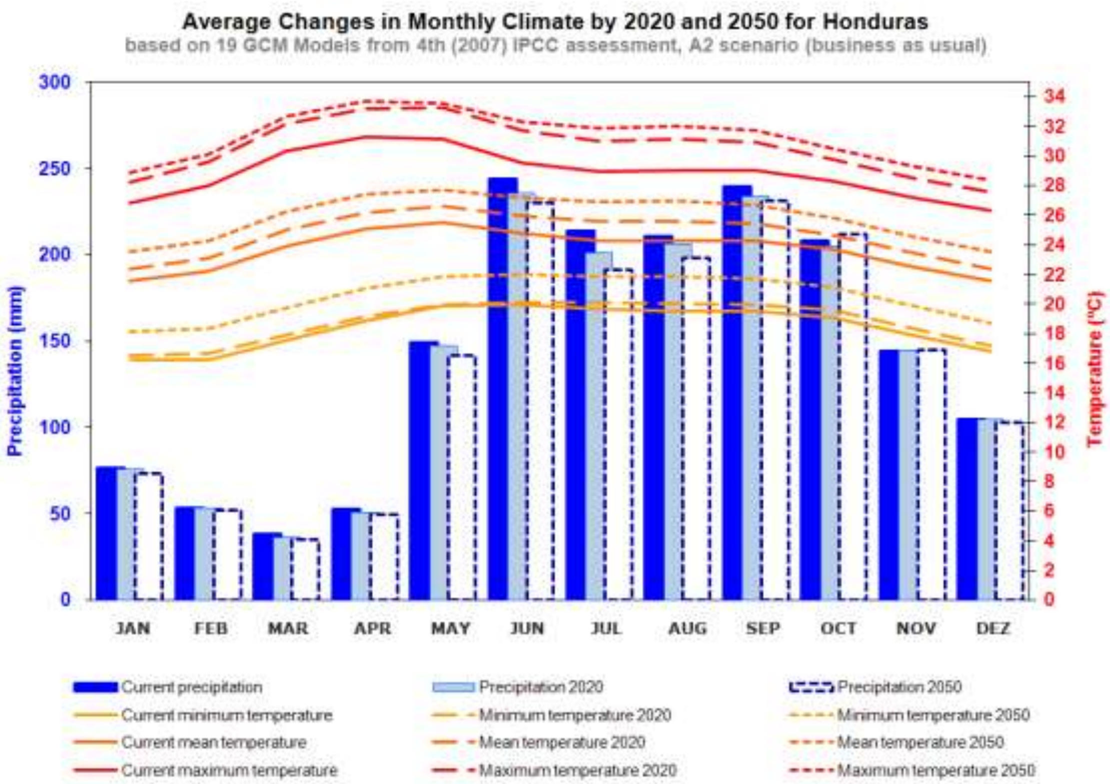


Figure 9: Climate change predictions for Honduras

General climatic characteristics

- Rainfall decreases from 1733 mm to 1653 mm in 2050, passing through 1693 mm in 2020
- Temperatures increase and the average increase is 2.3 ºC, passing through an increment of 1.1 ºC in 2020
- The mean daily temperature range increases from 10.4 ºC to 10.7 ºC in 2050
- The maximum number of cumulative dry months decreases from 5 months to 4 months

Extreme conditions

- The maximum temperature of the year increases from 31.5 ºC to 34 ºC, while the warmest quarter gets hotter by 2.4 ºC in 2050
- The minimum temperature of the year increases from 16.2 ºC to 18.1 ºC, while the coldest quarter gets hotter by 2 ºC in 2050
- The wettest month gets drier, with 272 mm instead of 275 mm, while the wettest quarter gets drier by 24 mm in 2050
- The driest month gets drier, with 30 mm instead of 35 mm, while the driest quarter gets drier by 9 mm in 2050

Climate seasonality

- Overall this climate becomes more seasonal in terms of variability throughout the year in temperature and more seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 3%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 9.2%
- Precipitation predictions were uniform between models and thus no outliers were detected

6.2.3 El Salvador

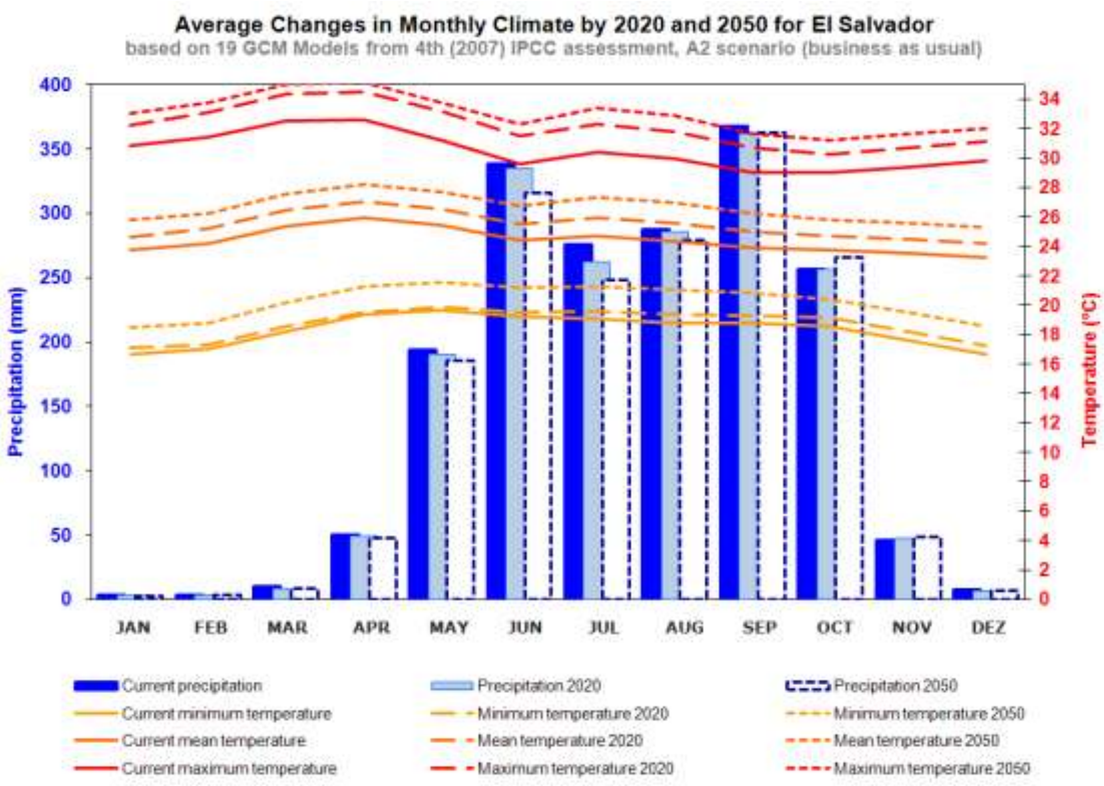


Figure 10: Climate change predictions for El Salvador

General climatic characteristics

- Rainfall decreases from 1839 mm to 1773 mm in 2050, passing through 1810 mm in 2020
- Temperatures increase and the average increase is 2.2 ºC, passing through an increment of 1.1 ºC in 2020
- The mean daily temperature range increases from 12.2 ºC to 12.7 ºC in 2050
- The maximum number of cumulative dry months decreases from 6 months to 5 months

Extreme conditions

- The maximum temperature of the year increases from 32.7 ºC to 35.3 ºC, while the warmest quarter gets hotter by 2.3 ºC in 2050
- The minimum temperature of the year increases from 16.6 ºC to 18.4 ºC, while the coldest quarter gets hotter by 2 ºC in 2050
- The wettest month gets drier with 371 mm instead of 373 mm, while the wettest quarter gets drier by 18 mm in 2050
- The driest month gets drier with 2 mm instead of 3 mm, while the driest quarter gets drier by 3 mm in 2050

Climate seasonality

- Overall this climate becomes more seasonal in terms of variability through the year in temperature and more seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 2.6%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 9.1%
- Precipitation predictions were uniform between models and thus no outliers were detected

6.2.4 Guatemala

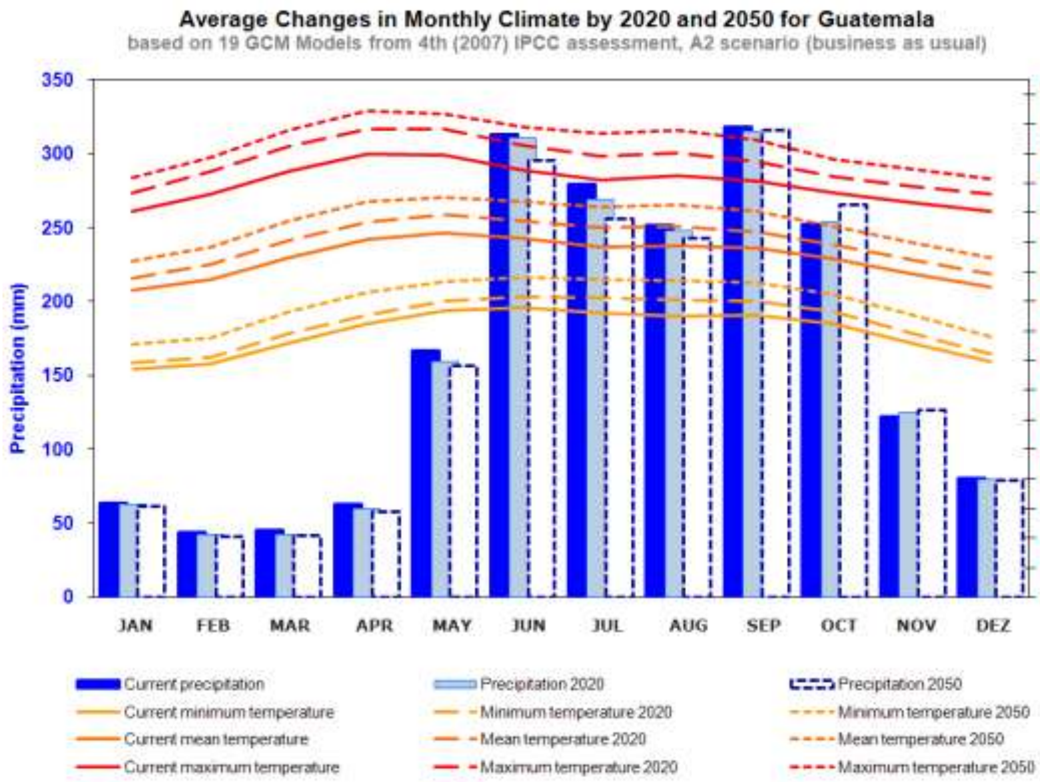


Figure 11: Climate change predictions for Guatemala

General climatic characteristics

- Rainfall decreases from 1998 mm to 1938 mm in 2050, passing through 1968 mm in 2020
- Temperatures increase and the average increase is 2.4 ºC, passing through an increment of 1.1 ºC in 2020
- The mean daily temperature range increases from 10.1 ºC to 10.8 ºC in 2050
- The maximum number of cumulative dry months decreases from 5 months to 4 months

Extreme conditions

- The maximum temperature of the year increases from 30.2 ºC to 33.2 ºC, while the warmest quarter gets hotter by 2.6 ºC in 2050
- The minimum temperature of the year increases from 15.4 ºC to 17 ºC, while the coldest quarter gets hotter by 2 ºC in 2050
- The wettest month gets wetter with 347 mm instead of 345 mm, while the wettest quarter gets drier by 9 mm in 2050
- The driest month gets drier with 32 mm instead of 37 mm, while the driest quarter gets drier by 11 mm in 2050

Climate seasonality

- Overall this climate becomes more seasonal in terms of variability through the year in temperature and more seasonal in precipitation

Variability between models

- The coefficient of variation of temperature predictions between models is 3.2%
- Temperature predictions were uniform between models and thus no outliers were detected
- The coefficient of variation of precipitation predictions between models is 7.9%
- Precipitation predictions were uniform between models and thus no outliers were detected

6.3 Climate cluster and potential areas of bean and maize with EcoCrop

6.3.1 Climate cluster

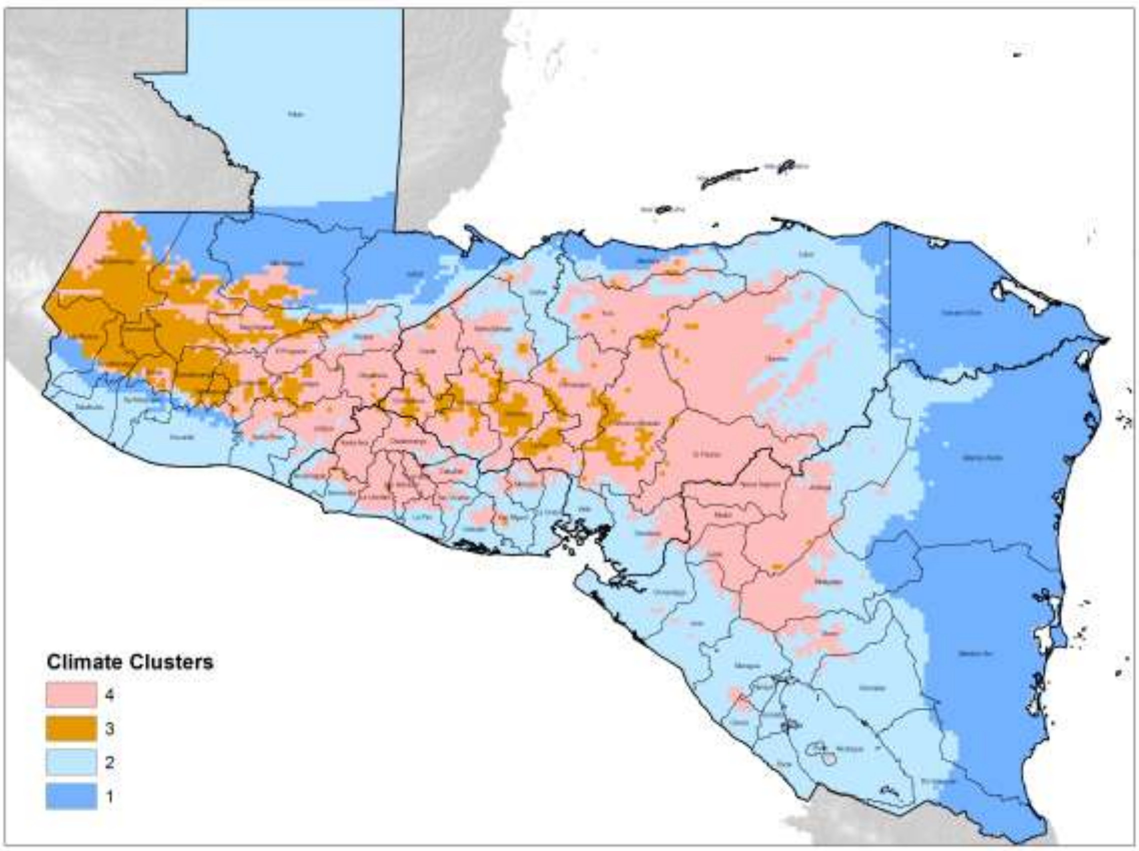


Figure 12: Result of cluster analysis using 19 bioclimatic variables

Results of cluster analysis show that the 4 different clusters match to the climate classification of Köppen. Obtained Cluster 1 is congruent to Af (tropical rainforest climate), Cluster 2 would be Am (tropical monsoon climate), Cluster 3 would be Cwa (humid subtropical climate) and Bw (dry, arid and semiarid climate), and Cluster 4 corresponds to the Aw (tropical savanna climate). We can summarize that the bioclimatic variables used for the following bio-physical and crop physiological methods are confirmed to be adequate for the study area.

6.3.2 Potential suitable areas of beans with EcoCrop

EcoCrop was calibrated to common bean (*Phaseolus vulgaris* L.), taking into account parameters of elevation and climate (temperature and precipitation) as follows:

- Nicaragua: land use map and optimal heights above sea level for cultivating; commonly used as INTA Estelí in Nicaragua, INTA red (IICA 2009), elevation between 100 and 1500 meters.

- Honduras: land use map and optimal heights above sea level for cultivating; commonly used as DICTA 113, DICTA 122, Tio Canela, Don Silvio, y Dorado (DICTA 2004), elevation between 100 and 1500 meters.

- El Salvador: land use map and optimal heights above sea level for cultivating; commonly used as CENTA 2000, CENTA San Andrés y CENTA Pipil (IICA 2008a), elevation between 100 and 1500 meters.

- Guatemala: land use map and optimal heights above sea level for cultivating; commonly used as ICTA Ligero, ICTA Ostúa, ICTA Texel, ICTA Hunapú y ICTA Altense (IICA 2008b), elevation between 100 and 2300 meters.

After calibrating the models experts in each country were consulted to confirm the potential distribution of current suitable areas (Figure 13) in each country before projecting to future climate models (Figure 14 and Figure 15). The following experts confirmed our "current suitability map": Aldemaro Clara (El Salvador), Juan Carlos Rosas (Zamorano, Honduras), Aurelio Llano (Nicaragua), Luis Fernando Aldana (Guatemala), Roger Urbina (Nicaragua).

Results from EcoCrop modeling show that potential climate-suitable areas will decrease for beans in Central America. As EcoCrop only takes into account climate variables as temperature and precipitation ranges of mean values, these results serve only for a first estimate of potential impacts for bean production systems in the region.

In the case of maize suitability according to the outputs of the EcoCrop model will also decrease throughout the region. For Honduras (Figure 16) most of the country area showed slight reductions in suitability as well as some areas where conditions will improve, mainly highland areas where rising temperatures will allow shorter maturity varieties. Some areas in the South East would lose considerably concerning suitability, this area already being in the marginal dry belt.

For Guatemala (Figure 17) most of the country area showed slight reductions in suitability as well as some areas where conditions will improve, mainly highland areas where rising temperatures will allow shorter maturity varieties. A decrease in suitability implies that the monthly rainfall and temperature conditions needed for maize cultivation become more marginal. An increase implies that conditions become more apt for producing maize or other crops. A decrease in rainfall or rising temperatures does not necessarily mean that suitability will decrease. In many areas with high rainfall conditions for maize, cultivation can actually improve as humidity and related pests and diseases diminish. Likewise rising temperatures allow certain crops to be produced in areas were low temperatures reduced suitability before.

With regard to El Salvador and Nicaragua, the EcoCrop model showed no significant changes for maize which is likely due to the wide adaptation of maize to a range of climates. Since EcoCrop takes only climate parameters into account, soil-climate interactions seem to be the important factors to be analyzed. DSSAT which includes soil parameters will therefore highlight these interactions.

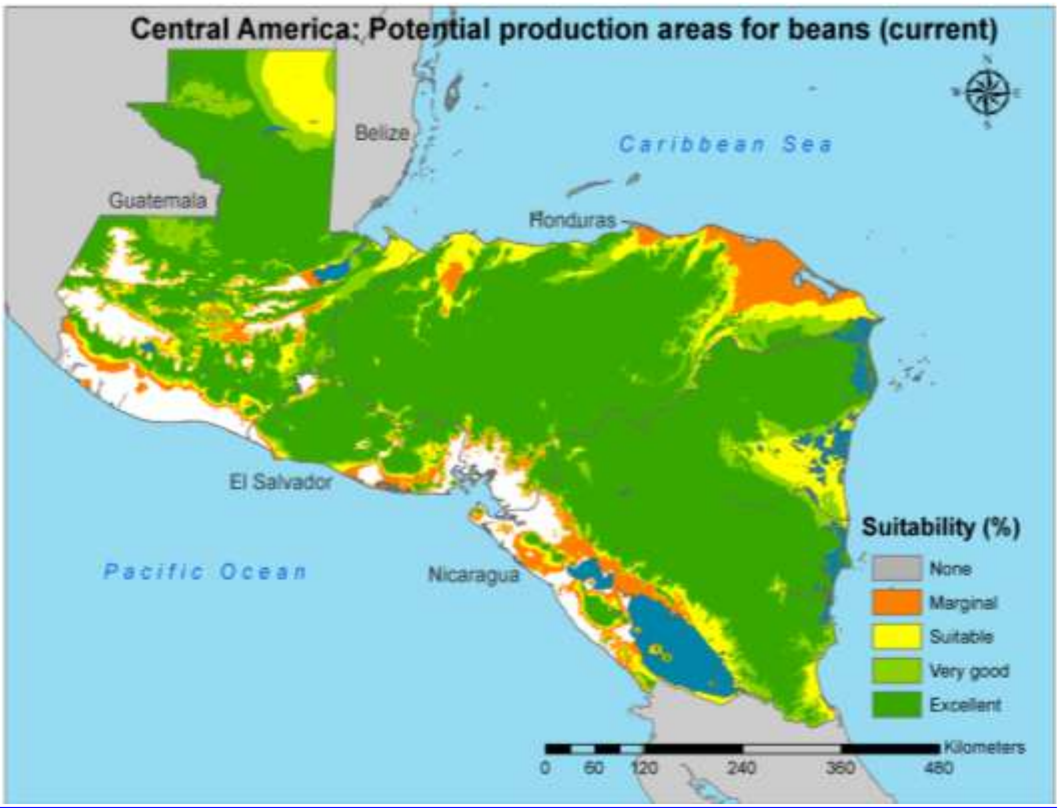


Figure 13: Current potential suitable areas for beans

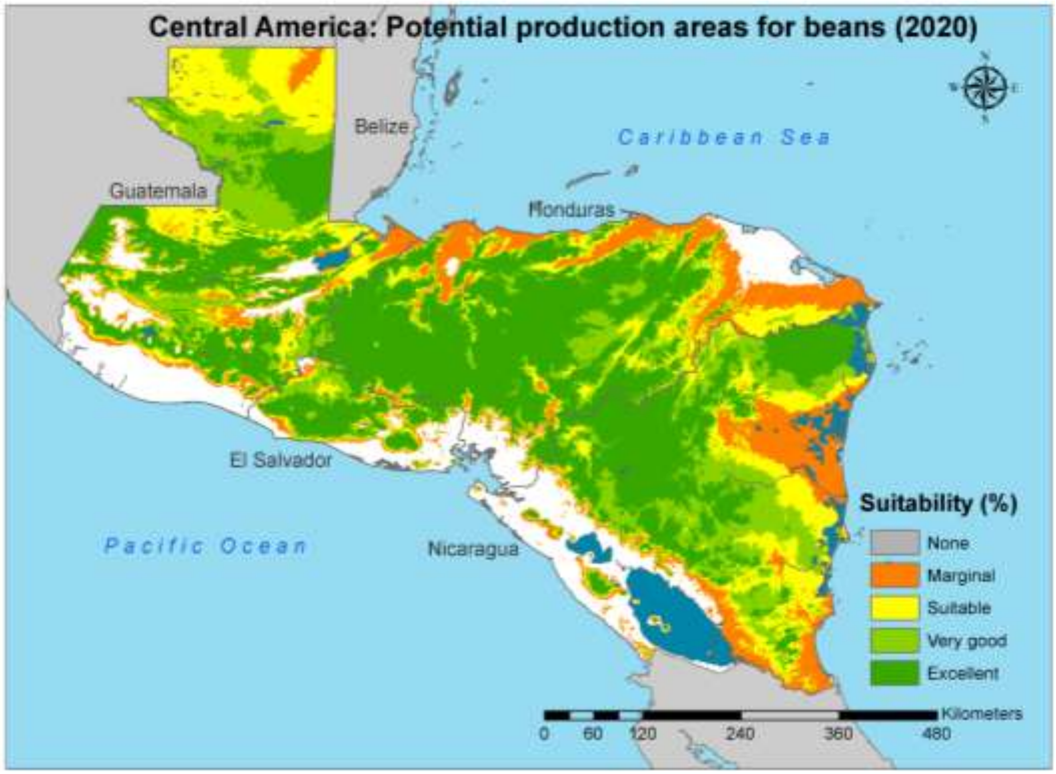


Figure 14: Potential suitable areas for beans by 2020

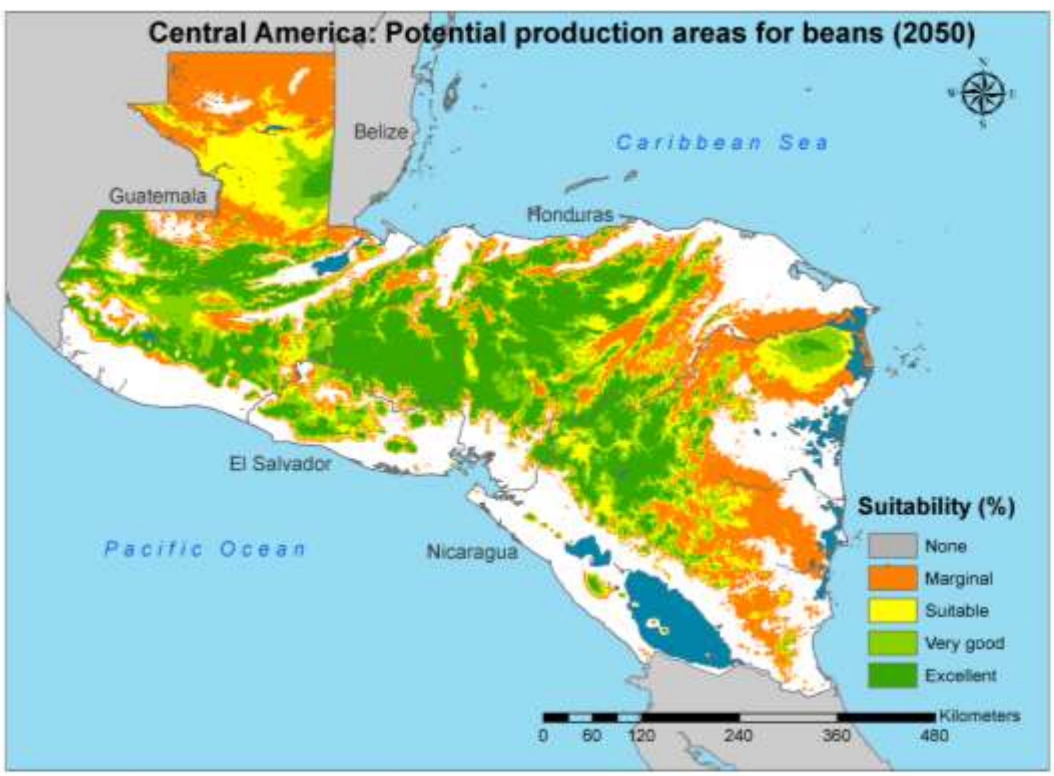


Figure 15: Potential suitable areas for beans by 2050

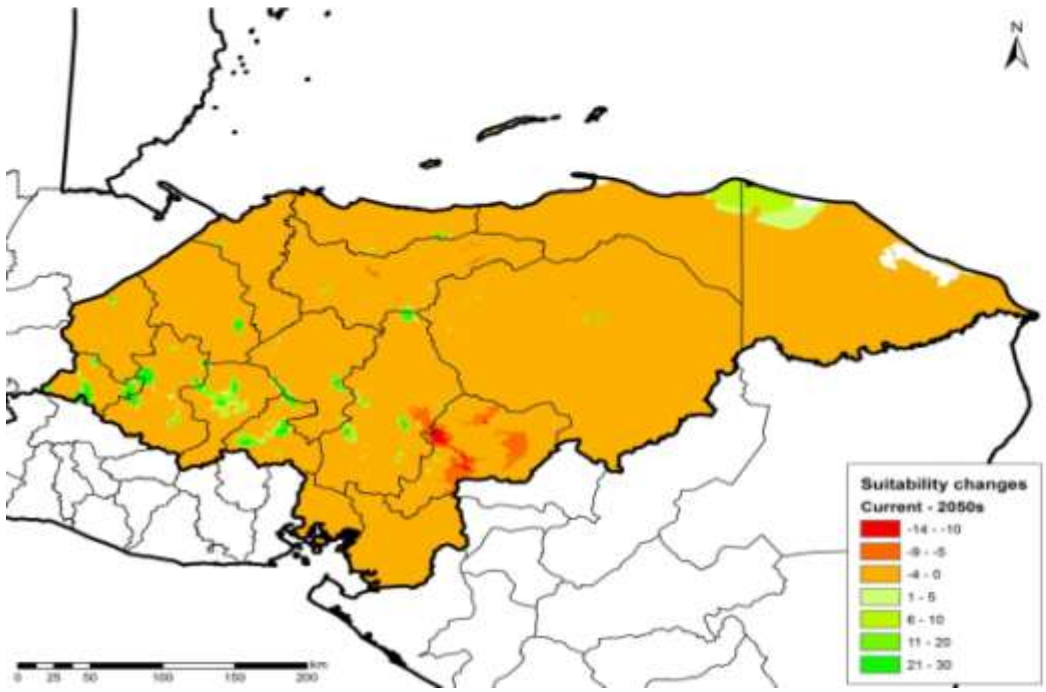


Figure 16: Suitability changes for maize production in Honduras comparing current long term climate conditions with the predicted conditions during the 2050s. Suitability is ranked according to the FAO CIAT EcoCrop methodology where a score of 100- 80 is Excellent, 80-61 Very Suitable, 60-41 Suitable, 40-21 Marginal, 20-1 Very Marginal and 0 Not suited

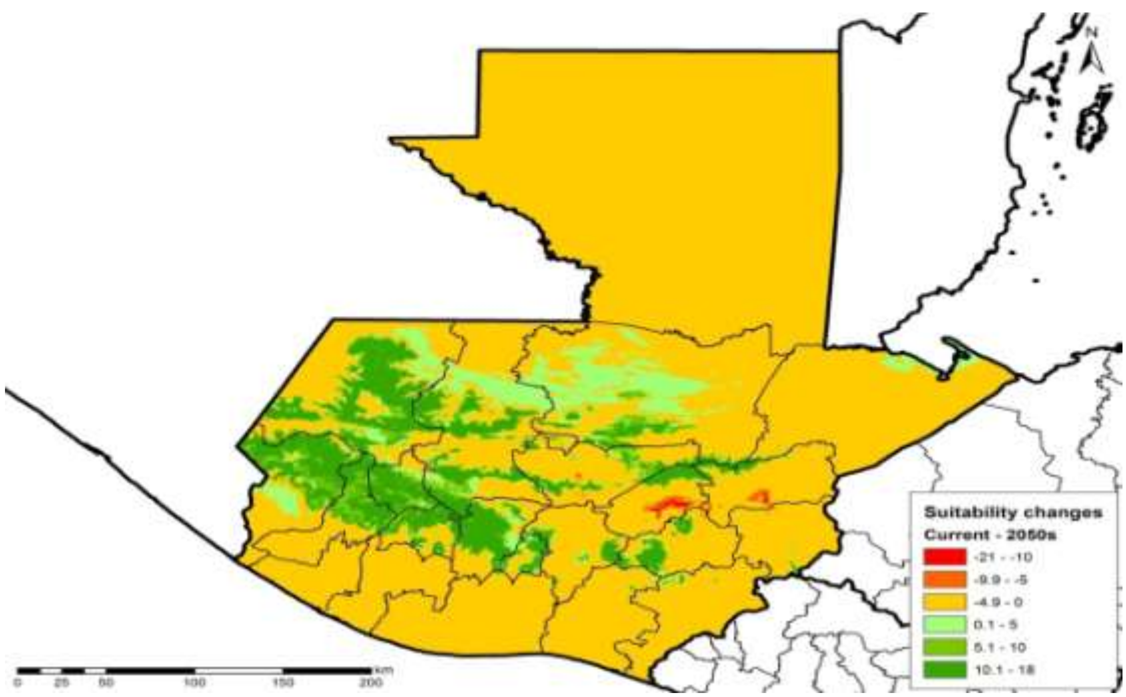


Figure 17: Suitability changes (EcoCrop) for maize production in Guatemala comparing current long term climate conditions with those predicted for the2050s.

6.4 Quantified impacts on bean production systems

6.4.1 Impact on bean production systems simulated by DSSAT (first analysis run)

We ran DSSAT with available bean variety calibration sets (2 fertilizer levels, 2 varieties, 2 soils, common smallholder conditions and management) to simulate current average yields and future expected yield. Results for current yields were ground-proofed through expert consultation throughout the region.

Planting date: Between 15th of April and 30th of June
Variety 1: IB0006 ICTA-Ostua
Variety 2: IB0020 BAT1289
Soil 1: IB00000005 (generic medium silty loam)
Soil 2: IB00000008 (generic medium sandy loam)
Fertilizer 1: 64 kg/ha 12-30-0
6 to 10 days after germination and 64 kg/ha Urea (46% N) at 22 to 25 days after germination.
Fertilizer 2: 128 kg/ha 18-46-0
Fertilizer application at planting and 64 kg/ha Urea 22 to 30 days after germination.

Figure 18: Eight different DSSAT trials

6.4.2 DSSAT results for 8 trial simulations

As shown on the following maps, there are areas where yields will decrease dramatically, whereas others are improving their production potential. The already described changes in climate conditions and their interactions with other location specific conditions determine crop production. Heat and drought stress and high night temperatures are the main culprits for these results. This is broadly sustained by scientific evidence.

Table 8: Comparison of DSSAT trial yield simulations

kg/ha	Mean yield 2000	% yield loss by 2020	% yield loss by 2050
trial 1	611	**13**	**21**
trial 3	779	**14**	**22**
trial 5	533	10	16
trial 7	689	11	17
trial 2	554	**13**	**21**
trial 4	730	**14**	**22**
trial 6	484	10	16
trial 8	647	12	18

As presented in Table 8 and Figure 19, average yield is expected to decrease. The decrease is predicted by all DSSAT trials for 2020 and even more for 2050. Total beans production is reported by FAO (2010) as 476 thousand tons for Nicaragua, Honduras, El Salvador and Guatemala and would be reduced by changing yield as predicted by DSSAT simulation on an average to 418 thousand by 2020 and 384 thousand tons by year 2050, producing in the same areas and under the same agronomic management conditions.

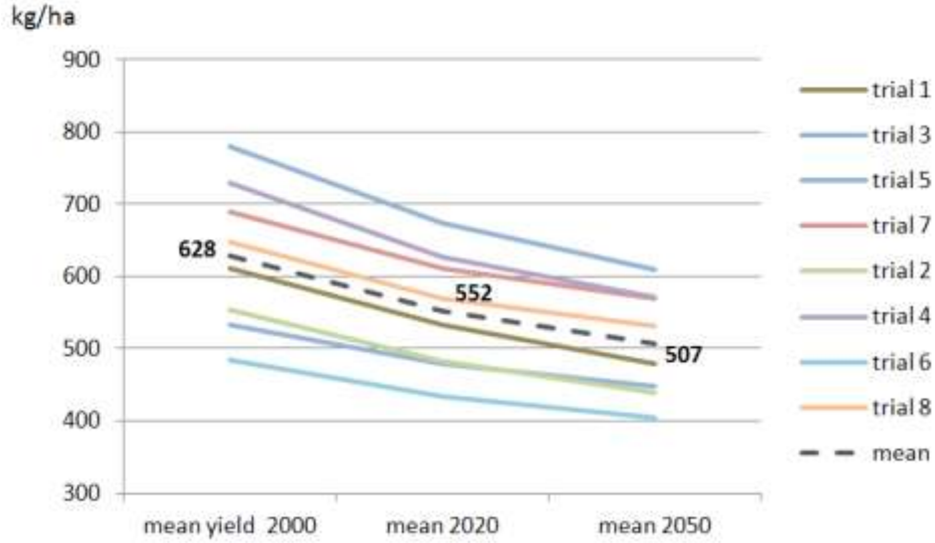


Figure 19: Current and future performance of simulated DSSAT yields

Detailed maps of DSSAT trial results show that impact is quite different on different simulation-trial runs and the main parameter seems to be fertilizer application. As we can see in Figures 19-21 trials 3, 7, 4 and 8 are performing better than others and these are exactly those using “Fertilizer 2” option, which is 128 kg/ha 18-46-0 fertilizer application on sowing and 64 kg/ha UREA at 22 to 30 days after germination.

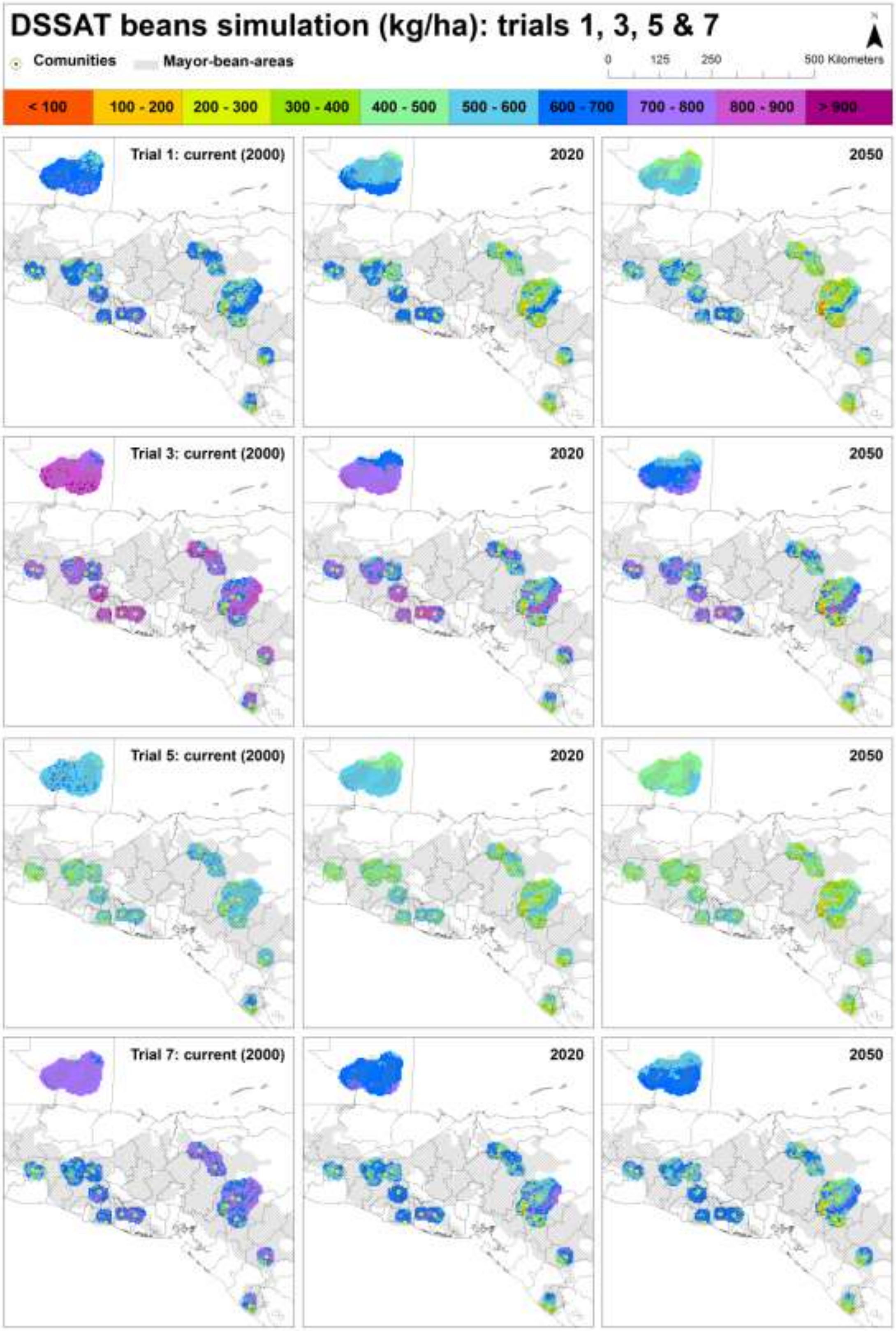


Figure 20: DSSAT yield results: trials 1, 3, 5 and 7

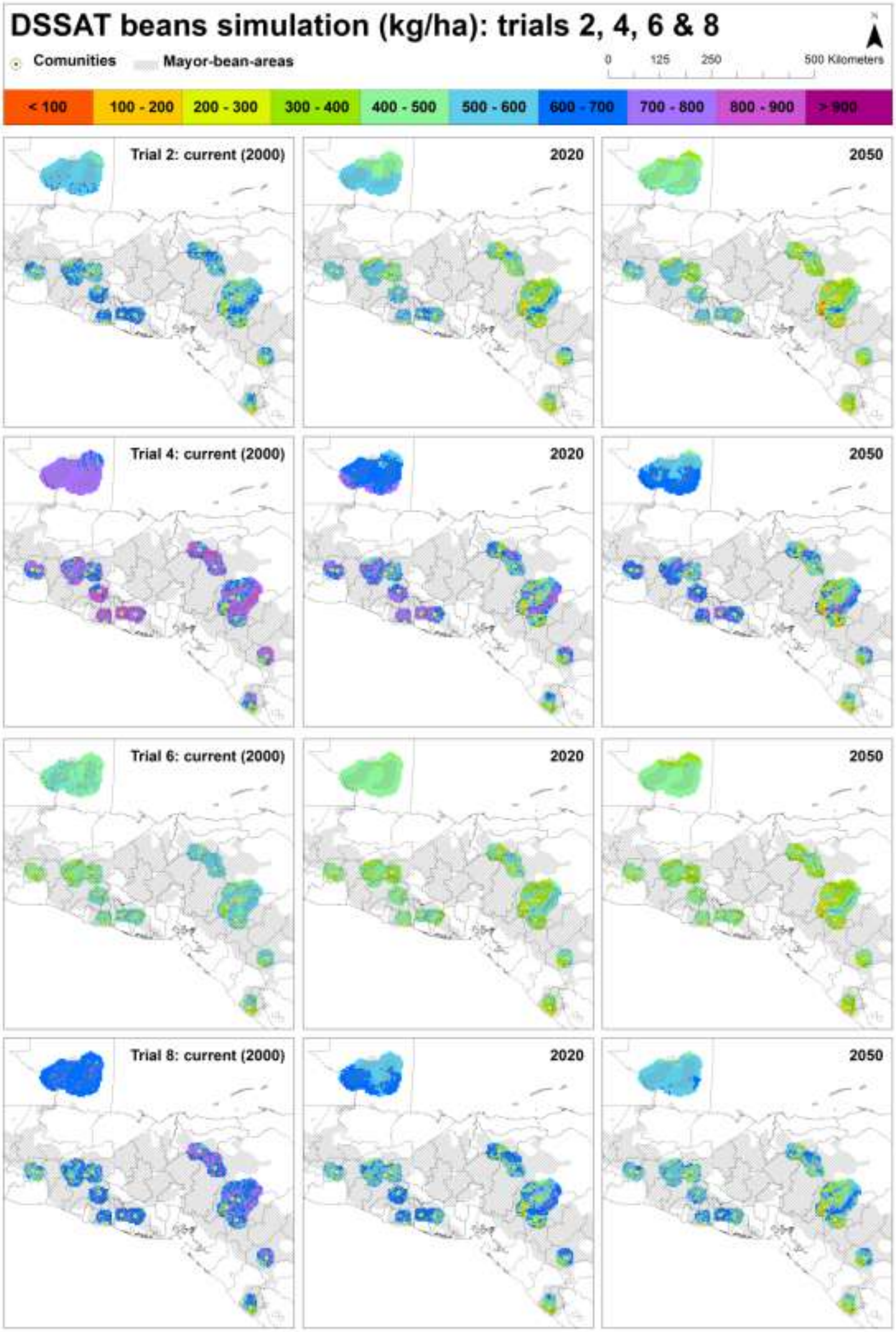


Figure 21: DSSAT yield results: trials 2, 4, 6 and 8

6.4.3 Specific country results (average of 8 trials, 1st DSSAT run)

The following section shows maps from the first DSSAT run which cover the entire study area using ensembles of GCMs and running them through MarkSim and DSSAT on a 5- kilometer resolution.

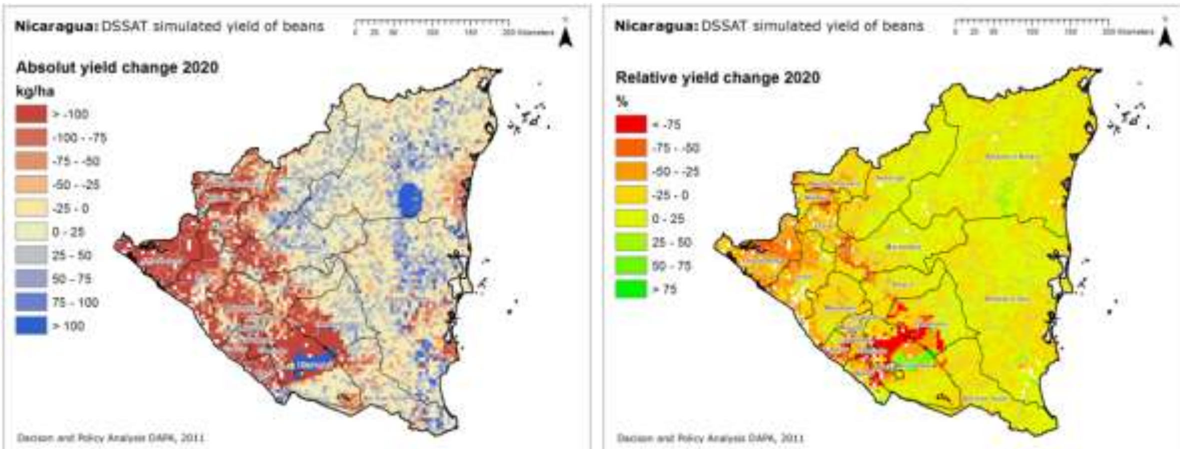


Figure 22: Predicted absolute and relative yield change for Nicaragua by 2020

In Nicaragua highest impact would be expected on the dry corridor (Corredor seco) from Rivas, to Granada and up to Estelí and Madriz (Figure 22). Building an average of decrease within mayor bean areas identified throughout Beans Atlas from the University of Michigan (Mejía et al. 2001), highest decrease in yield will be expected by the year 2020 for the department of Rivas (-48%), followed by Granada (-36%). Using actual production data from last season provided by MAGFOR (2011) a total production of 140 thousand tons would be reduced by 19,736 tons or 14% by 2020. Highest total impact in tons is predicted for Nueva Segovia, Matagalpa and Madriz. Constant or even improved yields are only predicted for the Atlantic region and Chontales which are traditionally used for Apante production (Table 9)

Table 9: Predicted change of bean production by 2020 in Nicaragua using data from MAGFOR and FAO-STAT

Nicaragua	Production (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020	STD	Change by 2020 (%)	Change by 2020 (t)
BOACO	3,815	1,896	497	533	96	468	130	-12	-231
CARAZO	2,451	1,221	498	585	96	412	180	-30	-361
CHINANDEGA	2,394	1,226	512	599	30	471	78	-21	-263
CHONTALES	3,980	2,998	753	604	22	610	8	1	26
ESTELI	9,413	4,446	472	590	73	479	138	-19	-834
GRANADA	1,577	706	448	566	92	361	179	-36	-256
JINOTEGA	30,748	23,266	757	662	37	640	82	-3	-779
LEON	8,051	3,626	450	513	75	460	51	-10	-371
MADRIZ	7,973	4,643	582	602	73	474	182	-21	-989
MANAGUA	2,323	982	423	487	70	450	100	-8	-75
MASAYA	882	589	668	534	91	443	106	-17	-101
MATAGALPA	46,818	26,347	563	610	77	577	156	-5	-1,425
NUEVA SEGOVIA	22,696	21,035	927	652	61	568	130	-13	-2,704
RIO SAN JUAN	11,335	5,937	524	627	32	620	28	-1	-62
RIVAS	3,569	1,966	551	402	68	210	118	-48	-941
Atlantico Norte	30,702	19,490	635	635	24	656	31	3	647
Atlantico Sur	30,435	20,600	677	592	35	601	33	1	290
MagFor (2011)	**219,164**	**140,973**						**-14.0**	**-19,736**
FAO (2010)	216,490	138,448							-19,382

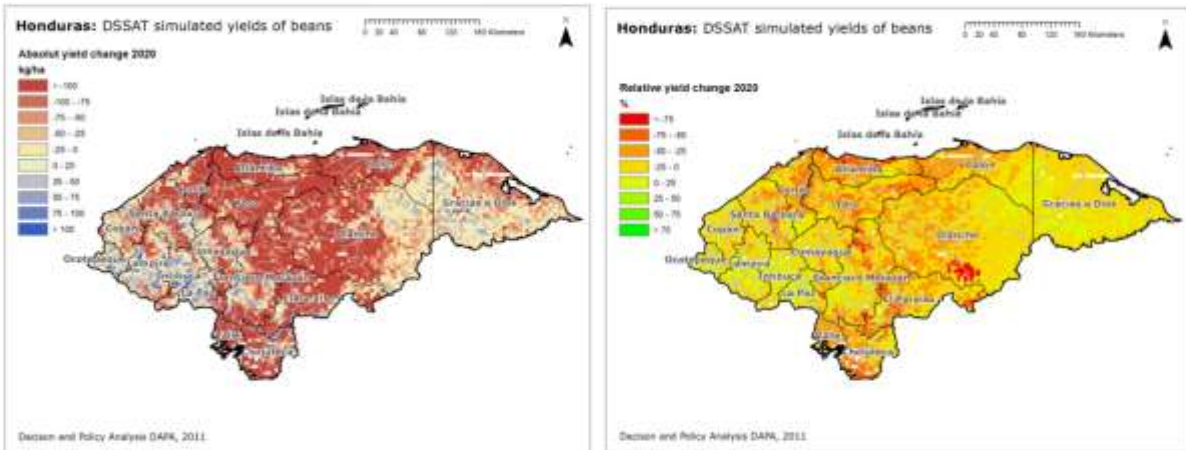


Figure 23: Predicted absolute and relative yield change for Honduras by 2020

The dry corridor continues its path up to Honduras and El Paraiso (-26%), Francisco Morazán (-19%), Yoro (-24%) (Figure 23). In South-West Honduras close to El Salvador border departments like Choluteca and Valle (-20%) also have expected high impact for the year 2020. Total reduction of 6,058 tons based on Beans Atlas data from 2004 and 9,596 related to FAO statistics from 2010 would be faced primary in Olancho, Francisco Morazán, Yoro and El Paraíso; Ocotepeque is the only beans producing department with an increasing average yield (Table 10).

Table 10: Predicted change of bean production by 2020 in Honduras using data from Beans Atlas and FAO-STAT

Honduras	Production (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020	STD	Change by 2020 (%)	Change by 2020 (t)
OLANCHO	12,862	8,108	630	601	70	474	101	-21	-1,714
FRANCISCO MORAZAN	13,144	4,826	367	643	48	524	139	-19	-894
YORO	5,679	4,076	718	615	81	466	126	-24	-991
COMAYAGUA	7,074	3,928	555	693	46	621	96	-10	-408
SANTA BARBARA	5,656	3,810	674	666	44	564	137	-15	-580
COPAN	6,119	3,494	571	683	23	642	50	-6	-211
EL PARAISO	11,127	3,175	285	600	93	444	174	-26	-829
LEMPIRA	5,586	2,228	399	675	50	658	56	-3	-59
INTUBUCA	4,607	2,183	474	673	34	662	46	-2	-34
CORTES	2,101	1,656	788	594	97	446	192	-25	-411
CHOLUTECA	4,241	1,335	315	567	118	451	152	-20	-272
LA PAZ	2,291	790	345	643	47	623	101	-3	-25
OCOTEPEQUE	957	527	551	663	58	690	31	4	21
VALLE	441	185	420	623	28	497	53	-20	-37
Bean Atlas (2004)	**85,461**	**43,275**						**-14.9**	**-6,058**
FAO (2010)	138,189	68,543							-9,596

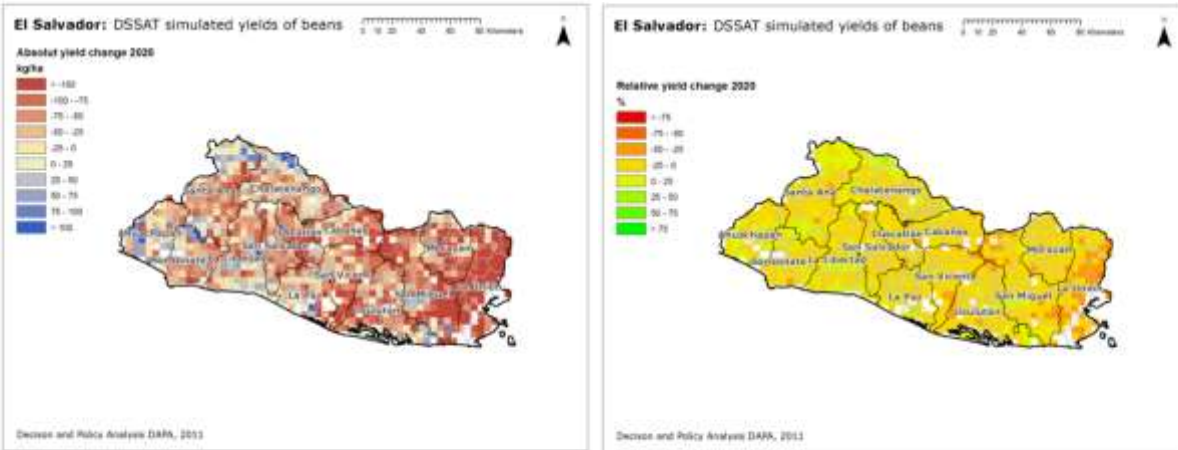


Figure 24: Predicted absolute and relative yield change for El Salvador by 2020

In El Salvador impact in general is less compared to the other 3 countries. Highest reduction in yield is expected to occur in the South-Eastern region in the departments Cuscatlán (-11%), Cabañas (-10%) and San Vicente (-9%) (Figure 24). Total reduction of roughly 6,000 tons (compared to Beans Atlas 2004 and FAO statistics 2010) are predominantly caused by San Vicente and Usulután, no department is predicted to have increasing bean yields caused by climate change (Table 11).

Table 11: Predicted change of bean production by 2020 in El Salvador using data from Beans Atlas and FAO-STAT

El Salvador	**Production (ha)**	**Production (t)**	**Yield (kg/ha)**	DSSAT yield mean 2000	STD	DSSAT yield mean 2020	STD	**Change by 2020 (%)**	**Change by 2020 (t)**
LA LIBERTAD	13,294	14,894	1,120	638	35	610	34	-4	-655
SANTA ANA	16,652	13,635	819	646	50	618	40	-4	-593
USULUTAN	8,959	11,121	1,241	649	44	600	54	-8	-850
SAN VICENTE	9,024	10,721	1,188	673	26	611	48	-9	-990
SAN SALVADOR	7,428	8,140	1,096	650	25	596	24	-8	-673
CUSCATLAN	5,711	6,011	1,053	666	32	593	38	-11	-660
SONSONATE	4,508	4,114	913	620	63	590	45	-5	-200
AHUACHAPAN	4,471	3,884	869	610	59	582	60	-4	-174
SAN MIGUEL	4,419	3,232	731	607	40	562	68	-7	-237
CHALATENANGO	2,397	2,408	1,005	650	35	609	32	-6	-151
CABAÑAS	3,027	2,392	790	662	27	593	37	-10	-248
MORAZÁN	1,555	1,051	676	713	0	662	0	-7	-74
Beans Atlas (2004)	**83,925**	**83,483**						**-7**	**-5,843**
FAO (2010)	108,336	87,514							-6,125

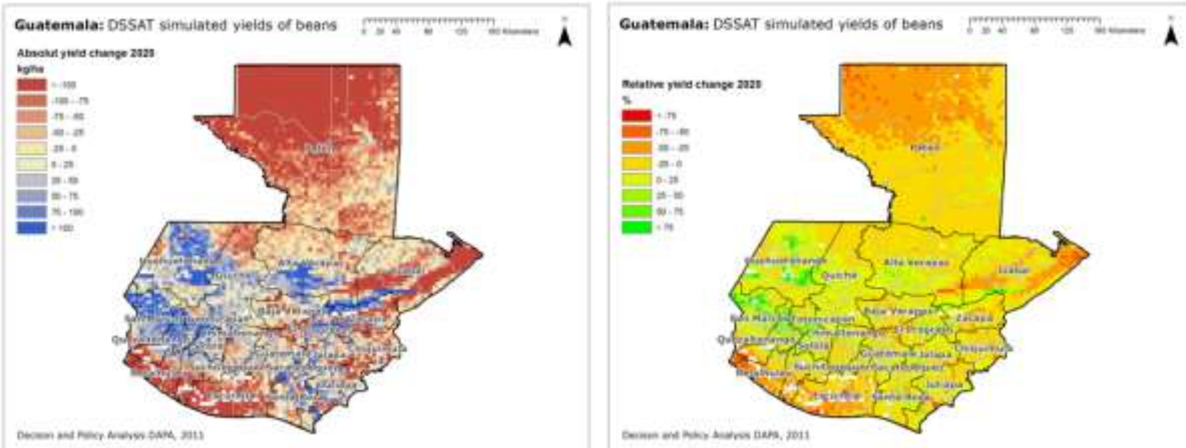


Figure 25: Predicted absolute and relative yield change for Guatemala by 2020

In Guatemala, Petén (mainly used for Apante), shows highest decrease in yields and would therefore not be suitable for the simulated Primera production cycle (Figure 25). Some departments have high potential for future bean production with regard to the changing climate and perhaps because of their different climate zone (see also Figure 12). San Marcos (+38%), Totonicapán (+23%) and Quetzaltenango (+31%) have high potentials for bean production by 2020 (considering only climate as factor, Table 12).

Table 12: Predicted change of bean production by2020 in Guatemala using data from Beans Atlas and FAO-STAT

Guatemala	Production (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020	STD	Change by 2020 (%)	Change by 2020 (t)
PETEN	35,383	27,718	783	660	49	571	49	-13	-3,736
JUTIAPA	28,222	13,576	481	610	57	583	105	-4	-593
CHIQUIMULA	17,621	10,187	578	619	69	570	84	-8	-793
STA ROSA	12,571	6,933	552	601	57	597	99	-1	-47
JALAPA	13,329	6,513	489	592	64	589	59	-1	-33
QUICHE	20,733	5,201	251	607	59	624	64	3	145
ALTA VERAPAZ	8,578	5,019	585	616	36	572	35	-7	-360
HUEHUETENANGO	16,859	4,206	249	543	210	610	115	12	518
GUATEMALA	9,511	4,185	440	594	38	578	72	-3	-114
CHIMALTENANGO	8,236	3,908	474	594	55	596	39	0	12
EL PROGRESO	5,366	2,790	520	501	129	531	87	6	168
BAJA VERAPAZ	7,236	2,705	374	628	44	583	86	-7	-191
ZACAPA	4,178	2,481	594	484	112	447	125	-8	-189
IZABAL	3,273	2,053	627	669	17	649	39	-3	-61
SAN MARCOS	5,992	1,547	258	435	235	601	136	38	593
SACATEPEQUEZ	1,430	814	569	577	57	597	26	4	29
TOTONICAPAN	3,255	775	238	510	172	625	72	23	176
SOLOLA	2,902	766	264	495	178	572	78	16	120
ESCUINTLA	907	605	667	578	24	549	41	-5	-31
QUETZALTENANGO	2,502	506	202	487	152	639	29	31	158
Beans Atlas (2004)	**208,557**	**102,702**						**4**	**4,108**
FAO (2010)	222,600	181,500							7,260

6.4.4 Specific DSSAT country results on maize production

The model runs were divided according to the two general soil types selected. Due to the differences in the soil quality in terms of water availability and retention as well as other traits, these can be considered as best and worst case scenarios. The impact under the poor soil condition scenario can be considered as more drastic and pronounced in all project countries, a serious issue considering the wide spread soil degradation in the region. Figures 26-29 show the maize yield reductions in percent for the 4 countries for both soil scenarios and the 2020s and 2050s, respectively. Similar to the changes of suitability as shown through the EcoCrop model which indicated predicted decreases of suitability of most lowland areas and increased suitability for highland areas, the modeled yield changes also differ between high reductions of yields in drier lowland areas and considerable increases for highland areas.

Looking at the impact at country level (Table 13) the most affected country would be Honduras which showed almost 30% losses under the worst case scenario for 2020s and 2050s while the predictions show that under the good case scenario losses would still reach 11.7% for both future time frames. Second most affected for the worst case scenario predictions is El Salvador with slightly over 30% losses. Losses for this country for the good soil scenario were very minor underlining at less than 2% the importance of soil management.

Nicaragua showed losses of just over 11% for the poor soil scenario for 2020s and 2050s and lower ones for the good soil scenario at 3.3% for 2020s and 4%. Guatemala stood out as it showed also relatively low overall production losses for the poor soil scenario at 10.8% for the 2020s and 11% for the 2050s, but a very slight increase in production under the good soil scenario overall.

Table 13: Maize production changes predicted for project countries for 2020s and 2050s

	Production changes poor soil scenario (%)		Production changes good soil scenario (%)	
Country	2020s	2050s	2020s	2050s
El Salvador	-32.2	-33.5	-1.1	-1.8
Guatemala	-10.8	-11.0	0.5	0.4
Honduras	-29.5	-29.8	-11.7	-11.7
Nicaragua	-11.0	-11.3	-3.3	-4.0

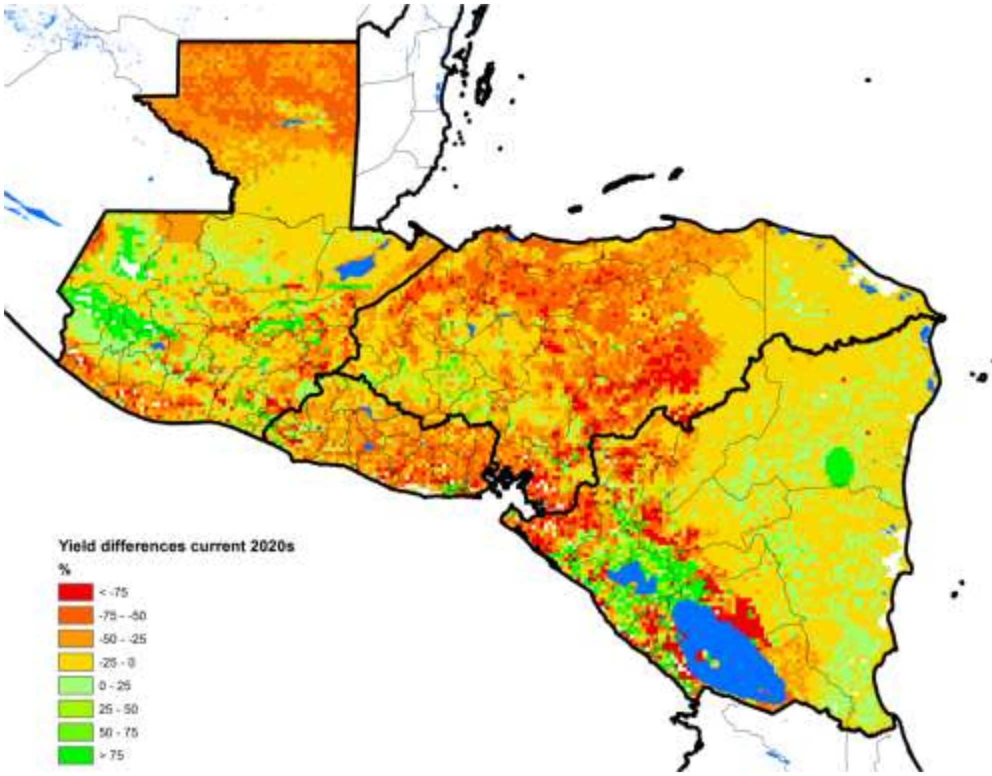


Figure 26: Maize yield differences between the current climate and 2020s predicted (poor soil conditions)

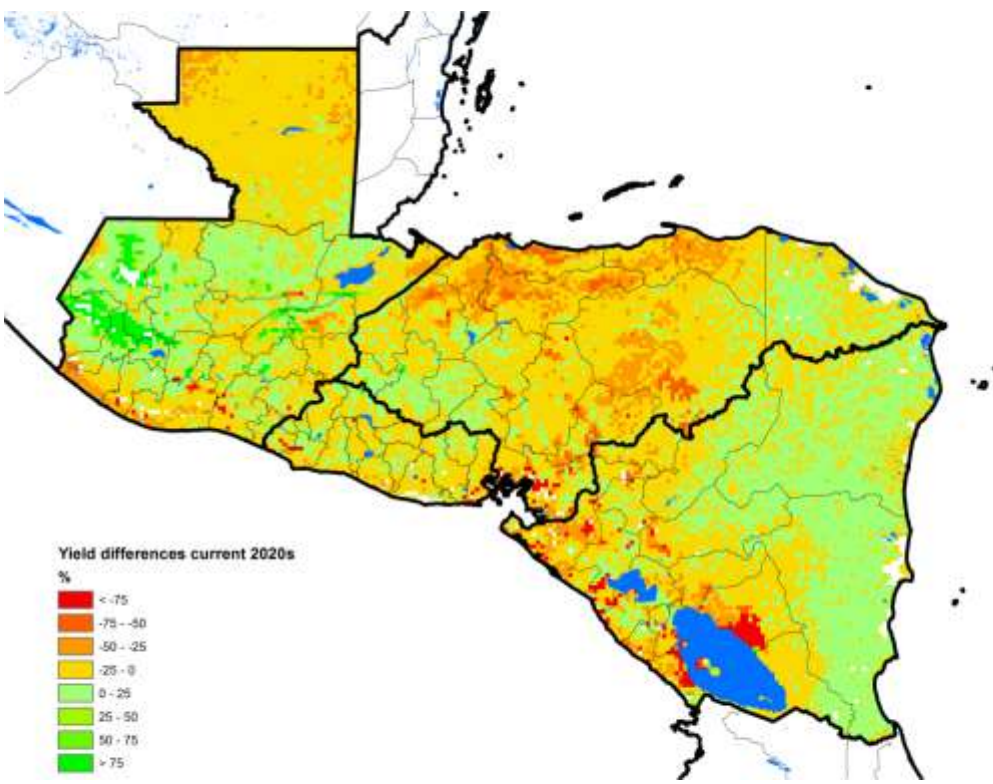


Figure 27: Maize yield differences between the current climate and 2020s predicted (good soil conditions)

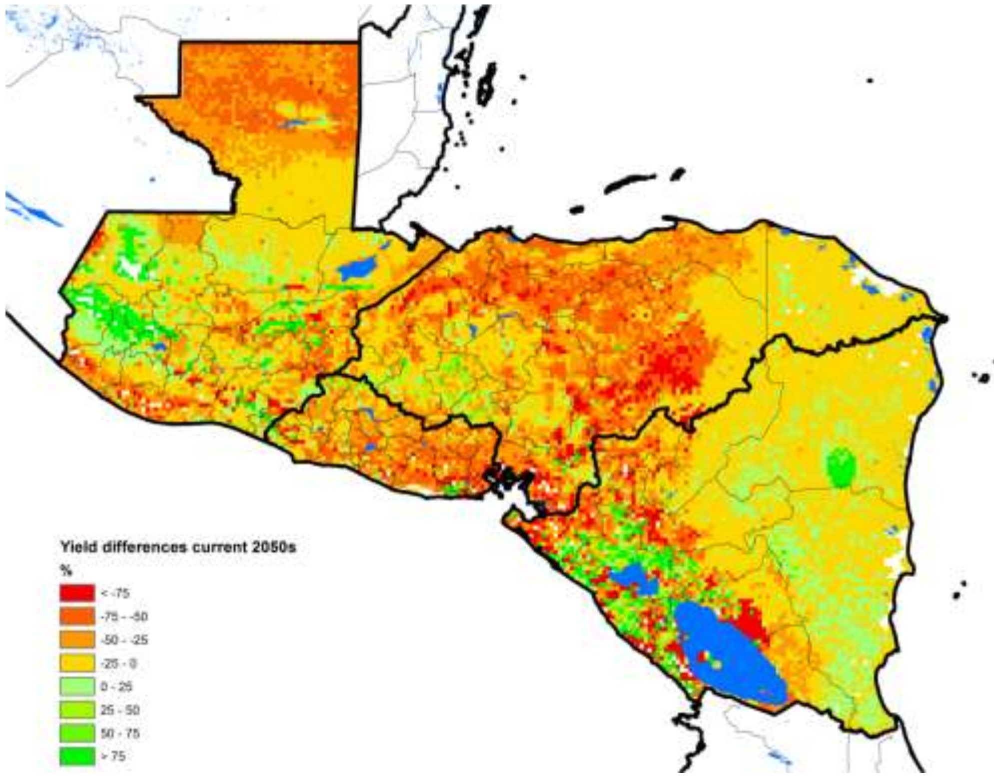


Figure 28: Maize yield differences between the current climate and 2050s predicted (poor soil conditions)

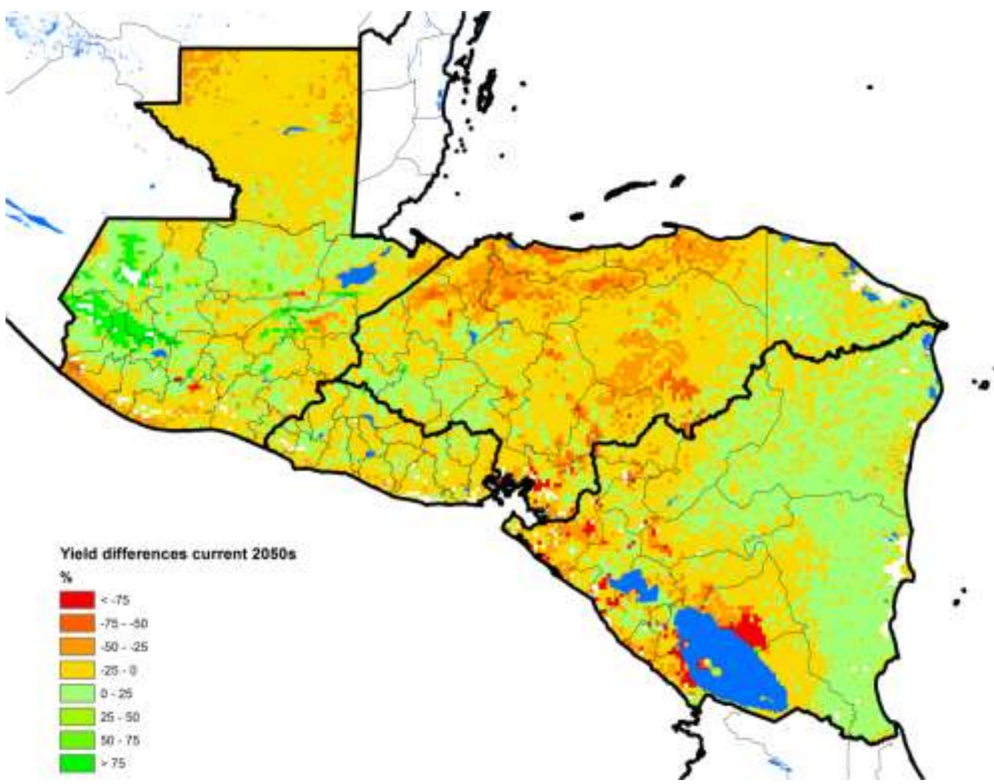


Figure 29: Maize yield differences between the current climate and 2050s predicted (good soil conditions)

El Salvador

Table 14 shows the predicted impacts for El Salvador for the poor soil scenario during the 2020s. All departamentos would face reductions in yield under the climate change conditions, the most affected being La Paz with almost 75% losses as well as La Union, San Miguel, Usulután, San Vicente, San Salvador and Cabañas, all of which are predicted to lose over 30% of the current yield levels. The remaining departamentos would face yield and thus production reductions of just under 30% down to Ahuachapán with just over 10%, being the least affected in the country possibly due to the highland areas included. Total losses for the country amount up to over 250,000 t of maize based on the 2009-2010 production year.

For the good soil scenario for the 2020s impact is far less pronounced (Table 15). La Paz is still the most affected departamento but losses are less than 10%. Most other departamentos show slight losses while for Chalatenango, Sonsonate and Ahuachapán slight increases are predicted. Overall losses for the country would be at 8,000 t compared to the 2009-2010 year.

Considering the 2050s the same picture for both scenarios is shown with overall conditions decreasing slightly further under the predicted continuing increases of temperature and changes in rainfall patterns (Table 16 and Table 17). Overall production losses for the worst case scenario would be over 266,000 t while for the good scenario losses still almost double to over 14,000 t as compared to the production year 2009-2010.

Table 14: Predicted change of maize production by 2020s in El Salvador for poor soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Ahuachapan	22,950	66,021	2,877	1,988	944	1,780	675	-10.5	-6,910
Cabañas	7,694	27,920	3,629	3,136	437	2,071	473	-34.0	-9,483
Chalatenango	23,869	94,211	3,947	3,193	491	2,642	570	-17.3	-16,277
Cuscatlán	13,681	54,469	3,981	3,038	335	1,978	552	-34.9	-19,004
La Libertad	21,969	74,116	3,374	2,583	567	1,891	603	-26.8	-19,863
La Paz	19,114	57,430	3,005	3,649	168	941	545	-74.2	-42,617
La Union	16,317	36,707	2,250	1,632	919	922	672	-43.5	-15,978
Morazán	14,992	35,293	2,354	2,726	628	1,910	976	-29.9	-10,557
San Miguel	19,643	35,308	1,798	1,841	833	1,042	614	-43.4	-15,319
San Salvador	20,031	65,794	3,285	2,662	632	1,730	492	-35.0	-23,034
San Vicente	18,116	64,400	3,555	2,124	832	1,291	757	-39.2	-25,254
Santa Ana	19,913	50,389	2,530	2,715	635	2,115	638	-22.1	-11,151
Sonsonate	19,944	68,635	3,441	2,486	731	1,936	586	-22.1	-15,198
Usulutan	23,658	64,706	2,735	1,437	805	864	529	-39.9	-25,821
Tot									-256,466

Source: Current maize production data, MAG 2009-2010.

Table 15: Predicted change of maize production by2020s in El Salvador for good soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Ahuachapan	22,950	66,021	2,877	3,087	827	3,292	312	6.7	4,394
Cabañas	7,694	27,920	3,629	3,674	122	3,533	161	-3.8	-1,072
Chalatenango	23,869	94,211	3,947	3,530	342	3,559	181	0.8	780
Cuscatlán	13,681	54,469	3,981	3,650	109	3,510	174	-3.8	-2,088
La Libertad	21,969	74,116	3,374	3,545	123	3,498	201	-1.3	-966
La Paz	19,114	57,430	3,005	3,649	168	3,366	437	-7.8	-4,452
La Union	16,317	36,707	2,250	3,384	918	3,266	413	-3.5	-1,277
Morazán	14,992	35,293	2,354	3,608	153	3,601	163	-0.2	-69
San Miguel	19,643	35,308	1,798	3,633	179	3,457	328	-4.9	-1,714
San Salvador	20,031	65,794	3,285	3,524	591	3,496	138	-0.8	-520
San Vicente	18,116	64,400	3,555	3,675	150	3,620	300	-1.5	-957
Santa Ana	19,913	50,389	2,530	3,474	170	3,428	201	-1.3	-672
Sonsonate	19,944	68,635	3,441	3,264	831	3,315	309	1.6	1,068
Usulutan	23,658	64,706	2,735	3,522	556	3,468	340	-1.5	-993
Tot									-8,538

Current Maize prod data MAG 2009-2010

Table 16: Predicted change of maize production by2050s in El Salvador for poor soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Ahuachapan	22,950	66,021	2,877	1,988	944	1,764	653	-11.3	-7,447
Cabañas	7,694	27,920	3,629	3,136	437	2,067	503	-34.1	-9,511
Chalatenango	23,869	94,211	3,947	3,193	491	2,623	560	-17.9	-16,823
Cuscatlán	13,681	54,469	3,981	3,038	335	1,938	512	-36.2	-19,721
La Libertad	21,969	74,116	3,374	2,583	567	1,795	593	-30.5	-22,627
La Paz	19,114	57,430	3,005	3,649	168	952	557	-73.9	-42,452
La Union	16,317	36,707	2,250	1,632	919	880	639	-46.1	-16,919
Morazán	14,992	35,293	2,354	2,726	628	1,883	919	-30.9	-10,915
San Miguel	19,643	35,308	1,798	1,841	833	1,028	638	-44.2	-15,599
San Salvador	20,031	65,794	3,285	2,662	632	1,685	484	-36.7	-24,152
San Vicente	18,116	64,400	3,555	2,124	832	1,255	717	-40.9	-26,345
Santa Ana	19,913	50,389	2,530	2,715	635	2,088	613	-23.1	-11,642
Sonsonate	19,944	68,635	3,441	2,486	731	1,970	593	-20.8	-14,253
Usulutan	23,658	64,706	2,735	1,437	805	816	510	-43.2	-27,976
Tot									-266,382

Current Maize prod data MAG 2090-2010

Table 17: Predicted change of maize production by 2050s in El Salvador for good soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Ahuachapan	22,950	66,021	2,877	3,087	827	3,270	370	6.0	3,930
Cabañas	7,694	27,920	3,629	3,674	122	3,541	170	-3.6	-1,007
Chalatenango	23,869	94,211	3,947	3,530	342	3,531	181	0.0	40
Cuscatlán	13,681	54,469	3,981	3,650	109	3,472	141	-4.9	-2,659
La Libertad	21,969	74,116	3,374	3,545	123	3,461	249	-2.3	-1,740
La Paz	19,114	57,430	3,005	3,649	168	3,322	433	-8.9	-5,135
La Union	16,317	36,707	2,250	3,384	918	3,222	423	-4.8	-1,755
Morazán	14,992	35,293	2,354	3,608	153	3,590	165	-0.5	-177
San Miguel	19,643	35,308	1,798	3,633	179	3,425	333	-5.7	-2,026
San Salvador	20,031	65,794	3,285	3,524	591	3,483	135	-1.2	-776
San Vicente	18,116	64,400	3,555	3,675	150	3,532	300	-3.9	-2,502
Santa Ana	19,913	50,389	2,530	3,474	170	3,411	203	-1.8	-911
Sonsonate	19,944	68,635	3,441	3,264	831	3,332	296	2.1	1,426
Usulutan	23,658	64,706	2,735	3,522	556	3,455	326	-1.9	-1,244
Tot									-14,535

Current Maize prod data MAG 2090-2010

Guatemala

In Guatemala, the overall impact is softened by the considerable highland areas mainly in the West of the country while drier areas like parts of Petén, coastal areas in the South (Retalhulehu, Escuintla), and the Eastern border (Chiquimula and Jutiapa) would face considerable losses. Also the largest producer in terms of area, Alta Verapaz, is little affected due to slight increases under the good soils scenario and only slight losses under the bad soils one (Table 18-21).

Most affected for the 2020s and the poor soils scenario would be Petén with over a third productions losses predicted, while Escuintla, Chiquimula, Jutiapa and Retalhuleu would lose between one third and one 5th of the production. Departamentos with considerable production increases are El Progreso, Quetzaltenango, San Marcos, and Totonicapán where production is predicted to increase by between 20 and over 40%. Overall losses for the country would still be considerable with 98,000 t in comparison with the latest production statistics.

For the good soils scenario the overall balance for the country is positive with 4,247 t increase due to strong increases in Quetzaltenango, San Marcos and Totonicapán between 25 and almost 52%. A total of 12 (out of the 22) departamentos show slight to considerable increases. Drier areas like Petén and Retalhuleu still face reductions of between 13.9% and 11.2%.

Changes between 2020s and 2050s are relatively small, the overall bad soils scenario damage increasing to losses of 99,000 t for the whole country, with Petén, Escuintla and Chiquimula having predicted production losses of between 33.2% and 26%.

For the good soils scenario again the balance is still positive but with decreasing figures especially for the drier parts of the country as compared to the 2020s, with again the coastal areas as well as Petén suffering most, loosing over 10% of the production while the highland areas increase production up to 51.9%.

Table 18: Predicted change of maize production by 2020s in Guatemala for poor soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Alta Verapaz	104,177	188,086	1,805	4,189	563	4,079	673	-2.6	-4,973
Baja Verapaz	10,259	16,441	1,603	3,161	875	2,580	1,135	-18.4	-3,021
Chimaltenango	456	1,688	3,704	2,466	778	2,041	696	-17.2	-291
Chiquimula	9,797	12,523	1,278	2,485	1,092	1,845	1,124	-25.8	-3,228
El Progreso	5,030	9,289	1,847	2,104	1,300	2,537	1,553	20.5	1,908
Escuintla	19,348	75,366	3,895	2,042	816	1,476	912	-27.7	-20,868
Guatemala	1,771	4,522	2,554	2,207	480	1,830	635	-17.1	-773
Huehuetenango	29,327	62,745	2,140	3,053	1,613	3,105	1,364	1.7	1,068
Izabal	12,082	23,146	1,916	3,743	682	3,163	851	-15.5	-3,589
Jalapa	1,574	3,409	2,166	2,488	809	2,118	892	-14.9	-507
Jutiapa	8,193	22,759	2,778	2,132	744	1,621	769	-24.0	-5,452
Peten	50,772	116,538	2,295	3,045	797	2,049	989	-32.7	-38,116
Quetzaltenango	11,686	29,757	2,546	2,159	1,518	2,628	1,257	21.7	6,451
Quiche	23,979	37,198	1,551	3,671	1,061	3,353	865	-8.7	-3,220
Retalhulehu	43,463	129,193	2,972	2,191	1,147	1,693	1,393	-22.7	-29,346
Sacatepequez	1,356	3,424	2,525	2,027	491	2,118	487	4.5	153
San Marcos	17,543	45,186	2,576	2,386	1,672	2,949	1,403	23.6	10,663
Santa Rosa	7,951	26,209	3,297	2,072	834	1,928	671	-7.0	-1,825
Solola	333	670	2,016	2,290	1,257	2,435	923	6.4	43
Suchitepequez	31,063	51,814	1,668	2,946	1,090	2,553	1,314	-13.3	-6,901
Totonicapan	5,468	12,136	2,220	1,594	1,304	2,274	719	42.6	5,175
Zacapa	17,389	32,556	1,872	2,242	1,431	2,142	1,503	-4.5	-1,454
Tot									-98,102

Source: Current maize production data INE 2008.

Table 19: Predicted change of maize production by2020s in Guatemala for good soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Alta Verapaz	104,177	188,086	1805	3513	476	3667	465	4.4	8,282
Baja Verapaz	10,259	16,441	1603	3314	306	3241	335	-2.2	-361
Chimaltenango	456	1,688	3704	3045	627	3190	503	4.8	80
Chiquimula	9,797	12,523	1278	3248	340	3066	458	-5.6	-704
El Progreso	5,030	9,289	1847	2868	682	3133	570	9.2	856
Escuintla	19,348	75,366	3895	3330	582	3025	632	-9.2	-6,904
Guatemala	1,771	4,522	2554	3124	251	3048	232	-2.4	-111
Huehuetenango	29,327	62,745	2140	2817	1295	3193	980	13.3	8,372
Izabal	12,082	23,146	1916	3512	402	3384	466	-3.7	-845
Jalapa	1,574	3,409	2166	3078	537	3136	318	1.9	65
Jutiapa	8,193	22,759	2778	3236	349	3105	492	-4.0	-919
Peten	50,772	116,538	2295	3373	274	2996	409	-11.2	-13,013
Quetzaltenango	11,686	29,757	2546	2196	1416	2774	918	26.3	7,840
Quiche	23,979	37,198	1551	3390	698	3517	362	3.8	1,395
Retalhulehu	43,463	129,193	2972	3369	327	2901	802	-13.9	-17,916
Sacatepequez	1,356	3,424	2525	2900	581	3089	375	6.5	223
San Marcos	17,543	45,186	2576	2137	1427	2771	1114	29.7	13,413
Santa Rosa	7,951	26,209	3297	3107	672	3116	348	0.3	73
Solola	333	670	2016	2426	1160	2979	791	22.8	153
Suchitepequez	31,063	51,814	1668	3420	527	3318	593	-3.0	-1,552
Totonicapan	5,468	12,136	2220	1784	1388	2704	851	51.6	6,259
Zacapa	17,389	32,556	1872	2876	714	2837	765	-1.3	-439
Tot									4,247

Current Maize prod data INE 2008

Table 20: Predicted change of maize production by 2050s in Guatemala for poor soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Alta Verapaz	104,177	188,086	1,805	4,189	563	4,080	670	-2.6	-4,912
Baja Verapaz	10,259	16,441	1,603	3,161	875	2,600	1,131	-17.7	-2,916
Chimaltenango	456	1,688	3,704	2,466	778	2,020	675	-18.1	-305
Chiquimula	9,797	12,523	1,278	2,485	1,092	1,838	1,088	-26.0	-3,261
El Progreso	5,030	9,289	1,847	2,104	1,300	2,529	1,560	20.2	1,876
Escuintla	19,348	75,366	3,895	2,042	816	1,467	902	-28.1	-21,211
Guatemala	1,771	4,522	2,554	2,207	480	1,821	629	-17.5	-792
Huehuetenango	29,327	62,745	2,140	3,053	1,613	3,096	1,379	1.4	887
Izabal	12,082	23,146	1,916	3,743	682	3,184	849	-14.9	-3,455
Jalapa	1,574	3,409	2,166	2,488	809	2,158	924	-13.2	-452
Jutiapa	8,193	22,759	2,778	2,132	744	1,645	757	-22.8	-5,197
Peten	50,772	116,538	2,295	3,045	797	2,033	989	-33.2	-38,746
Quetzaltenango	11,686	29,757	2,546	2,159	1,518	2,589	1,246	19.9	5,922
Quiche	23,979	37,198	1,551	3,671	1,061	3,339	879	-9.0	-3,361
Retalhulehu	43,463	129,193	2,972	2,191	1,147	1,696	1,362	-22.6	-29,207
Sacatepequez	1,356	3,424	2,525	2,027	491	2,019	515	-0.4	-13
San Marcos	17,543	45,186	2,576	2,386	1,672	2,939	1,418	23.2	10,484
Santa Rosa	7,951	26,209	3,297	2,072	834	1,910	660	-7.8	-2,046
Solola	333	670	2,016	2,290	1,257	2,431	923	6.2	41
Suchitepequez	31,063	51,814	1,668	2,946	1,090	2,599	1,297	-11.8	-6,103
Totonicapan	5,468	12,136	2,220	1,594	1,304	2,258	730	41.7	5,057
Zacapa	17,389	32,556	1,872	2,242	1,431	2,094	1,519	-6.6	-2,156
Tot									-99,865

Source: Current maize production data INE 2008.

Table 21: Predicted change of maize production by 2050s in Guatemala for good soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Alta Verapaz	104,177	188,086	1805	3513	476	3667	464	4.4	8,257
Baja Verapaz	10,259	16,441	1603	3314	306	3242	340	-2.2	-355
Chimaltenango	456	1,688	3704	3045	627	3176	518	4.3	73
Chiquimula	9,797	12,523	1278	3248	340	3072	473	-5.4	-679
El Progreso	5,030	9,289	1847	2868	682	3134	580	9.3	862
Escuintla	19,348	75,366	3895	3330	582	3018	639	-9.4	-7,052
Guatemala	1,771	4,522	2554	3124	251	3039	232	-2.7	-123
Huehuetenango	29,327	62,745	2140	2817	1295	3189	997	13.2	8,296
Izabal	12,082	23,146	1916	3512	402	3390	478	-3.5	-805
Jalapa	1,574	3,409	2166	3078	537	3132	317	1.8	60
Jutiapa	8,193	22,759	2778	3236	349	3126	458	-3.4	-771
Peten	50,772	116,538	2295	3373	274	2988	415	-11.4	-13,302
Quetzaltenango	11,686	29,757	2546	2196	1416	2777	909	26.5	7,871
Quiche	23,979	37,198	1551	3390	698	3522	370	3.9	1,447
Retalhulehu	43,463	129,193	2972	3369	327	2890	771	-14.2	-18,347
Sacatepequez	1,356	3,424	2525	2900	581	3094	343	6.7	229
San Marcos	17,543	45,186	2576	2137	1427	2755	1123	28.9	13,073
Santa Rosa	7,951	26,209	3297	3107	672	3115	352	0.3	72
Solola	333	670	2016	2426	1160	2981	795	22.9	153
Suchitepequez	31,063	51,814	1668	3420	527	3376	574	-1.3	-674
Totonicapan	5,468	12,136	2220	1784	1388	2709	847	51.9	6,297
Zacapa	17,389	32,556	1872	2876	714	2797	808	-2.8	-899
Tot									3,684

Current Maize prod data INE 2008

Honduras

As recent statistics for Honduras are not available on departamento level but are provided for the seven regions of the statistical system of INE (Figure 30), all calculations were made based on these boundaries with data available up to 2009-2010. The production changes data based on the model runs can be utilized for calculations within departamento or municipio boundaries when recent adequate statistics related to these administrative areas become available to further refine impact analysis on these lower sub national levels.

Honduras showed considerable impact of climate change both for the 2020s and 2050s for the worst case (poor soil) and good case (good soil) scenarios.

For the poor soil and the 2020s five regions (Norte, Centro Oriental, Sur, Nor Oriental and Litoral Atlantico) are predicted to lose between 30.9% and 36.8% of the maize production, while Occidental and Centro Occidental would face reductions of 19.6% and 12.3% respectively. Overall losses for the country compared to the 2009-2010 production would amount to 175,598 t of maize an overall loss of 30%. For the good soil and the 2020s losses overall are still considerable with a total of 69,534 t this representing a reduction 11.6% for the whole country.

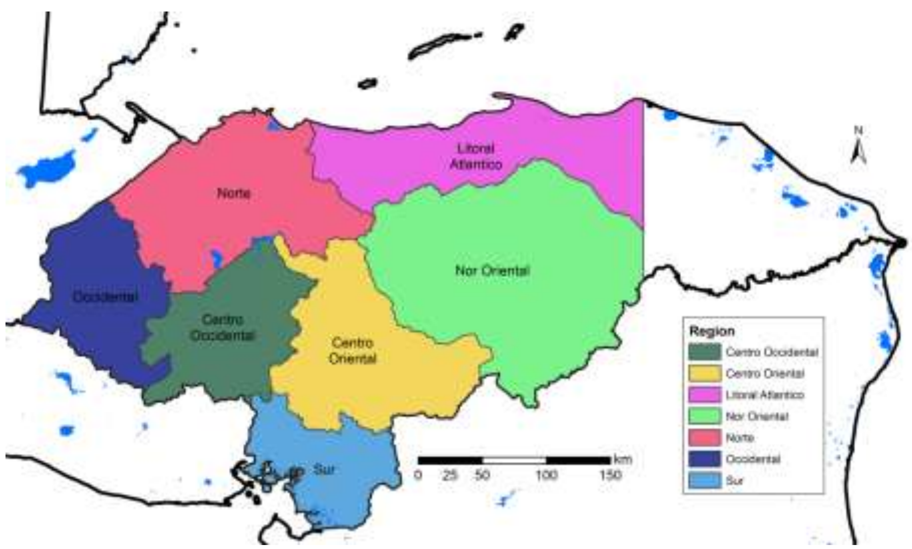


Figure 30: Regions utilized for agricultural statistics by INE

Losses of the individual regions varied from almost 40% for Norte, Litoral Atlantico and Sur to values around 20% for Nor Oriental and Centro Oriental while Centro Occidental and Occidental showed basically no differences compared to current climate. For the 2050s minor further reductions in production losses are shown for both scenarios in comparison with the 2020s.

Table 22: Predicted change of maize production by2020s in Honduras for poor soil scenario

Zone	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Sur	25,859	20,744	802	1,765	901	1,169	886	-33.8	-7,005
Centro Occidental	59,429	89,144	1,500	3,148	749	2,760	798	-12.3	-10,975
Norte	52,613	102,521	1,949	2,950	981	1,865	1,113	-36.8	-37,685
Litoral Atlántico	18,533	32,503	1,754	2,979	945	2,059	1,065	-30.9	-10,041
Nor Oriental	89,196	207,419	2,325	2,836	962	1,913	1,211	-32.5	-67,469
Centro Oriental	61,485	101,681	1,654	2,642	801	1,745	979	-34.0	-34,526
Occidental	28,734	40,270	1,401	3,426	485	2,754	857	-19.6	-7,897
Tot									-175,598

Source: Maize prod data INE 2090-2010.

Table 23: Predicted change of maize production by 2020s in Honduras for good soil scenario

Zone	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Sur	25,859	20,744	802	3,338	483	2,716	905	-18.6	-3,865
Centro Occidental	59,429	89,144	1,500	3,430	237	3,364	360	-1.9	-1,732
Norte	52,613	102,521	1,949	3,310	436	2,658	797	-19.7	-20,190
Litoral Atlántico	18,533	32,503	1,754	3,223	510	2,617	793	-18.8	-6,105
Nor Oriental	89,196	207,419	2,325	3,382	270	2,971	644	-12.2	-25,240
Centro Oriental	61,485	101,681	1,654	3,271	228	2,886	502	-11.7	-11,946
Occidental	28,734	40,270	1,401	3,443	281	3,420	229	-0.7	-278
Tot									-69,354

Current Maize prod data INE 2090-2010

Table 24: Predicted change of maize production by 2050s in Honduras for poor soil scenario

Zone	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Sur	25,859	20,744	802	1,765	901	1,169	897	-33.8	-7,007
Centro Occidental	59,429	89,144	1,500	3,148	749	2,729	804	-13.3	-11,849
Norte	52,613	102,521	1,949	2,950	981	1,852	1,126	-37.2	-38,162
Litoral Atlántico	18,533	32,503	1,754	2,979	945	2,056	1,078	-31.0	-10,072
Nor Oriental	89,196	207,419	2,325	2,836	962	1,912	1,208	-32.6	-67,548
Centro Oriental	61,485	101,681	1,654	2,642	801	1,739	987	-34.2	-34,752
Occidental	28,734	40,270	1,401	3,426	485	2,765	854	-19.3	-7,776
Tot									-177,165

Source: Maize prod data INE 2090-2010.

Table 25: Predicted change of maize production by 2050s in Honduras for good soil scenario

Zone	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Sur	25,859	20,744	802	3,338	483	2,726	916	-18.3	-3,802
Centro Occidental	59,429	89,144	1,500	3,430	237	3,367	339	-1.8	-1,638
Norte	52,613	102,521	1,949	3,310	436	2,640	808	-20.2	-20,742
Litoral Atlántico	18,533	32,503	1,754	3,223	510	2,609	804	-19.0	-6,186
Nor Oriental	89,196	207,419	2,325	3,382	270	2,977	634	-12.0	-24,844
Centro Oriental	61,485	101,681	1,654	3,271	228	2,878	522	-12.0	-12,200
Occidental	28,734	40,270	1,401	3,443	281	3,425	237	-0.5	-213
Tot									-69,625

Current Maize prod data INE 2090-2010

Nicaragua

Impact for Nicaragua for the 2020s and the poor soil scenario on the country overall is predicted to be a reduction of 11% implying a production loss of 51,741 t compared to the latest production statistics 2010-2011 from MAGFOR. Considering the different departamentos however big differences in impact can be observed. Areas like Masaya and Chinandega would face reductions of over 40% while some of the larger production areas like Jinotega, Matagalpa, Atlantico Sur and Norte are predicted to show reductions of less than 10%. The more humid areas in the last two departamentos are suffering less. They maintain their humid tropical climate. Managua is the only departamento showing predicted increases possibly due to the highland parts.

For the good soil scenario overall losses for the country would amount to about 15,000 t representing a reduction of 3% overall. High impacts would be more located in the Southern parts of the country in Rivas and Granada, while the more humid areas in the eastern departamentos along the coast would show slight increases in production.

Similar to Honduras further decreases between 2020s and 2050s were very minor, the total changes of production being less than one percent.

Table 26: Predicted change of maize production by2020 in Nicaragua for poor soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Atlantico Norte	71,948	82,178	1,142	3,845	485	3,818	280	-0.7	-587
Atlantico Sur	76,238	64,804	850	3,911	679	3,861	728	-1.3	-824
Boaco	11,103	10,573	952	1,762	1,353	1,541	1,213	-12.5	-1,324
Carazo	2,449	4,006	1,636	499	321	354	244	-29.0	-1,163
Chinandega	13,884	19,921	1,435	478	414	274	261	-42.7	-8,497
Chontales	8,000	8,807	1,101	1,573	1,437	1,349	1,373	-14.3	-1,256
Esteli	9,975	14,609	1,465	1,398	735	1,046	901	-25.2	-3,678
Granada	861	2,440	2,834	414	237	386	305	-6.7	-164
Jinotega	55,684	89,401	1,605	3,376	674	3,068	861	-9.1	-8,164
Leon	19,369	31,141	1,608	452	342	427	277	-5.5	-1,713
Madriz	8,273	8,731	1,055	2,184	849	1,580	1,037	-27.7	-2,415
Managua	3,855	4,038	1,048	302	294	411	291	36.2	1,464
Masaya	2,295	5,025	2,190	391	373	211	162	-46.0	-2,312
Matagalpa	47,235	60,746	1,286	2,976	1,170	2,715	1,329	-8.8	-5,326
Nueva Segovia	13,305	44,353	3,334	2,789	760	2,028	1,022	-27.3	-12,102
Rio San Juan	16,008	15,417	963	3,110	823	2,482	1,179	-20.2	-3,110
Rivas	2,330	3,675	1,577	1,227	1,272	1,037	1,164	-15.5	-569
Tot									-51,741

Source: Current maize production data MAGFOR 2010-2011.

Table 27: Predicted change of maize production by 2020s in Nicaragua for good soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2020s	STD	Change by 2020s (%)	Change by 2020s (t)
Atlantico Norte	71,948	82,178	1142	3,518	138	3652	208	3.8	3,139
Atlantico Sur	76,238	64,804	850	3,573	300	3741	388	4.7	3,045
Boaco	11,103	10,573	952	3,096	394	2818	889	-9.0	-950
Carazo	2,449	4,006	1636	3,305	286	2826	795	-14.5	-580
Chinandega	13,884	19,921	1435	3,399	646	2724	691	-19.9	-3,956
Chontales	8,000	8,807	1101	2,821	722	2202	1340	-21.9	-1,932
Esteli	9,975	14,609	1465	3,169	184	2935	676	-7.4	-1,076
Granada	861	2,440	2834	3,020	395	2306	1056	-23.6	-577
Jinotega	55,684	89,401	1605	3,459	127	3447	262	-0.4	-326
Leon	19,369	31,141	1608	3,087	625	2767	784	-10.4	-3,232
Madriz	8,273	8,731	1055	3,211	190	2796	601	-12.9	-1,130
Managua	3,855	4,038	1048	2,828	441	2788	555	-1.4	-57
Masaya	2,295	5,025	2190	3,294	294	3146	492	-4.5	-225
Matagalpa	47,235	60,746	1286	3,379	208	3295	548	-2.5	-1,512
Nueva Segovia	13,305	44,353	3334	3,400	167	3040	489	-10.6	-4,699
Rio San Juan	16,008	15,417	963	3,567	203	3412	435	-4.4	-671
Rivas	2,330	3,675	1577	3,152	599	2313	1296	-26.6	-977
Tot									-15,715

Source: Current maize production data MAGFOR 2010-2011.

Table 28: Predicted change of maize production by 2050s in Nicaragua for poor soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Atlantico Norte	71,948	82,178	1,142	3,845	485	3,766	259	-2.1	-1,694
Atlantico Sur	76,238	64,804	850	3,911	679	3,878	724	-0.8	-546
Boaco	11,103	10,573	952	1,762	1,353	1,466	1,255	-16.8	-1,774
Carazo	2,449	4,006	1,636	499	321	331	296	-33.7	-1,351
Chinandega	13,884	19,921	1,435	478	414	321	319	-32.8	-6,531
Chontales	8,000	8,807	1,101	1,573	1,437	1,235	1,272	-21.5	-1,894
Esteli	9,975	14,609	1,465	1,398	735	909	829	-34.9	-5,104
Granada	861	2,440	2,834	414	237	389	282	-6.1	-149
Jinotega	55,684	89,401	1,605	3,376	674	3,066	870	-9.2	-8,218
Leon	19,369	31,141	1,608	452	342	467	312	3.4	1,064
Madriz	8,273	8,731	1,055	2,184	849	1,617	1,036	-26.0	-2,267
Managua	3,855	4,038	1,048	302	294	343	309	13.5	544
Masaya	2,295	5,025	2,190	391	373	216	185	-44.7	-2,244
Matagalpa	47,235	60,746	1,286	2,976	1,170	2,657	1,338	-10.7	-6,511
Nueva Segovia	13,305	44,353	3,334	2,789	760	2,007	992	-28.0	-12,433
Rio San Juan	16,008	15,417	963	3,110	823	2,435	1,177	-21.7	-3,342
Rivas	2,330	3,675	1,577	1,227	1,272	1,026	1,171	-16.4	-602
Tot									-53,051

Source: Current maize production data MAGFOR 2010-2011.

Table 29: Predicted change of maize production by 2050s in Nicaragua for good soil scenario

Departamento	Area (ha)	Production (t)	Yield (kg/ha)	DSSAT yield mean 2000	STD	DSSAT yield mean 2050s	STD	Change by 2050s (%)	Change by 2050s (t)
Atlantico Norte	71,948	82,178	1142	3,518	138	3612	156	2.7	2,195
Atlantico Sur	76,238	64,804	850	3,573	300	3728	393	4.3	2,818
Boaco	11,103	10,573	952	3,096	394	2661	964	-14.1	-1,486
Carazo	2,449	4,006	1636	3,305	286	2750	863	-16.8	-673
Chinandega	13,884	19,921	1435	3,399	646	2713	795	-20.2	-4,024
Chontales	8,000	8,807	1101	2,821	722	2108	1341	-25.3	-2,224
Esteli	9,975	14,609	1465	3,169	184	2930	696	-7.5	-1,099
Granada	861	2,440	2834	3,020	395	2262	1016	-25.1	-613
Jinotega	55,684	89,401	1605	3,459	127	3425	261	-1.0	-887
Leon	19,369	31,141	1608	3,087	625	2756	902	-10.7	-3,341
Madriz	8,273	8,731	1055	3,211	190	2847	573	-11.3	-989
Managua	3,855	4,038	1048	2,828	441	2563	593	-9.4	-378
Masaya	2,295	5,025	2190	3,294	294	2894	772	-12.1	-609
Matagalpa	47,235	60,746	1286	3,379	208	3276	532	-3.1	-1,869
Nueva Segovia	13,305	44,353	3334	3,400	167	3100	406	-8.8	-3,916
Rio San Juan	16,008	15,417	963	3,567	203	3405	451	-4.5	-701
Rivas	2,330	3,675	1577	3,152	599	2290	1311	-27.3	-1,005
Tot									-18,802

Source: Current maize production data MAGFOR 2010-2011.

6.5 Identified hot-spots, adaptation and pressure areas for bean production

We mapped hot-spots, adaptation- and pressure areas within the study area based on the described methodology (Figure 31). The red hot-spots are, not surprisingly, lined-up through the dry corridor of Central America and include all mayor and important bean production areas of the region, specifically the north of Nicaragua and the center of Honduras. These areas are the main bean producers in the region, not only supplying the national respective national markets but also exporting to other countries. El Salvador is known to buy huge quantities of beans from these areas for its own consumption, but also for the Latin-market in the USA. A dramatic decrease in bean supply will have negative effects in all countries in and outside the region, not to mention consumer prices in urban areas and its socio-political impacts. This is further complicated from the huge number of adaptation areas where without adequate and timely intervention bean production will further decline causing even more havoc on the regional bean markets. The green pressure areas deserve mayor attention by the respective authorities. Past and current experiences in the region however raises fears that these areas might be lost in the next decade due to the described climate change impacts and other factors such as population increase and land tenure problems. The condensed information in this map is very useful for a number of different stakeholders and decision makers, development agencies and the donor community. The maps indicate location and degree of the predicted impact and thus reduce the uncertainty with regard to climate change. The respective areas can now manage their specific climate change risks.

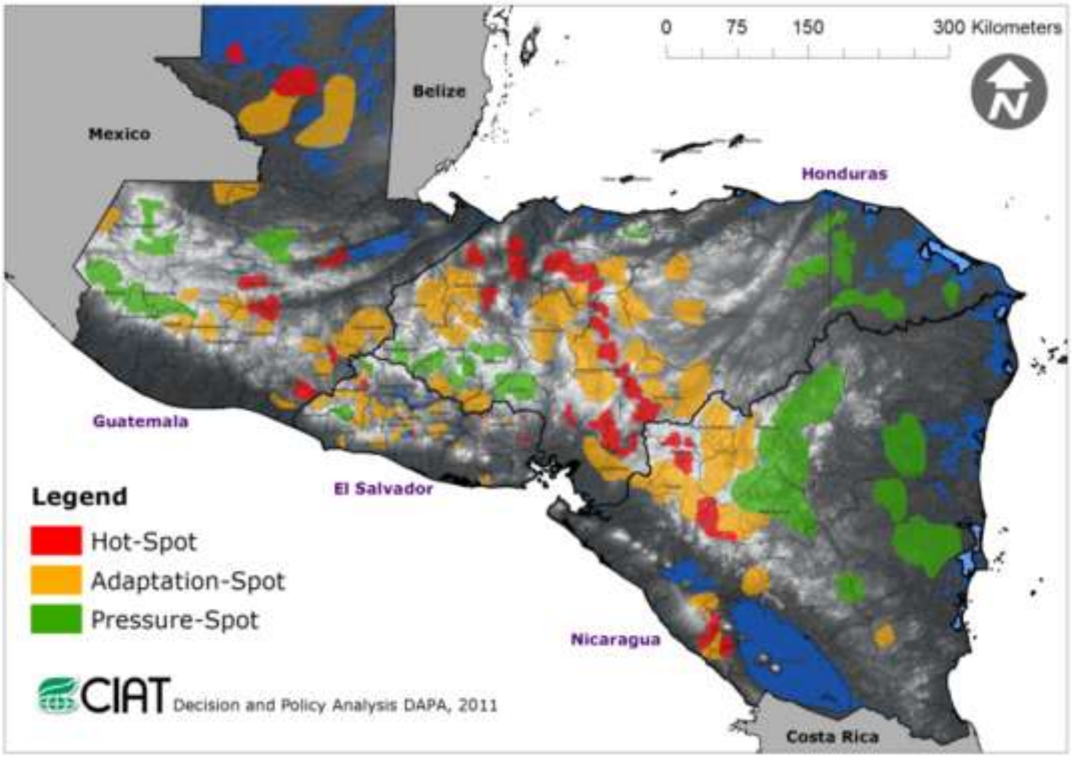


Figure 31: Bean focus areas within the entire study area

6.5.1 Results for Nicaragua

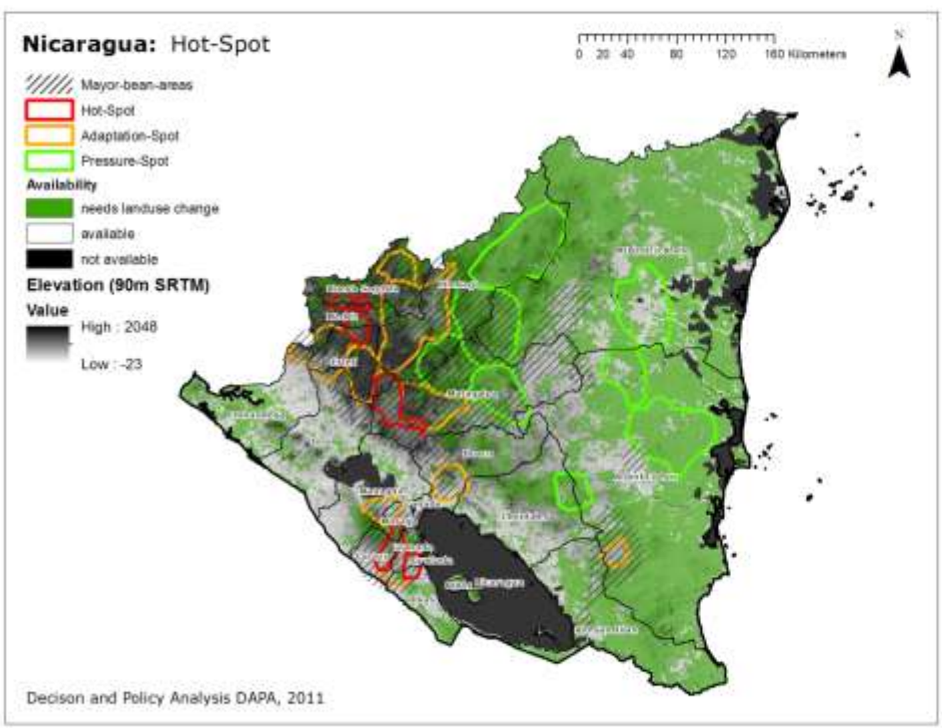


Figure 32: Bean focus areas in Nicaragua

Results for Nicaragua show that areas along the dry corridor between Madriz to Masaya are identified as hot-spots and adaptation areas. Therefore these areas need high attention and the implementation of adaptation strategies in a short term perspective. In some hot-spots where impact is predicted to be more than 50% until 2020, diversification of farmers' livelihoods has to be taken into consideration. Examples for these hot-spots are (i) department Carazo, Diriamba and La Conquista, (ii) department Granada, Diriomo and Diria, and (iii) department Rivas, Belén and Potosí. The green identified Pressure-Areas need high attention to avoid a potential shift of bean production areas to current Apante production areas causing significant changes in the agricultural frontier through deforestation (Figure 32).

6.5.2 Results for Honduras

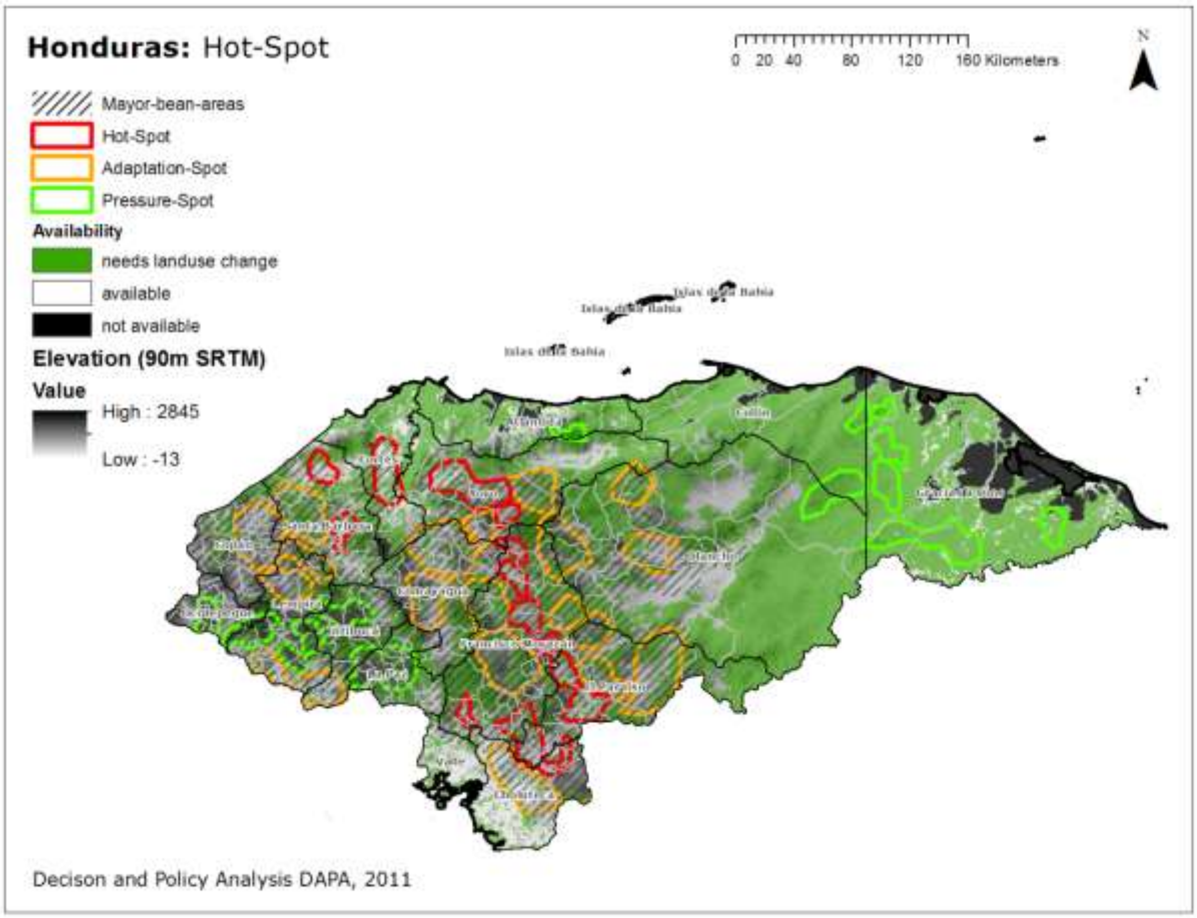


Figure 33: Bean focus areas in Honduras

Identified hot-spots in Honduras continue along the dry corridor from Nicaragua. Examples for hot-spots are (i) department El Paraíso; Alauca, Liure and Soledad, (ii) department Yoro, Yorito and (iii) department Choluteca, Morolica. Areas for adaptation options are located east and west of the dry corridor and in the department Copán and Lempira. Pressure areas are again in the Atlantic region and close to El Salvador border on higher altitudes (Figure 33

6.5.3 Results for El Salvador

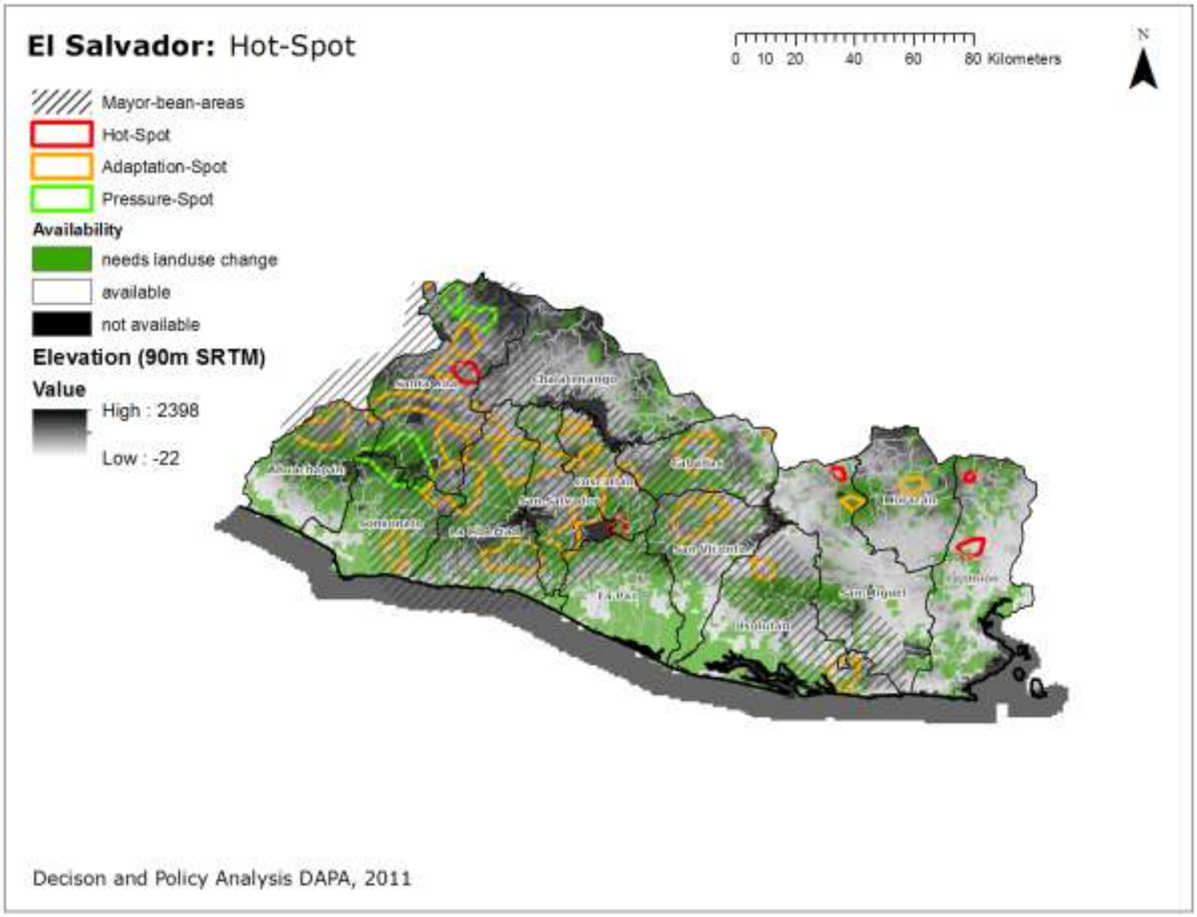


Figure 34: Bean focus areas in El Salvador

El Salvador is expected to be less affected by climate change impacts on bean production compared to Nicaragua and Honduras. Here hot-spots were identified in the departments of Santa Ana (Texistepeque), La Unión and Cuscatlán (Figure 34). There is high potential for adaptation of bean production to climate change in most areas within the country

6.5.4 Results for Guatemala

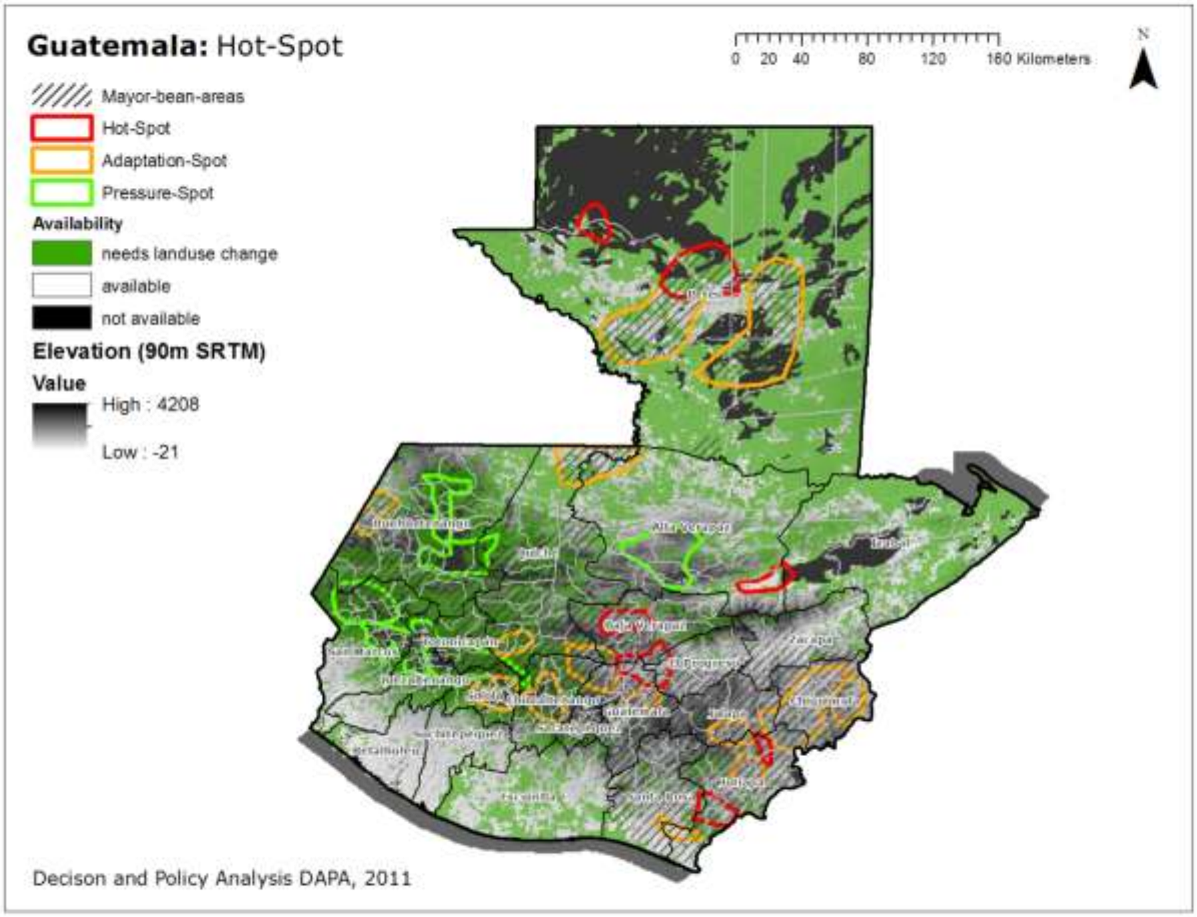


Figure 35: Bean focus areas in Guatemala

In Guatemala the mayor bean producing departments in the southwest close to border to Honduras (Jutiapa, Chiquimula Santa Rosa and Jalapa; except Pelén, which is mainly for Apante production) are identified as adaptation- and some hot-spot areas and need high attention for adaptation strategies in order to maintain national total production by 2020 (Figure 35)

6.6 Identified hot-spots, adaptation-and pressure areas for maize production

While overall losses for some countries in the balance of good and bad soils scenarios may seem low, impact on some individual areas of the country may be considerably higher as shown in the country specific paragraphs. For farmers in these most affected areas adaptation measures will be of highest priority. The country tables on predicted production changes (Table 14 - 29) show areas that would have to adapt according to the classification CIAT proposed highlighted as orange, only one area La Paz in El Salvador would be considered a true hot-spot highlighted red. Areas highlighted green, mainly in departamentos containing Guatemala's highlands, would be considered pressure areas. Many of these areas also several in the other countries are currently in use for higher value crops such as coffee or still forested systems which may still be suitable for these crops in the future. Here careful management and planning of transition between systems if appropriate is crucial. For the good soil scenario the coastal parts of Nicaragua as well as the North East part of Honduras which is not currently covered in the statistics for agricultural production for maize or beans show up as areas that may become more suitable and interesting for maize production. As these areas often contain tropical rainforest, even protected areas and are not under agricultural use yet future migration and utilization for crop production has to be handled with utmost caution. A more detailed analysis based on currently not available district or lower level agricultural statistics or a current land use map detailing the precise location of annual crops could improve furthermore the prediction of yield changes. A mayor effort on data recording on district level is recommended.

6.7 Address uncertainty of DSSAT output using multiple GCM (2nd analysis run) on selected sites

To address the uncertainty of using climate change prediction data from GCM models for DSSAT simulation we ran DSSAT again with the full set of available models and produced 4 different outcomes. First the mean value for each grid cell of all 19 GCMs on emission scenario A2 (business as usual), the average of the first quartile of models which can also be called the pessimistic scenario, the average of the third quartile also stated the very optimistic scenario, and the percentage of agreeing models on their prediction direction (negative, no- or positive-change) on each grid cell. As results show in Figure 36d, there is a higher uncertainty of DSSAT simulations in central Guatemala and zones close to the pacific in Nicaragua and El Salvador for 2020.

Results of using 2050 GCM models and their uncertainty of prediction are quite similar to 2020 and show in the pessimistic scenario very high impact on yield change for Honduras and Nicaragua, slight impact in El Salvador and Guatemala (Figure 37b). In an optimistic scenario Guatemala and El Salvador and even Nicaragua would gain from climate change by 2050 predictions of first quartile of 19 GCMS but Honduras would still have slight or no reduce in yields. For adaptation- and mitigation recommendations we took into account the mean of all 19 DSSAT simulations using different GCMs (Figure 36a and Figure 37a)

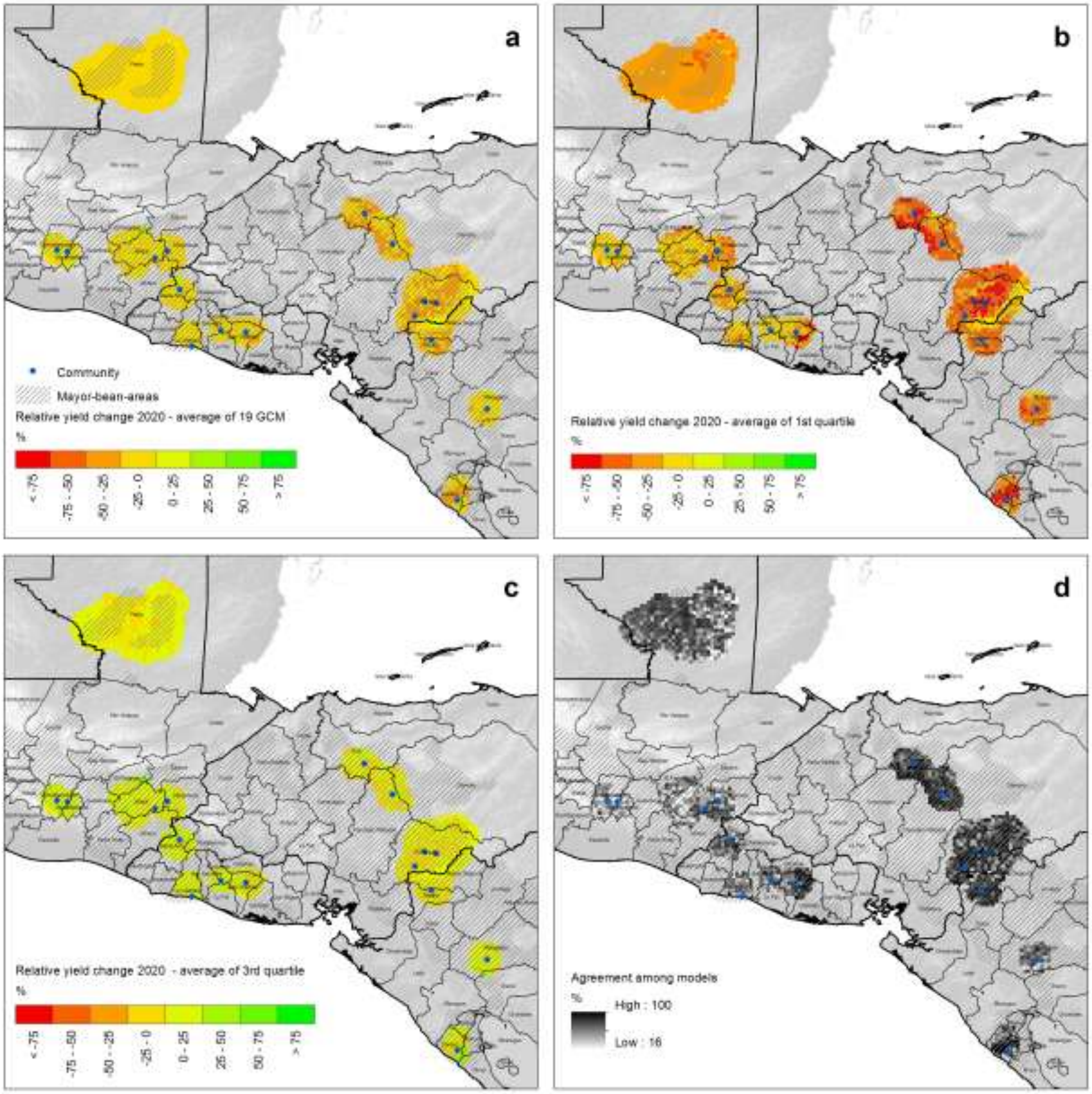


Figure 36: Predicted changes in beans yield and breadth of climate models uncertainty. a relative yield change as average of 19 GCMs for 2020, b average of the 1st quartile of GCMs, c average of 3rd quartile of GCMs, and d breadth of GCMs agreeing in yield change prediction by DSSAT

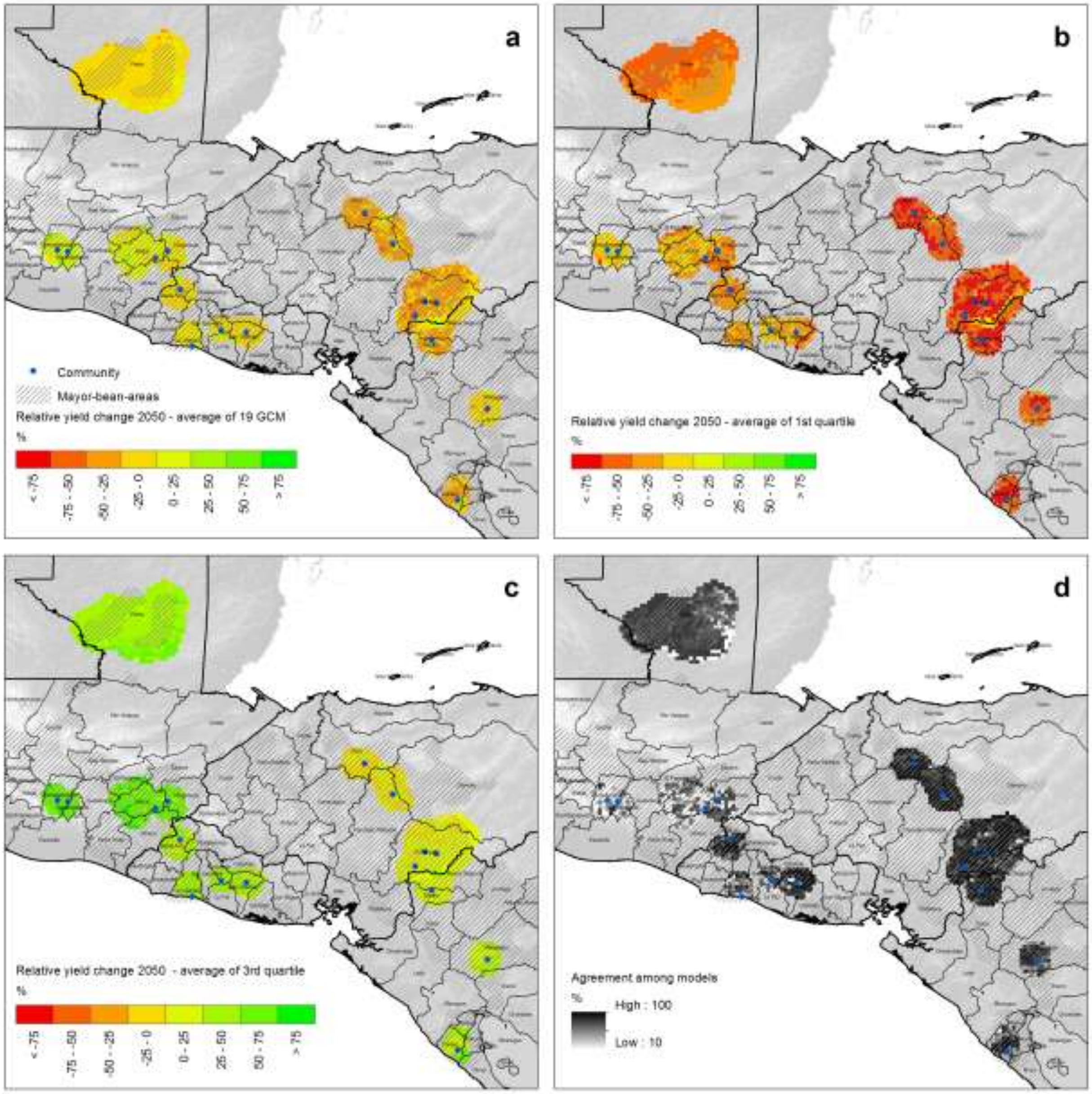


Figure 37: Predicted changes in beans yield and breadth of climate models uncertainty. a relative yield change as average of 19 GCMs for 2050, b average of the 1st quartile of GCMs, c average of 3rd quartile of GCMs, and d breadth of GCMs agreeing in yield change prediction by DSSAT

6.8 Socio-economic impacts and focus area vulnerability analyses

Based on the presented results we selected 3-4 sites in each country to carry out socio-economic analyses.

Nicaragua

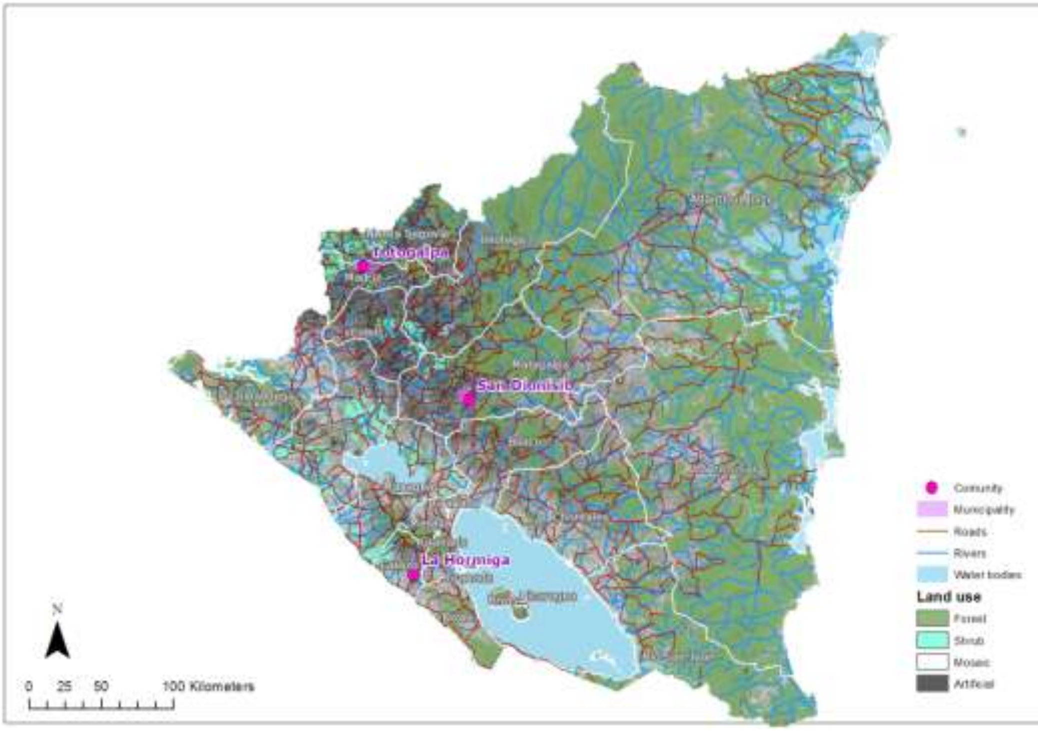


Figure 38: Selected locations in Nicaragua for participatory research activities

Honduras

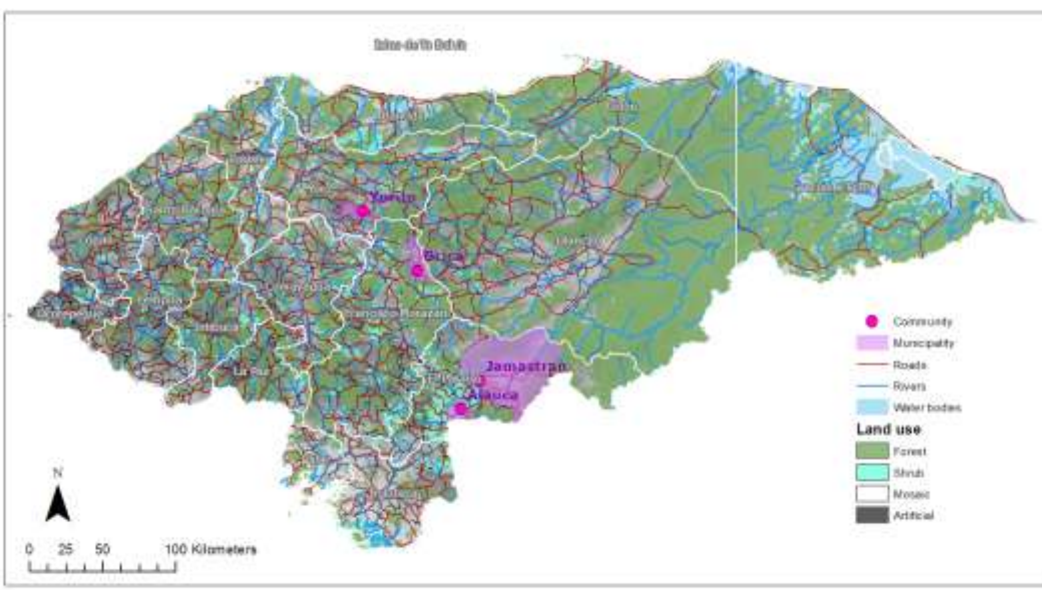


Figure 39: Selected locations in Honduras for participatory research activities

El Salvador

Figure 40: Selected locations in El Salvador for participatory research activities

Guatemala

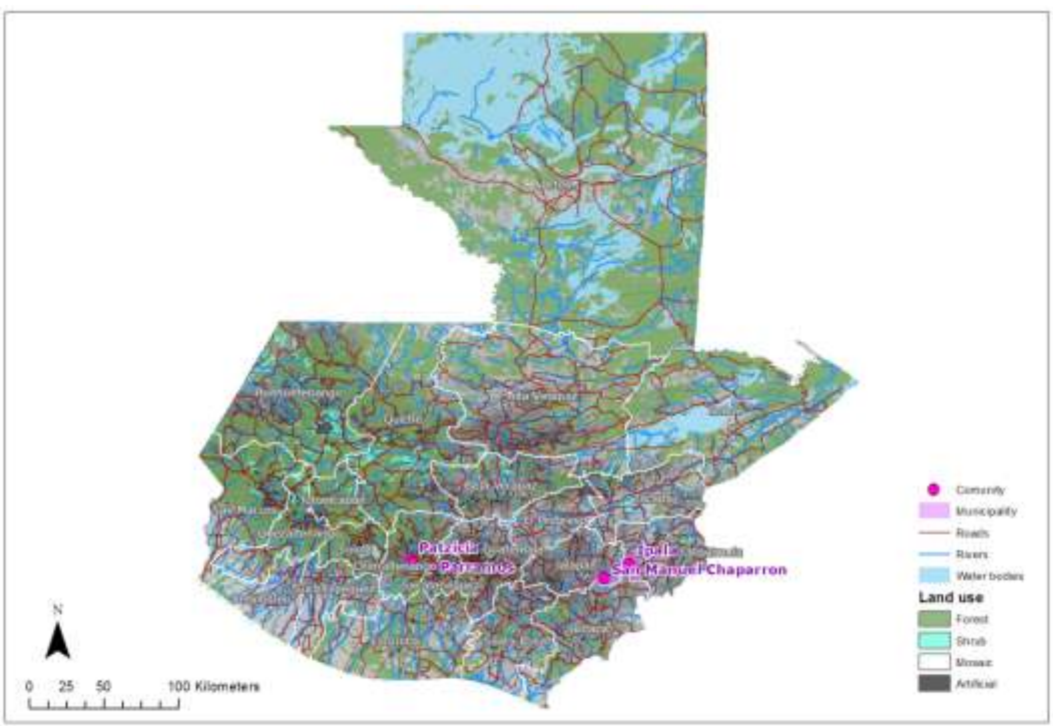


Figure 41: Selected locations in Guatemala for participatory research activities

6.8.1 Focus groups and general characteristics of selected focus areas

Focal Groups were carried out in Honduras, El Salvador, and Nicaragua since unexpected climatic events (flooding in Oct-Nov 2011) prevented us from implementing focal groups in Guatemala. The meetings allowed collecting information on four general aspects of the focus areas: main activities and trends, main sources of food and income, availability of different types of capital and a general perception of communal future strengths and threats. The information was used to characterize the focus areas and to adjust the questionnaire to be used in the survey. We present a short summary of the focal group meetings

6.8.1.1 Main activities and trends

As expected, maize and beans were found as important activities in all selected focus areas (Figure 42) proofing the correct selection of these focus areas. Sorghum ("maicillo") and activities related to the production of animal proteins were also mentioned as important activities. Growing fruits and vegetables was not important in Nicaragua, while coffee production was important only in Honduras.

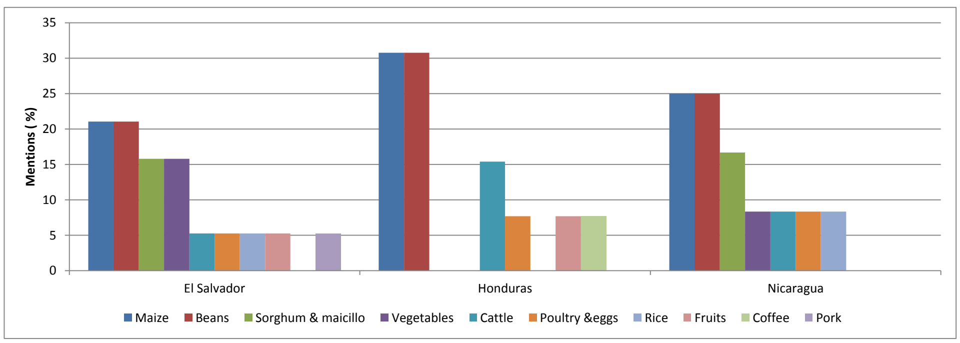


Figure 42: Main activities identified in focus areas

The information about trends of main activities was not conclusive at the focus area level. Table 30 shows the perceptions at the country level. Although this might be influenced by recent climatic and/or economic events, the information points to a trend slightly declining with respect to maize and beans and slightly increasing with respect to sorghum and livestock.

Table 30: Perceived trends of main activities by country

	Country		
Activity	**El Salvador**	**Honduras**	**Nicaragua**
Beans	Same/Decreasing	Decreasing/Same	Mixed situation
Maize	Same	Decreasing/Same	Mixed situation
Sorghum/Maicillo	Same/Increasing		Mixed situation
Vegetables	Decreasing		
Livestock	Same	Increasing	Same

Farmers‘ perceptions point to economic as well as climatic events as main drivers of perceived trends (Figure 43) with the exception of El Salvador where climatic drivers (rain intensity and frequency) were strongly associated to the perceived trends.

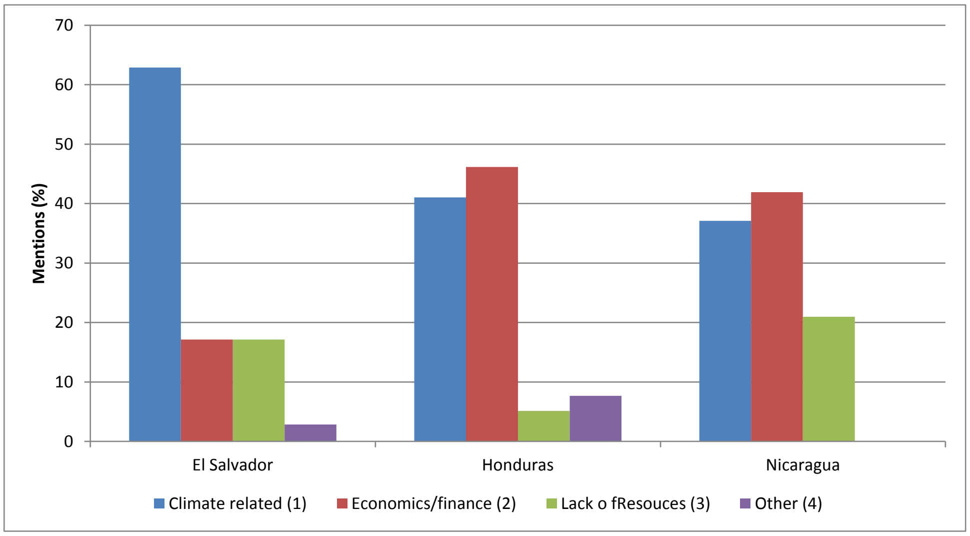


Figure 43: Main drivers perceived by the community

Notes. (1) Drought at planting time, rain frequency, intensity, *canícula*, heat, flooding; (2) expensive inputs, lack of access to credit, low production prices, lack of market access (3) lack of labor, seeds, machinery, good land, (4) poor crop management, diseases/pests.

With respect to the main planting season for maize and beans, all the focus areas coincide that main planting season for maize is “Primera” (beginning of the rainy season) while beans is mainly planted in the “Postrera” season, although a significant amount of beans is also planted in “Primera”. With respect to the 2010 harvest, maize production was superior relative to 2005 and 2000 while beans could not match previous years’ results. These changes were attributed equally to climatic (drought, canícula, rain and wind) and to economic (prices and lack of resources) causes.

6.8.1.2 Livelihoods, food and income

Information on food composition shows the consumption of maize and beans as main source of energy. (Figures 44 - 45). In general, households seem to follow a diversified and balanced diet (Figure 44) with respect to the consumption of carbohydrates and proteins, showing some deficiencies in the consumption of fruits and vegetables.

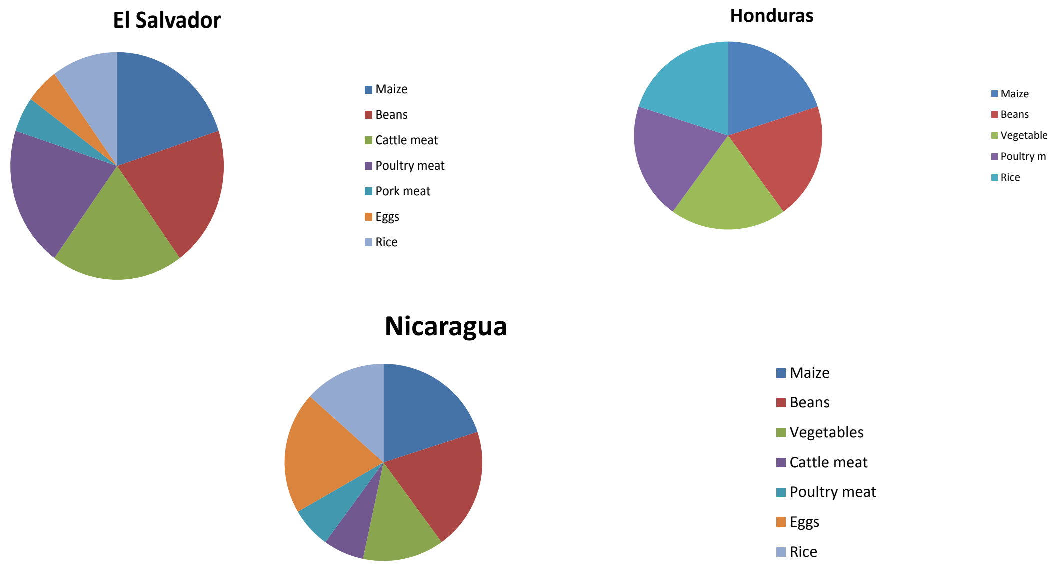


Figure 44: Approximate composition of the diet in focus areas

The profile of the main sources of income shows a significant level of diversification, were beans, maize, remittances and nonagricultural activities are important income sources in all the three countries. Poultry and egg production are important for income generation in El Salvador and Honduras but not in Nicaragua, where sorghum is important.

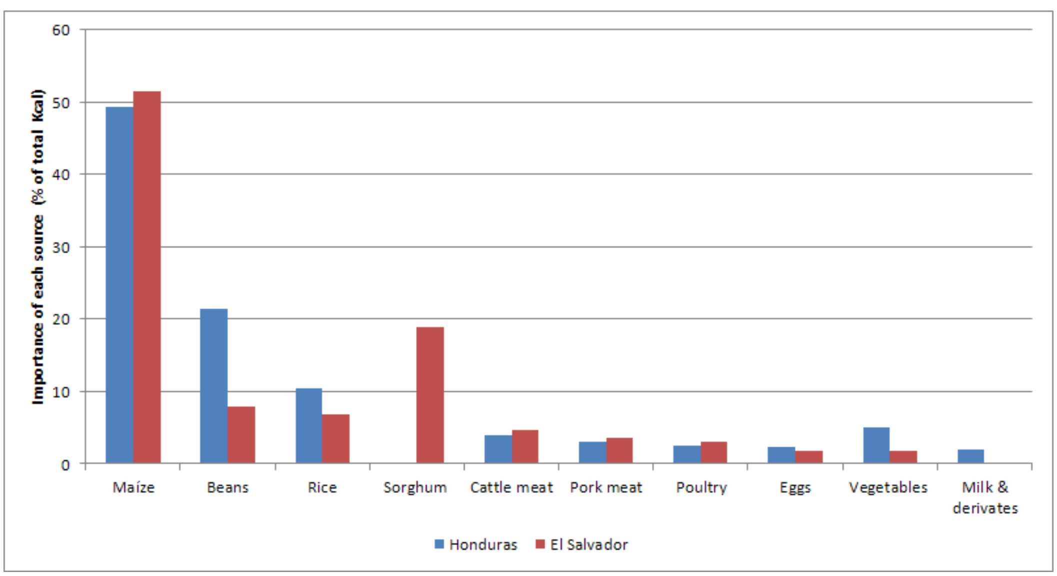


Figure 45: Sources of energy (Kcal) in Honduras and El Salvador

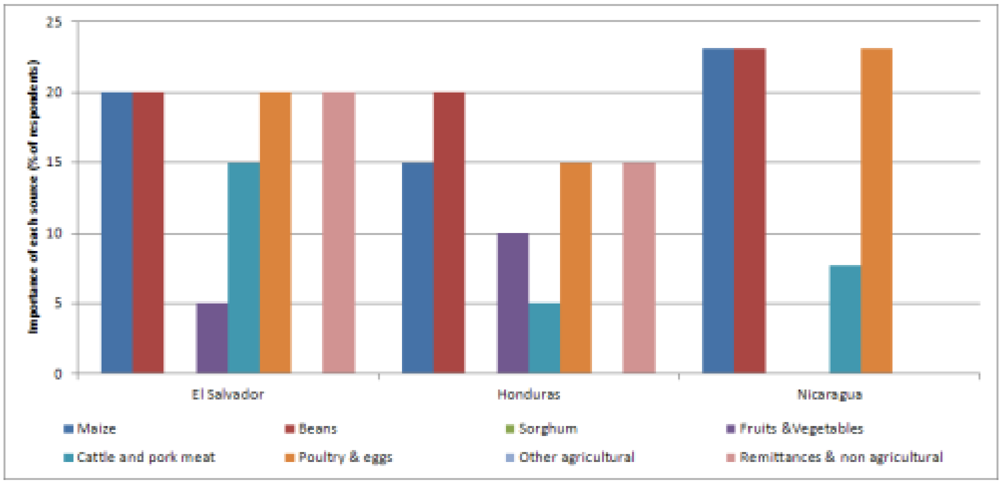


Figure 46: Main sources of income

6.8.1.3 Livelihoods and availability of different capitals

In terms of the availability of capital the farmer groups focused on three aspects: land tenure, water availability and access to the products and inputs (types of roads) markets. The information allowed for the identification of the general land tenure structure of the respective country (Figure 47) but showing also some variability among focus areas. Nicaragua show more permanent (owners and rental) land tenure structures. The reverse is reflected in terms of water availability where Nicaragua seems to have the greater fragility in terms of consumption of untreated water (Figure 48). In all countries there seems to exist a certain level of availability of water for irrigation.

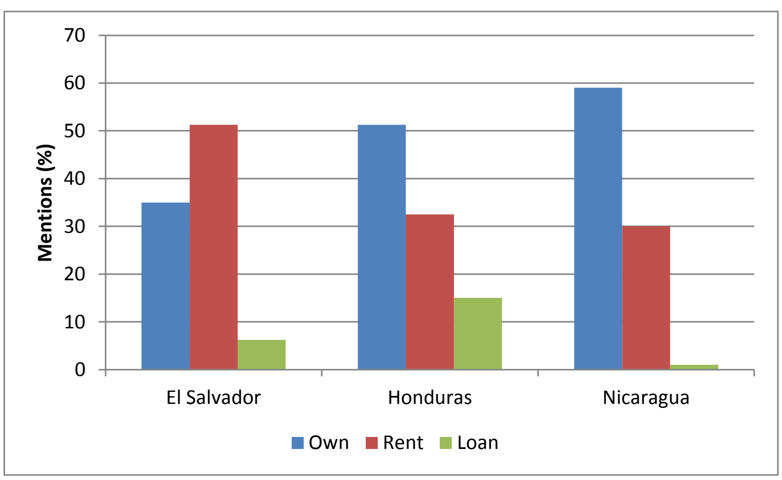


Figure 47: Forms of land tenure

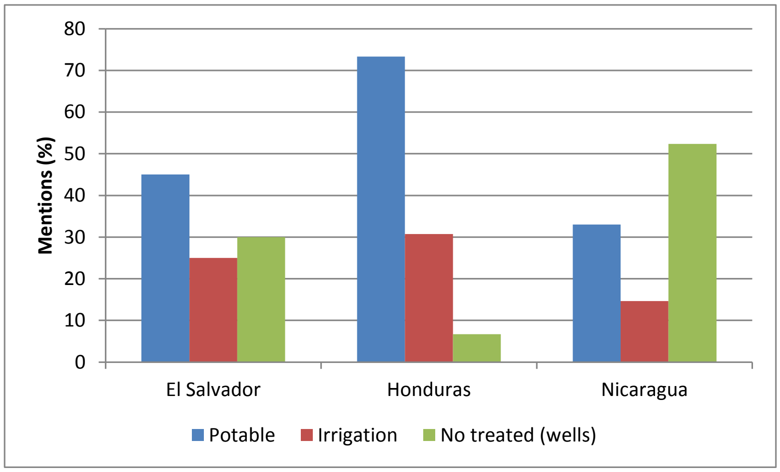


Figure 48: Water availability

With regard to the quality of access roads, information from the focus groups (Figure 49) show a good availability of access roads throughout the year in Honduras and Nicaragua, but not in El Salvador, where the road network often allow access only during the dry season.

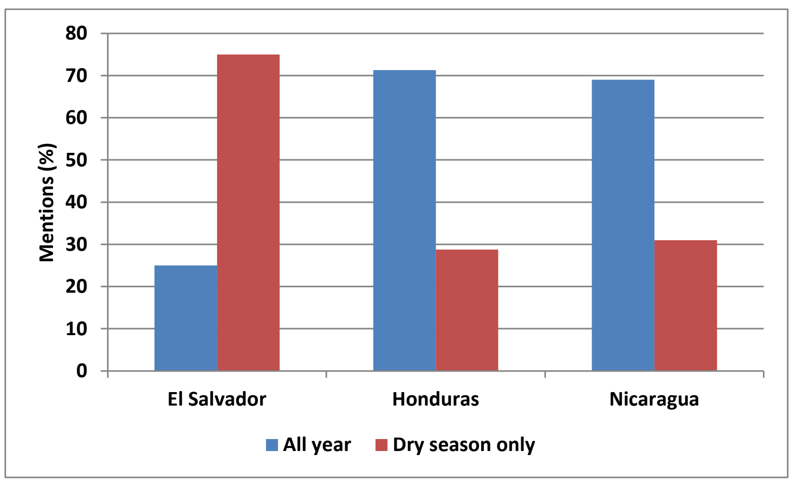


Figure 49: Availability of access roads

6.8.1.4 Perceptions of future threats and opportunities

Information on future threats perceived by the participants as important focused on those related to climatic events and social threats (security) which are common to all focus areas, while economic and financial factors were more of a concern in Honduras.

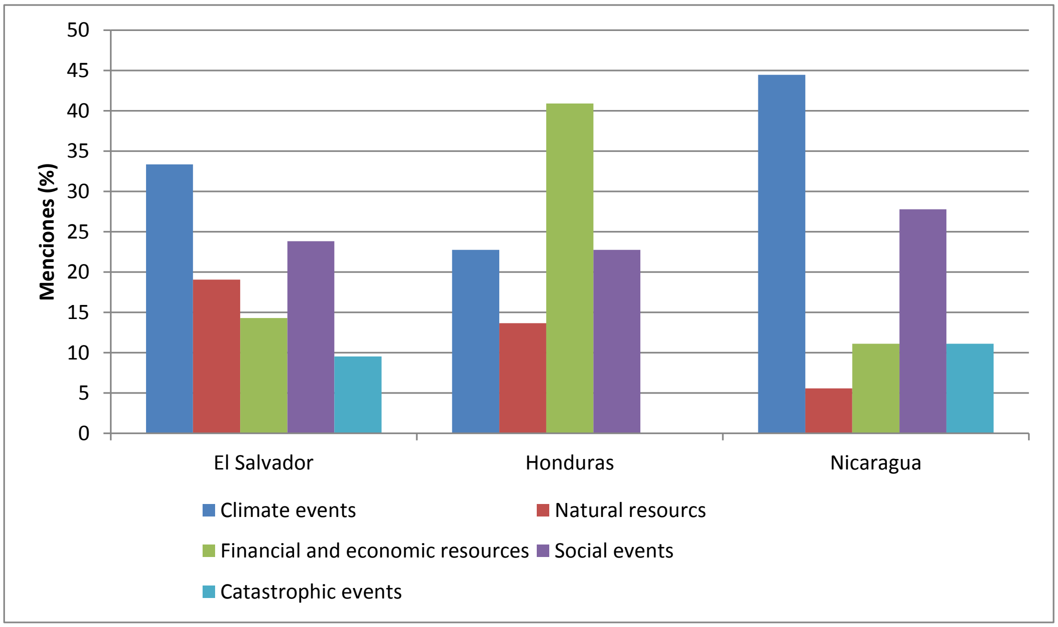


Figure 50: Perception of the nature of future threats

With regard to future opportunities, the information revealed some specificity of views by country, perhaps reflecting the recent experiences in each of them (Figure 51). In all countries, strengthening of human and social resources is important, being also important the promotion of projects of sustainable development in El Salvador, public investment in Honduras, and the change of activities in Nicaragua.

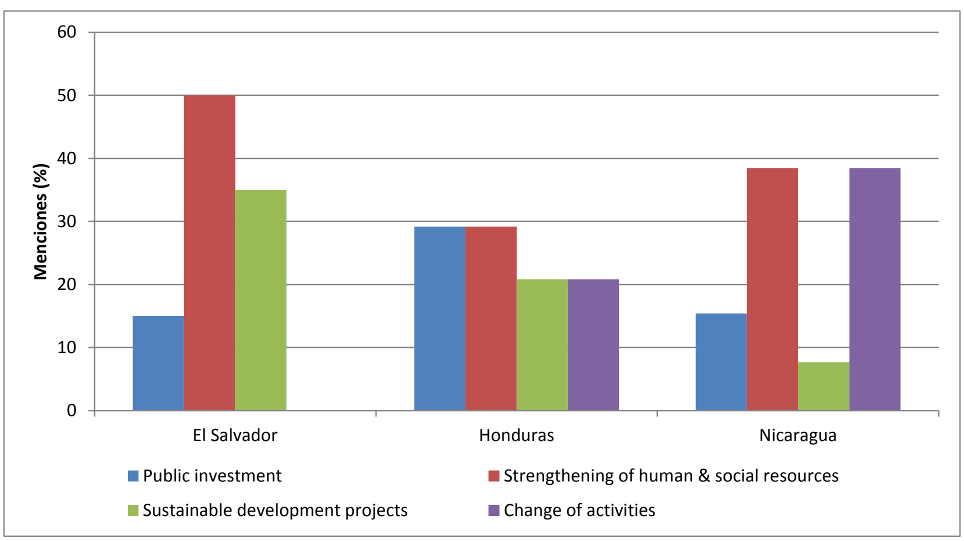


Figure 51: Perception of the nature of future opportunities

6.8.2 Impact on yield distribution at the aggregate level

The following sections present the impact on yield distribution at the aggregate level for each of the four countries. For each country, the first table presents the area cropped with maize and beans in each department, as well as the mean and standard deviation of beans and maize productivity estimated by the DSSAT model for the base (2000) and the target (2020s) years. The second table presents the resulting simulated distribution of potential loss.

6.8.2.1 Nicaragua

Table 31: Estimated change in maize and beans productivity in Nicaragua by 2020 at the department level

Department		Beans: DSSAT yield (kg/ha)						Maize: DSSAT yield (kg/ha)				
	Area (ha)	Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)	Area (ha)	Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)
Atlántico Norte	30,702	635	24	656	31	3	71,948	3,518	138	3,652	208	4
Atlántico Sur							74,093	3,709	393	3,780	334	2
Boaco	3,815	533	96	468	130	-12	43,671	3,504	537	3,340	809	-5
Carazo	2,451	585	96	412	180	-30	6,776	2,534	820	2,184	1,004	-14
Chinandega	2,394	599	30	471	78	-21	8,167	1,949	484	1,539	468	-24
Chontales	3,980	604	22	610	8	1	10,942	1,650	568	1,238	801	-32
Estelí	9,413	590	73	479	138	-19	8,988	2,371	811	2,142	1,025	-11
Granada	1,577	566	92	361	179	-36	5,418	2,209	565	1,676	979	-24
Jinotega	30,748	662	37	640	82	-3	28,273	1,937	182	1,917	284	-4
Leon	8,051	513	75	460	51	-10	37,527	3,232	650	2,918	823	-10
Madriz	7,973	602	73	474	182	-21	13,821	1,832	266	1,612	439	-9
Managua	2,323	487	70	450	100	-8	6,064	2,506	645	2,184	796	-15
Masaya	882	534	91	443	106	-17	3,075	1,798	294	1,779	392	16
Matagalpa	46,818	610	77	577	156	-5	24,765	1,885	291	1,753	355	-24
Nueva Segovia	22,696	652	61	568	130	-13	30,270	3,188	669	2,878	909	-10
Rio San Juan	11,335	627	32	620	28	-1	14,657	3,178	482	2,720	729	-16
Rivas	3,569	402	68	210	118	-48	9,169	3,131	711	2,398	1,238	-23

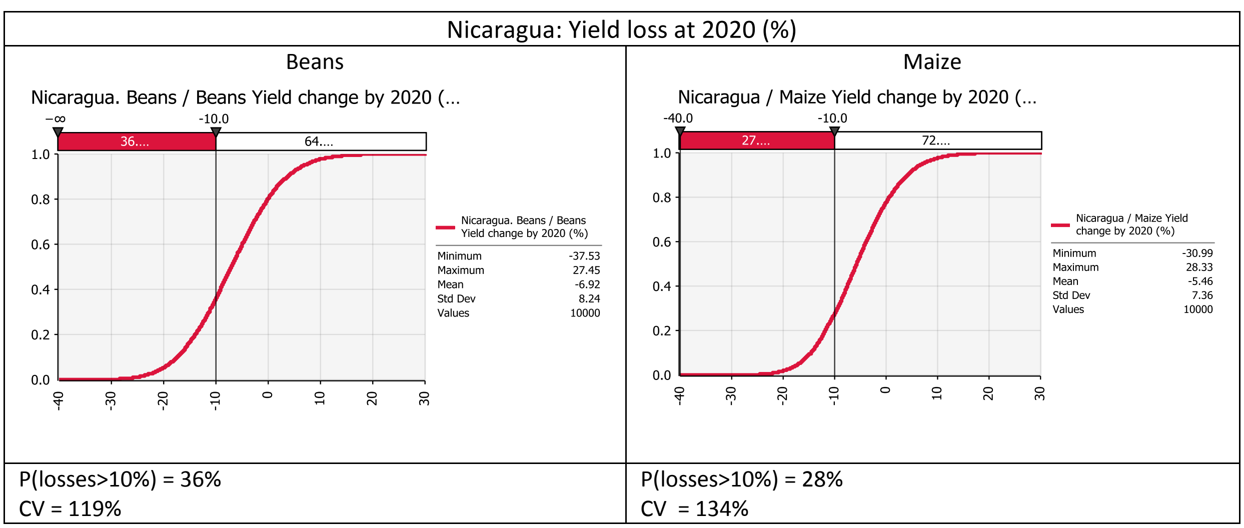
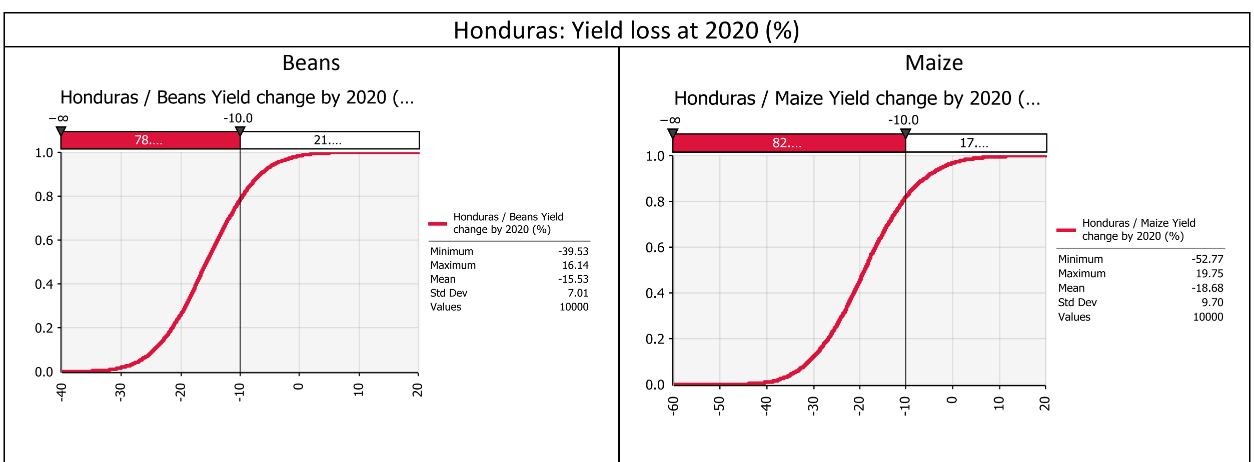


Figure 52: Distribution of the potential yield loss in Nicaragua by 2020

6.8.2.2 Honduras

Table 32: Estimated change in maize and beans productivity in Honduras by 2020 at the department level

Department / Region	Area (ha)	Beans: DSSAT yield (kg/ha)					Area (ha)	Maize: DSSAT yield (kg/ha)				
		Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)		Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)
Olancho	12,862	601	70	474	101	-21						
F. Morazán	13,144	643	48	524	139	-19						
Yoro	5,679	615	81	466	126	-24						
Comayagua	7,074	693	46	621	96	-10						
Santa Bárbara	5,656	666	44	564	137	-15						
Copán	6,119	683	23	642	50	-6						
El Paraíso	11,127	600	93	444	174	-26						
Lempira	5,586	675	50	658	56	-3						
Intibucá	4,607	673	34	662	46	-2						
Cortés	2,101	594	97	446	192	-25						
Choluteca	4,241	567	118	451	152	-20						
La Paz	2,291	643	47	623	101	-3						
Ocotepeque	957	663	58	690	31	4						
Valle	441	623	28	497	53	-20						
Sur							802	2,552	692	1,943	896	-26
C. Occidental							1,500	3,289	493	3,062	579	-7
Norte							1,949	3,130	709	2,262	955	-28
L. Atlántico							1,754	3,101	728	2,338	929	-25
Nor oriental							2,325	3,109	616	2,442	928	-22
C. Oriental							1,654	2,957	515	2,316	741	-23
Occidental							1,401	3,435	383	3,087	543	-10



Beans	Maize
P(losses>10%) = 79% CV = 45%	P(losses>10%) = 82% CV = 52%

Figure 53: Distribution of the potential yield loss in Honduras by 2020

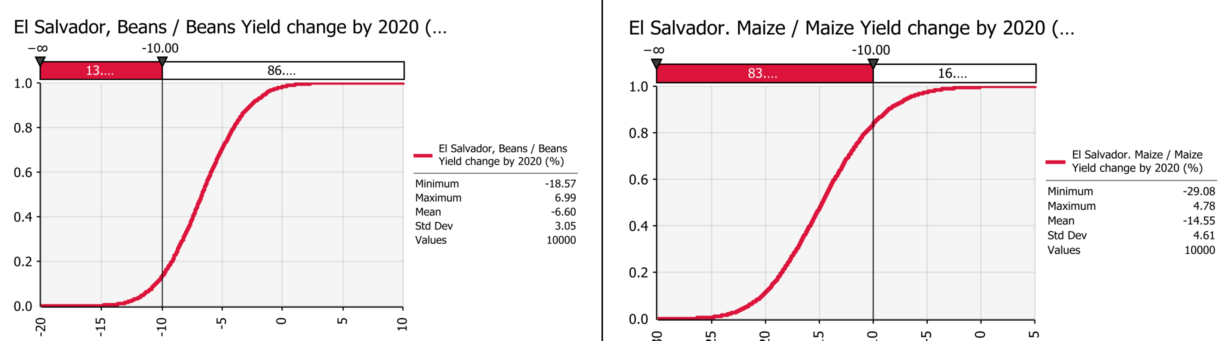
6.8.2.3 El Salvador

Table 33: Estimated change in maize and beasn productivity in El Salvador by 2020 at the department level

Department		Beans: DSSAT yield (kg/ha)						Maize: DSSAT yield (kg/ha)				
	Area (ha)	Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)	Area (ha)	Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)
Ahuachapán	4,471	610	59	582	60	-4	22,950	2,538	886	2,536	494	-2
Cabañas	3,027	662	27	593	37	-10	7,694	3,405	280	2,802	317	-19
Chalatenango	2,397	650	35	609	32	-6	23,869	3,362	417	3,101	376	-8
Cuscatlán	5,711	666	32	593	38	-11	13,681	3,344	222	2,744	363	-19
La Libertad	13,294	638	35	610	34	-4	21,969	3,064	345	2,695	402	-14
La Paz							19,114	3,649	168	2,154	491	-41
La Unión							16,317	2,508	919	2,094	543	-24
Morazán	1,555	713		662		-7	14,992	3,167	391	2,756	570	-15
San Miguel	4,419	607	40	562	68	-7	19,643	2,737	506	2,250	471	-24
San Salvador	7,428	650	25	596	24	-8	20,031	3,093	612	2,613	315	-18
San Vicente	9,024	673	26	611	48	-9	18,116	2,900	491	2,456	529	-20
Santa Ana	16,652	646	50	618	40	-4	19,913	3,095	403	2,772	420	-12
Sonsonate	4,508	620	63	590	45	-5	19,944	2,875	781	2,626	448	-10
Usulután	8,959	649	44	600	54	-8	23,658	2,480	681	2,166	435	-21

El Salvador: Yield loss at 2020 (%)

Beans | Maize



P(losses>10%) = 13%
CV = 46%

P(losses>10%) = 84%
CV = 32%

Figure 54: Distribution of the potential yield loss in El Salvador by 2020

6.8.2.4 Guatemala

Table 34: Estimated change in maize and beans productivity in Guatemala by 2020 at the department level

Department		Beans: DSSAT yield (kg/ha)						Maize: DSSAT yield (kg/ha)				
	Area (ha)	Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)	Area (ha)	Mean 2000	STD 2000	Mean 2020	STD 2020	Change by 2020 (%)
Alta Verapaz	8,578	616	36	572	35	-7	104,177	3,851	520	3,873	569	1
Baja Verapaz	7,236	628	44	583	86	-7	10,259	3,238	591	2,911	735	-10
Chimaltenango	8,236	594	55	596	39	0	456	2,756	703	2,616	600	-6
Chiquimula	17,621	619	69	570	84	-8	9,797	2,867	716	2,456	791	-16
El Progreso	5,366	501	129	531	87	6	5,030	2,486	991	2,835	1,062	15
Escuintla	907	578	24	549	41	-5	19,348	2,686	699	2,251	772	-18
Guatemala	9,511	594	38	578	72	-3	1,771	2,666	366	2,439	434	-10
Huehuetenango	16,859	543	210	610	115	12	29,327	2,935	1,454	3,149	1,172	8
Izabal	3,273	669	17	649	39	-3	12,082	3,628	542	3,274	659	-10
Jalapa	13,329	592	64	589	59	-1	1,574	2,783	673	2,627	605	-7
Jutiapa	28,222	610	57	583	105	-4	8,193	2,684	547	2,363	631	-14
Petén	35,383	660	49	571	49	-13	50,772	3,209	536	2,523	699	-22
Quetzaltenango	2,502	487	152	639	29	31	11,686	2,178	1,467	2,701	1,088	24
Quiche	20,733	607	59	624	64	3	23,979	3,531	880	3,435	614	-2
Retalhuleu							43,463	2,780	737	2,297	1,098	-18
Sacatepéquez	1,430	577	57	597	26	4	1,356	2,464	536	2,604	431	6
San Marcos	5,992	435	235	601	136	38	17,543	2,262	1,550	2,860	1,259	27
Santa Rosa	12,571	601	57	597	99	-1	7,951	2,590	753	2,522	510	-3
Sololá	2,902	495	178	572	78	16	333	2,358	1,209	2,707	857	15
Suchitepéquez							31,063	3,183	809	2,936	954	-8
Totonicapán	3,255	510	172	625	72	23	5,468	1,689	1,346	2,489	785	47
Zacapa	4,178	484	112	447	125	-8	17,389	2,559	1,073	2,490	1,134	-3

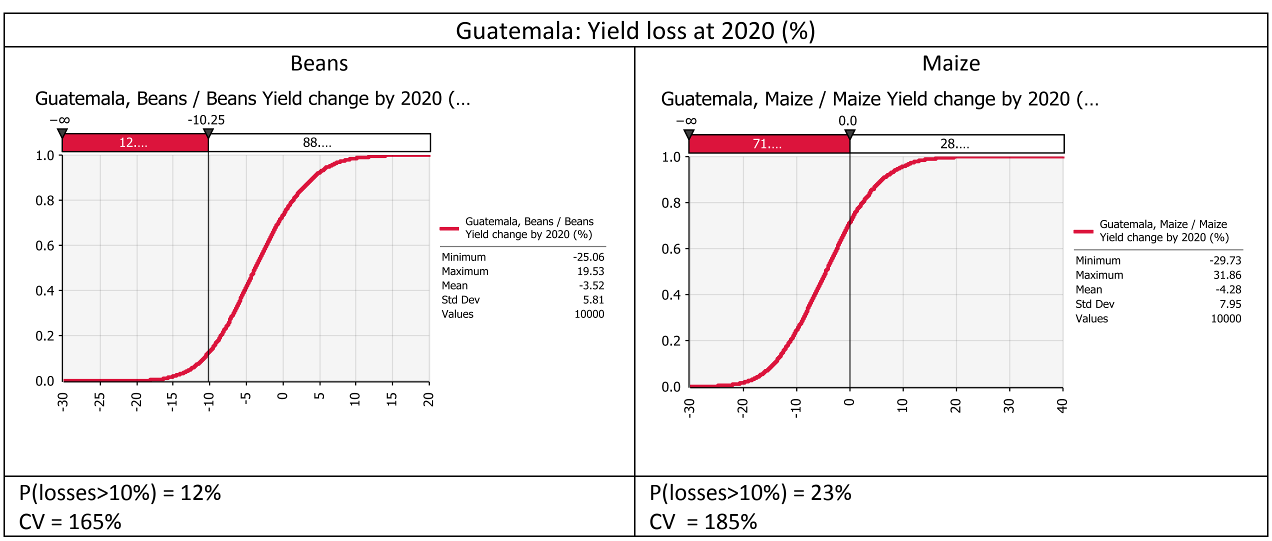


Figure 55: Distribution of the potential yield loss in Guatemala by 2020

Table 35 summarizes the results of the simulation for each country and crop. In the case of beans, Honduras and Nicaragua have the highest probability of facing yield losses larger than 10% by 2020. In the case of maize, Honduras and El Salvador have high probability (greater than 80%) of having losses above 10% of maize yield by 2020.

Table 35: Summary of expected changes in yield distribution by 2020

Country	Bean	Maize
Nicaragua	P(losses>10%) = 36% CV = 119%	P(losses>10%) = 28% CV = 134%
Honduras	P(losses>10%) = 79% CV = 45%	P(losses>10%) = 82% CV = 52%
El Salvador	P(losses>10%) = 13% CV = 46%	P(losses>10%) = 84% CV = 32%
Guatemala	P(losses>10%) = 12% CV = 165%	P(losses>10%) = 23% CV = 185%

6.8.3 Value of aggregate production losses

Table 36 summarizes the means and standard deviation of maize and bean yield distributions at the country level for two key time periods (current and 2020s) and their relative change.

Table 36: Estimated maize and beans yield changes in 2000 and 2020 at the country level

	Maize yield (kg/ha)											
	Nicaragua			Honduras			El Salvador			Guatemala		
	2000	2020	Change (%	2000	2020	Change (%)	2000	2020	Change (%)	2000	2020	Change (%
Average	3,033	2,904	-5	3,101	2,511	-19	2,985	2,547	-15	3,148	3,004	-4
SD	421	549	7	582	801	10	526	443	5	785	812	8
	Bean yield (kg/ha)											
	Nicaragua			Honduras			El Salvador			Guatemala		
	2000	2020	Change (%	2000	2020	Change (%	2000	2020	Change (%	2000	2020	Change (%
Average	615	571	-7	636	537	-16	646	603	-7	589	576	-4
SD	56	103	8	62	115	7	39	42	3	77	76	6

Figure 56 shows the time series of maize and beans prices paid to farmers for the period 1985-2010, as well as the estimated linear trend line up to the year 2020.

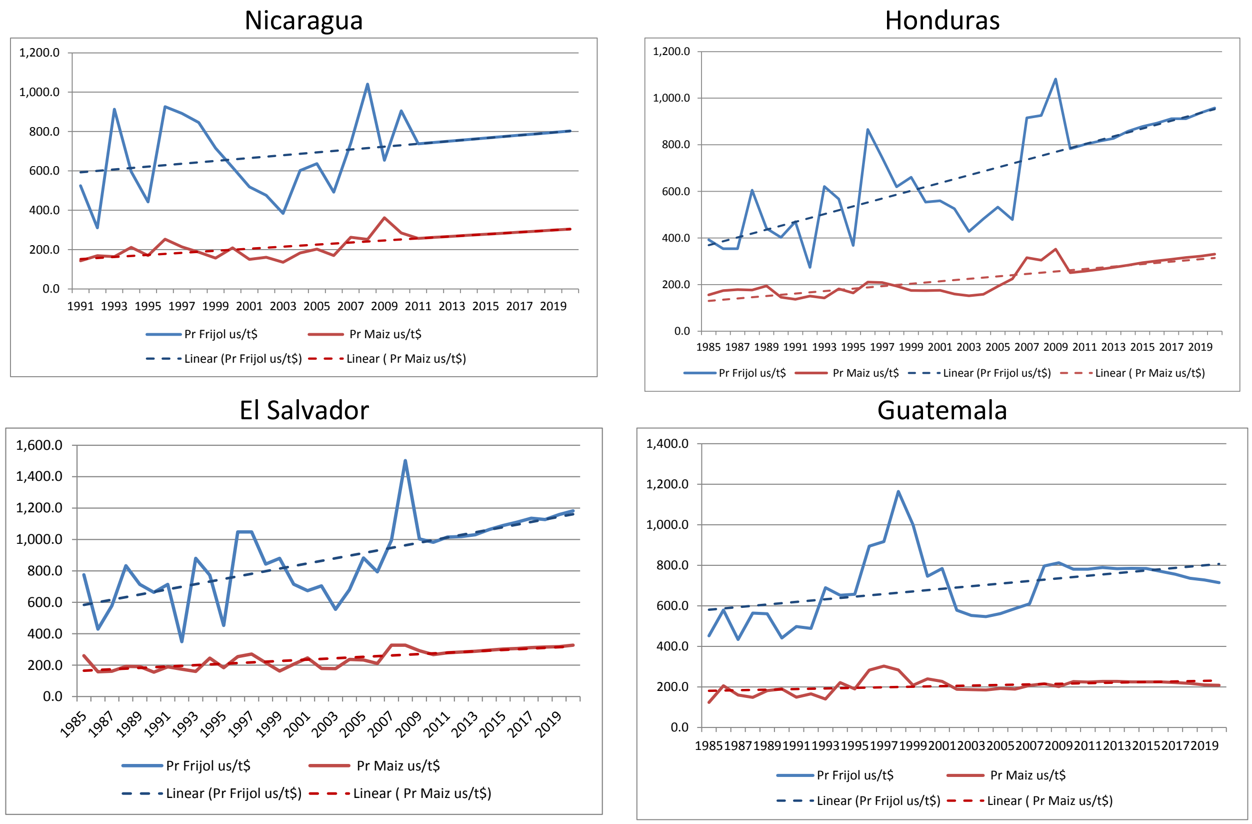


Figure 56: Maize and beans prices paid to farmers (1985-2020)

Prices at 2020 for both crops are displayed in Figure 57. Maintaining the trend, beans prices are above of those paid for maize by approximately a ratio of 2.5 to 1. This is important considering that prices are the weighting factor when estimating value of production.

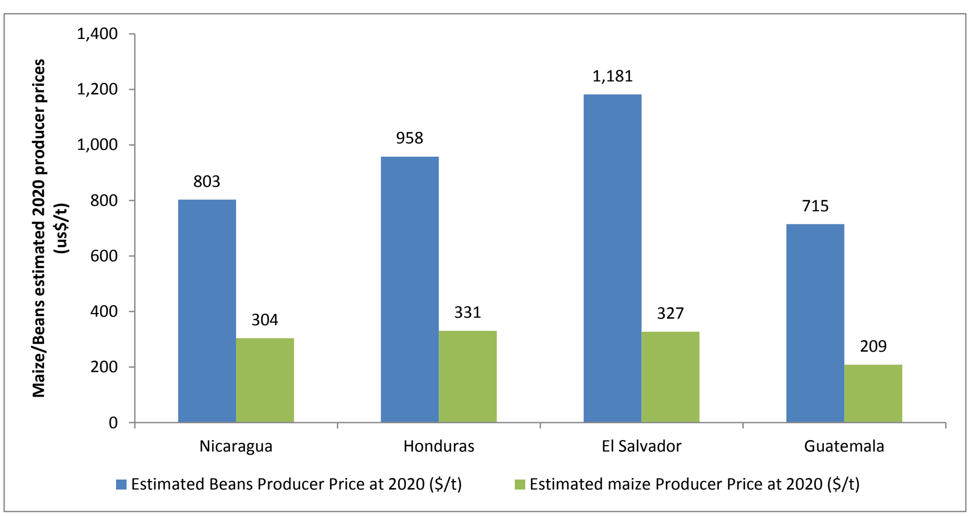


Figure 57: Estimated 2020 farm prices for maize and beans

Figure 58 shows the results of the estimated average production losses in physical (t) and value (thousands of US$) terms for maize, beans and the total values for all four countries.

Although these are rough estimates based on linear assumptions and not taking into account the variability across time and regions, some key points emerge from the analysis. In general production losses for maize are by far larger than those for beans. This is also true in terms of value even when price differences tend to smooth the losses in value terms. Honduras and El Salvador are the two countries with larger maize production losses while in terms of beans only Guatemala differentiates from the other three countries with a relatively low level of potential losses. As a result the pattern of total potential losses points to El Salvador and Honduras as the two countries with larger potential losses followed by Nicaragua and Guatemala.

In the case of El Salvador, high potential maize losses together with high maize prices are main factors influencing this result. On the other hand, changes in variability seem not to be a problem in this country. On the opposite, Nicaragua presents low changes in the average production value but a substantial increase in production variability (increased risk level). Honduras presents the worst situation since it presents both high losses in the average production together with a substantial increase in variability (increased risk level).

Guatemala presents small changes in both average production and small change in variability. As a result the potential impact of climate change over maize-beans production in Guatemala seems to be much less important than that for the other three countries included in the analysis.

Table 37 summarizes the classification of each country according to type of changes predicted.

Table 37: Summary of the predicted types of changes on country level

		Change in the production average	
		Low	High
Change in the production variability	Low	**Guatemala**	**El Salvador**
	High	Nicaragua	**Honduras**

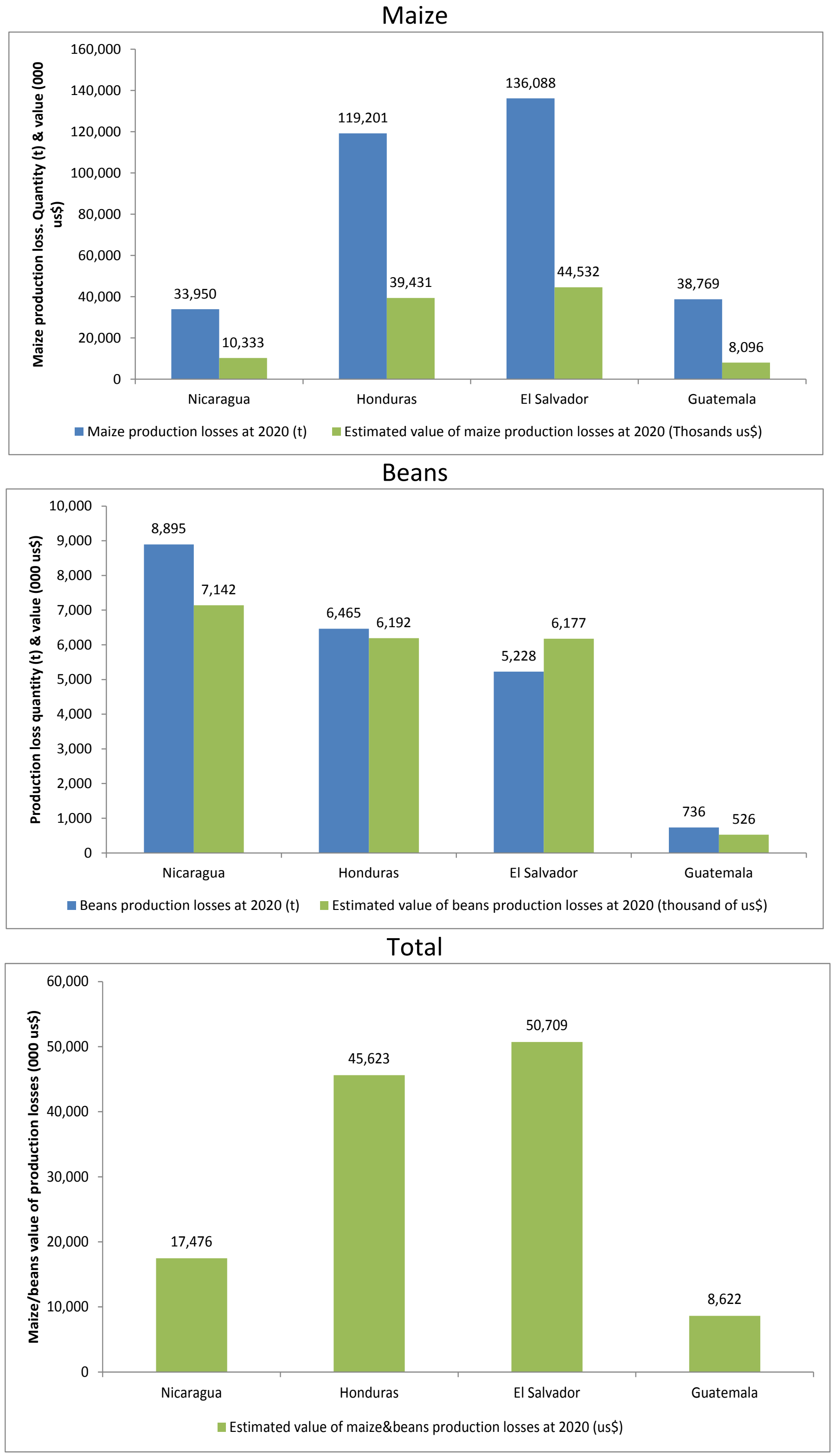


Figure 58: Quantity and value of maize and beans production losses in 2020

To illustrate predicted economic impacts on maize and beans production from climate change, we mapped the values in US$ on department level. The maps facilitate targeting of interventions on all levels to areas with significant losses and thus particular need for help. They also indicate areas with net economic gains.

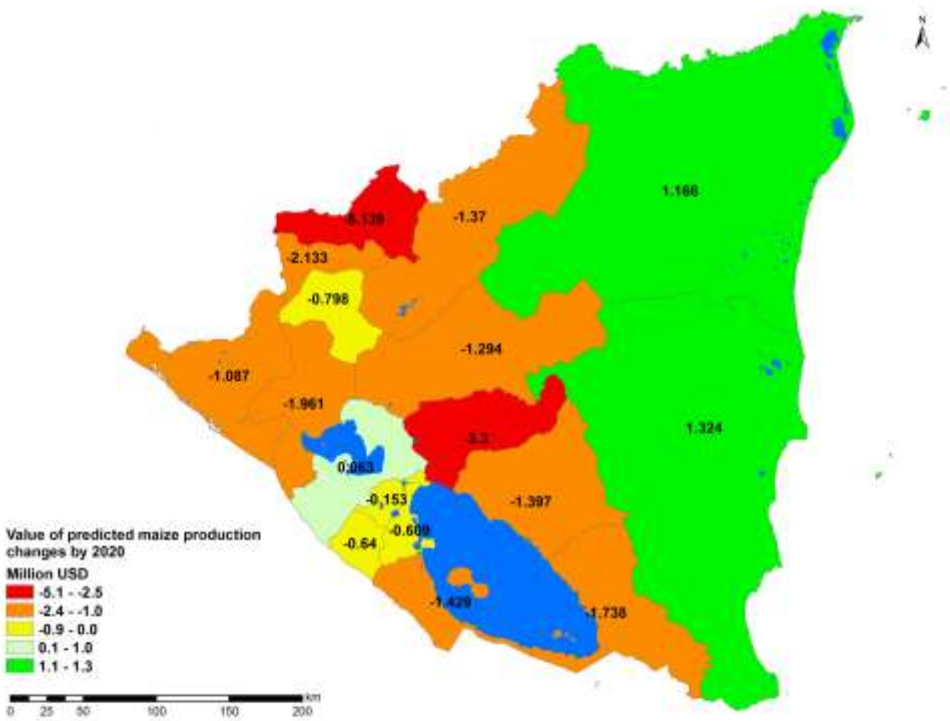


Figure 59: Value of predicted maize production changes for Nicaragua by 2020

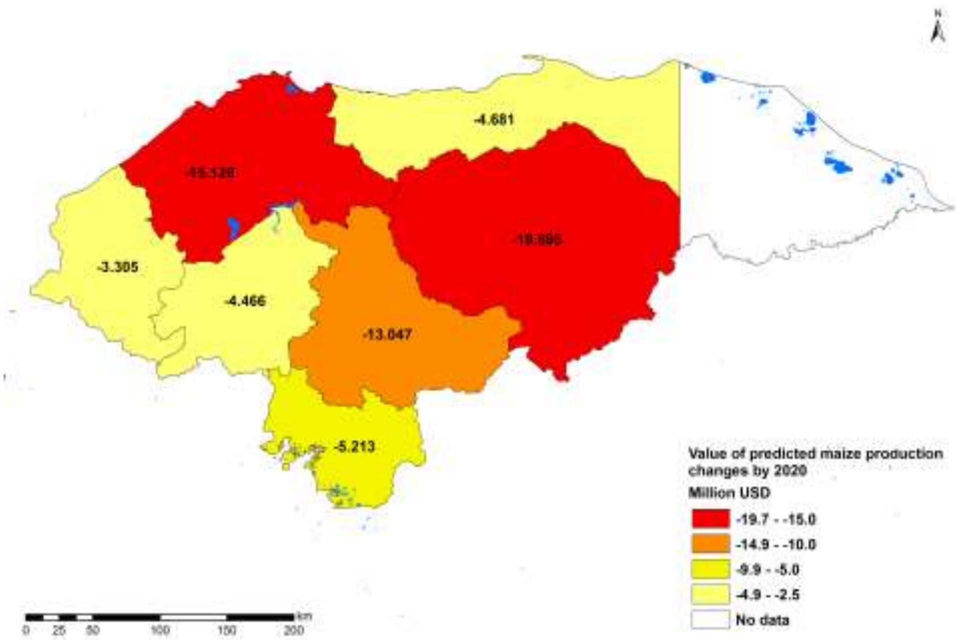


Figure 60: Value of predicted maize production changes for Honduras by 2020

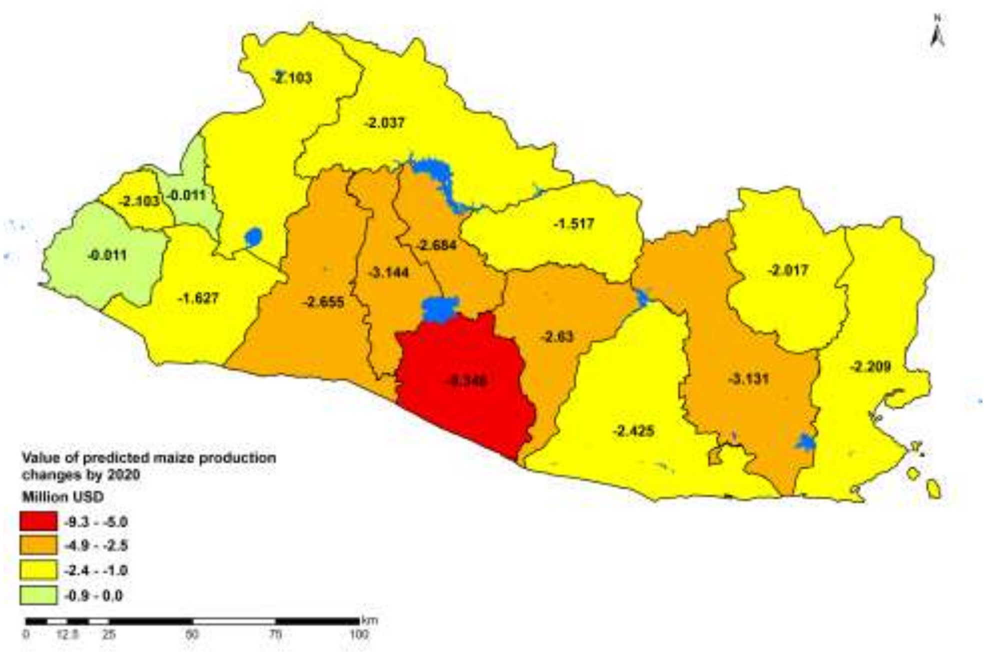


Figure 61: Value of predicted maize production changes for El Salvador by 2020

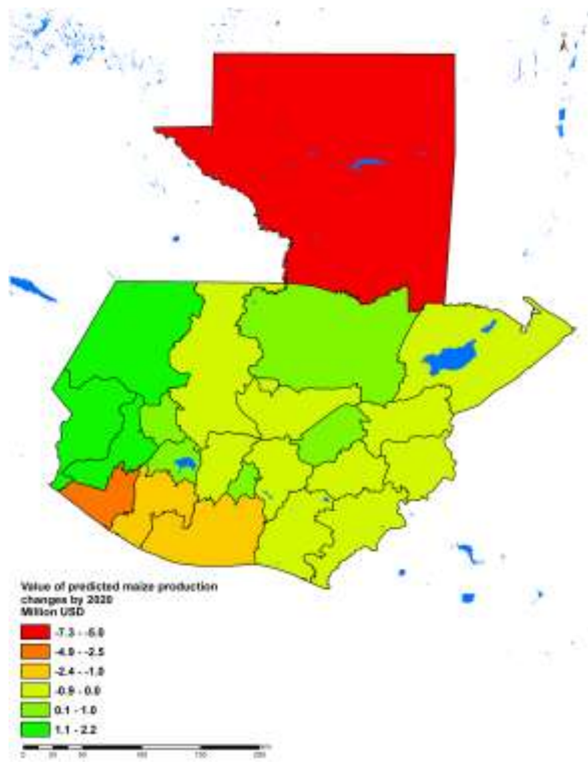


Figure 62: Value of predicted maize production changes for Guatemala by 2020

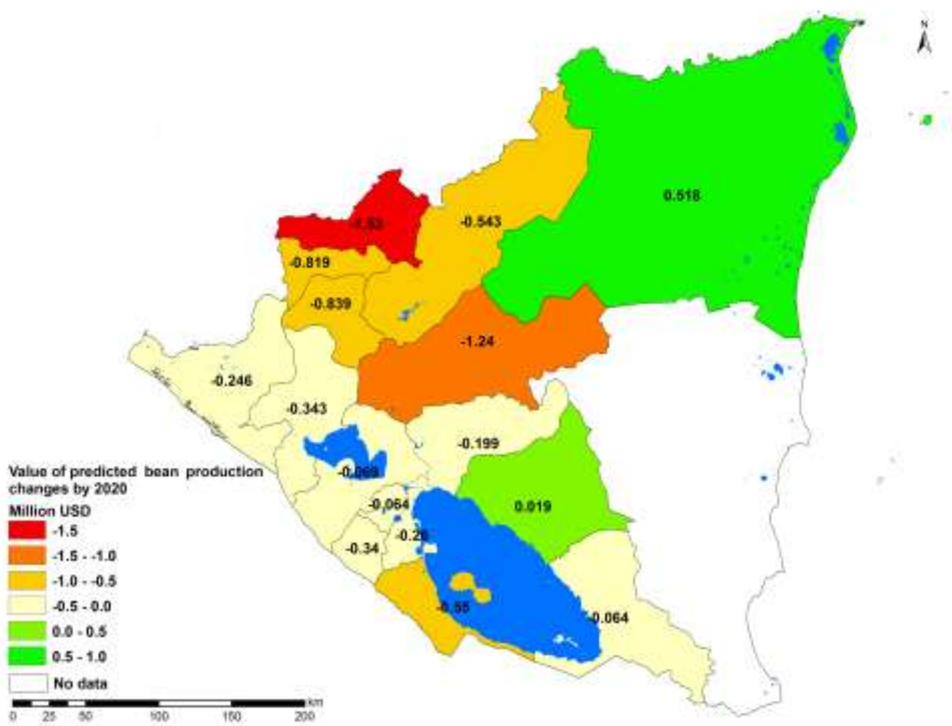


Figure 63: Value of predicted beans production changes for Nicaragua by 2020

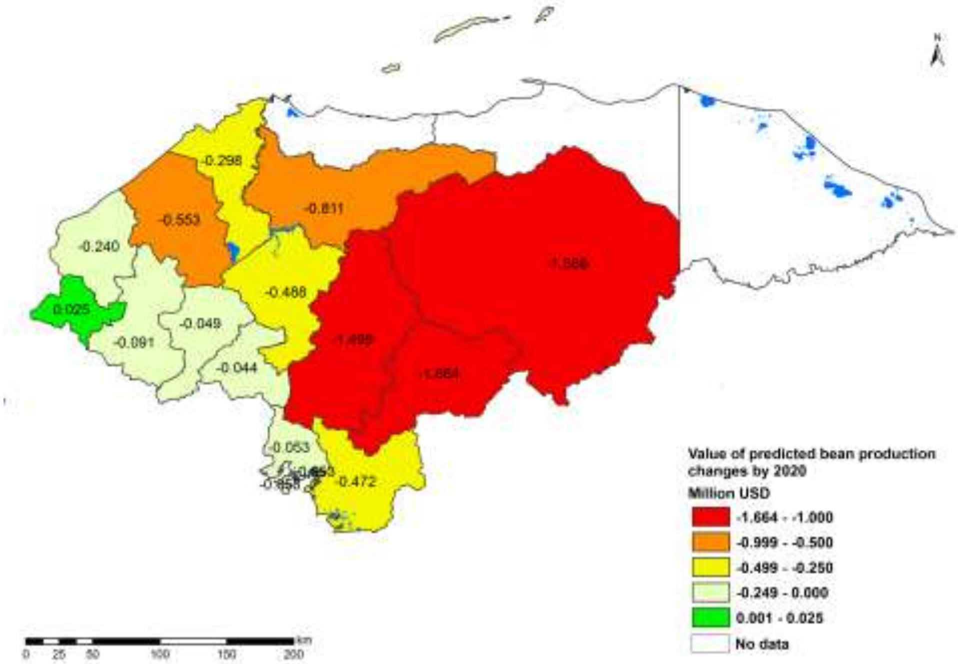


Figure 64: Value of predicted beans production changes for Honduras by 2020

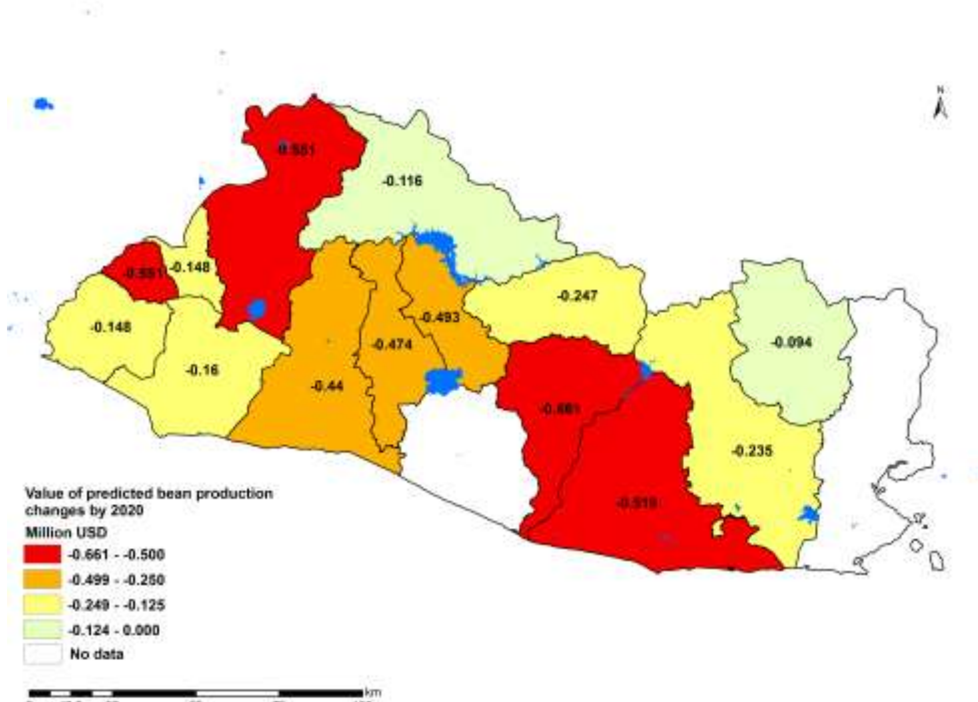


Figure 65: Value of predicted beans production changes for El Salvador by 2020

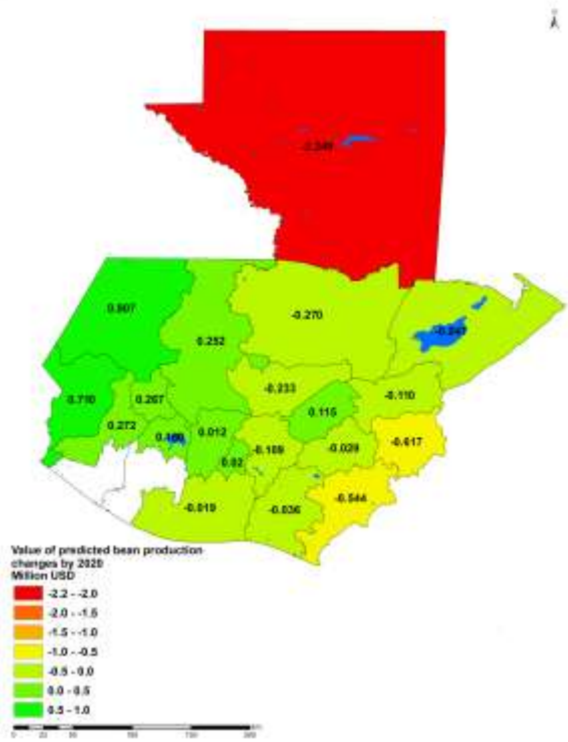


Figure 66: Value of predicted beans production changes for Guatemala by 2020

6.8.4 Impact at the disaggregate level

As outlined in chapter 5.6.2, field survey information was primarily aimed at the estimation of the ***vulnerability index of the household***, which is composed of three composite indices: (1) the ***level of exposure*** of the maize-beans cropping system to changes caused by climate change; (2) the ***level of sensitivity*** of the household to changes in the maize-beans production system, and (3) the ***resilience*** *or* ***adaptive capacity*** of the household. Once estimated the different components and the vulnerability index of the household "***i***" belonging to the focus area "***j***" (V_{ij} = high, medium, low), each focus area "***j***" is characterized by the frequency of occurrence of household within the different classes of vulnerability. The specific results are examined in the remaining of this section.

6.8.4.1 Exposure level of the maize-beans cropping system

This indicator refers to the impact of climate change at farm level, and modifies the impact on productivity predicted by climate models at the focus area level. Figure 67 illustrates the process of estimation.

Changes in temperature and precipitation	➡	I Impact on land productivity at the focus area level (predicted by the bio-physical model)	➡	II Adjustment factor at the household level (estimated)	➡	III ***Indicator***: Exposure level of the maize-beans cropping system (high, medium, low)

Figure 67: Process for the estimation of climate change impact on household level

In the following, we present the main results for the three stages.

Household exposure

Tables 9 and 10 show the minimum, the more likely and maximum values of the changes in the productivity of maize and beans at municipality level predicted by bio-physical models for two key time periods: the 2020s and 2050s, expressed in relative terms to the average performance in the country in the last 5 years. Expressing them in relative terms reveals that the impact on productivity of maize is generally higher than for beans. In terms of countries and focus areas, those of Guatemala presented the lowest levels of changes in both crops; the other three countries have significant levels of impact ranging from 12% to 46% for more likely values in maize and from no-losses to 16% for the more likely values in the case of bean

Table 38: Relative change in maize yield predicted by the bio-physical model at the focus area level

Country	Household	Average yield (kg/ha) (1)	Relative yield change predicted by the bio-physical model (% of the country yield average)(2)					
			2020s			2050s		
			Min.	More likely	Max.	Min.	More likely	Max.
El Salvador	El Rosario	**3,108**	-2	-17	-32	-3	-18	-33
	San Felipe		-2	-17	-32	-3	-19	-35
	San Rafael		0	-11	-22	-2	-15	-27
	Las Mesas		-2	-12	-22	-2	-12	-22
Honduras	Alauca	**1,551**	-33	-25	-34	-15	-21	-26
	Orica		-19	-21	-33	-9	-21	-32
	Jamastrán		-33	-25	-34	-17	-25	-34
	Yorito		-31	-30	-44	-16	-30	-44
Guatemala	S.M Chaparrón	**2,117**	4	-5	-13	4	-4	-13
	Ipala		-11	-19	-27	-11	-19	-27
	Patzicia		0	0	0	0	0	0
Nicaragua	Totogalpa	**1,414**	-14	-24	-35	-39	-27	-14
	San Dionisio		-33	-37	-41	-25	-38	-51
	La Hormiga		-40	-46	-51	-29	-42	-55

Notes:
(1) National yield average for the period 2005-2010. Source: FAOSTATS.
(2) The minimum values correspond to the values of the model adjusted for good soils; the maximum values correspond to poor soils; and the more likely value was estimated as the average between the two, under the premise that in the majority of the unit's production will be in a mixture of good and poor soils.

Table 39: Relative change in bean yield predicted by the bio-physical model at the focus area level

Country	Household	Average yield (kg/ha) [(1)]	Relative yield change predicted by the bio-physical model (% of the country yield average)					
			2020s			2050s		
			Min.	More likely	Max.	Min.	More likely	Max.
El Salvador	El Rosario	**875**	-3	-7	-10	-7	-10	-13
	San Felipe		-1	-3	-4	-3	-6	-8
	San Rafael		0	-4	-7	-4	-6	-9
	Las Mesas		-1	-4	-7	-6	-9	-12
Honduras	Alauca	**716**	-10	-16	-22	-17	-52	-34
	Orica		-11	-16	-21	-19	-23	-27
	Jamastrán		-7	-14	-21	-17	-23	-28
	Yorito[(1)]		-12	-19	-25	-20	-24	-29
Guatemala	S.M Chaparrón	**778**	0	-3	-6	-1	-4	-9
	Ipala		-4	-8	-11	-8	-10	-15
	Parramos		2	0	-2	1	0	-2
	Patzicia		1	-1	-3	-1	-1	-5
Nicaragua	Totogalpa	**725**	-13	-16	-22	-22	-26	-33
	San Dionisio		-7	-10	-15	-14	-16	-22
	La Hormiga		-4	-16	-28	-8	-23	-37

Note:
(1) National yield average for the period 2005-2010. Source: FAOSTATS.

The adjustment level

The factor to adjust these values to the household level was estimated according to the combinations shown in Table 40:

Table 40: Combinations used to estimate the adjustment level at the farming system

Conservation technologies	Inclination	Results	Adjustment
Yes	Flat	Conservation on flat land	3= Low
	Inclined	Conservation on slopes	3= Low
	Craggy	Conservation on craggy slopes	2= Moderate
No	Flat	No conservation on flat land	2= Moderate
	Inclined	No conservation on slopes	1= High
	Craggy	No conservation on craggy slopes	1= High

The household was considered as using a conservation technology if at least a conservation technique for soil preparation was used and/or if any technique of conservation for the crop management was applied. In the case of maize, the results (Figure 68) show that low adjustments dominate (i.e. the household receive the average impact predicted by the model), particularly in Honduras, with the exception of San Felipe (El Salvador), Patzicia in Guatemala and San Dionisio and Totogalpa in Nicaragua. However in all the focus areas of Guatemala, El Salvador and Nicaragua there are significant medium and high levels of adjustment, particularly in three focus areas of Nicaragua, two in El Salvador and one in Guatemala

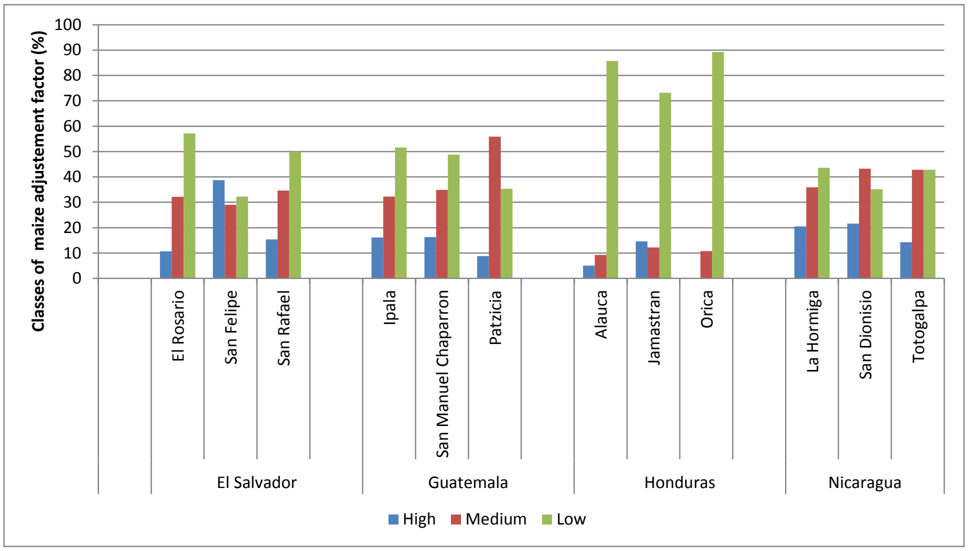


Figure 68: Classes of maize adjustement factor at farming level

In the case of beans, results show a similar distribution, which is predominantly a low level of adjustment (Figure 69) with the exception of Patzicia in Guatemala, and San Dionisio and La Hormiga in Nicaragua. However, there are significant levels of medium and high adjustments in all focus areas, with the exception of those of Honduras.

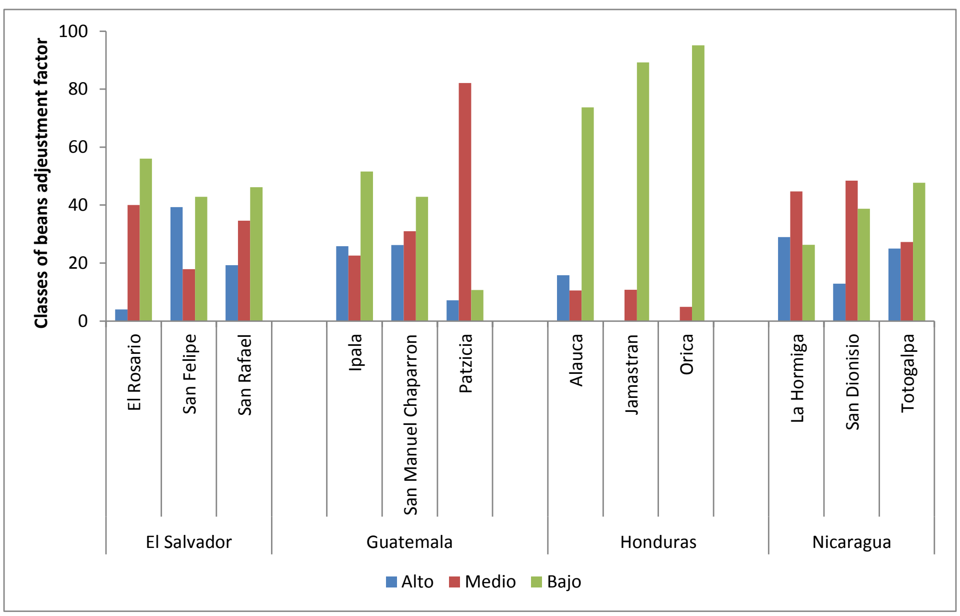


Figure 69: Classes of beans adjustment factor at farming level

Exposure of maize-beans production at the household level

The impact on productivity at the farm level was obtained by weighing the impact predicted at the focus area level with the adjustment factor corresponding to the class to which the respective household belongs. This impact was weighted by the total area sown with maize and beans in 2011, and expressed as a percentage of the total production of that year. This percentage was grouped in three categories of impact on the production of maize and beans at the household level:

1 = High, when the change in production corresponds to more than 66% of the total farm output

2 = Medium, when the change in production corresponds to more than 33% and less than 66% of total farm production, and

3 = low, when the change in production corresponds to less than 33% of the total production of the farm.

Results for maize and beans were combined to produce the indicator of exposure of the maize-beans production system. The level of exposure of the maize-beans system was obtained by combining the estimated exposure levels for each crop. Results are displayed in the central lower panel of Figure 70, where low exposure levels predominate, particularly at focus areas in Guatemala and Honduras but with a higher level of exposure in the focus areas of El Salvador and Nicaragua.

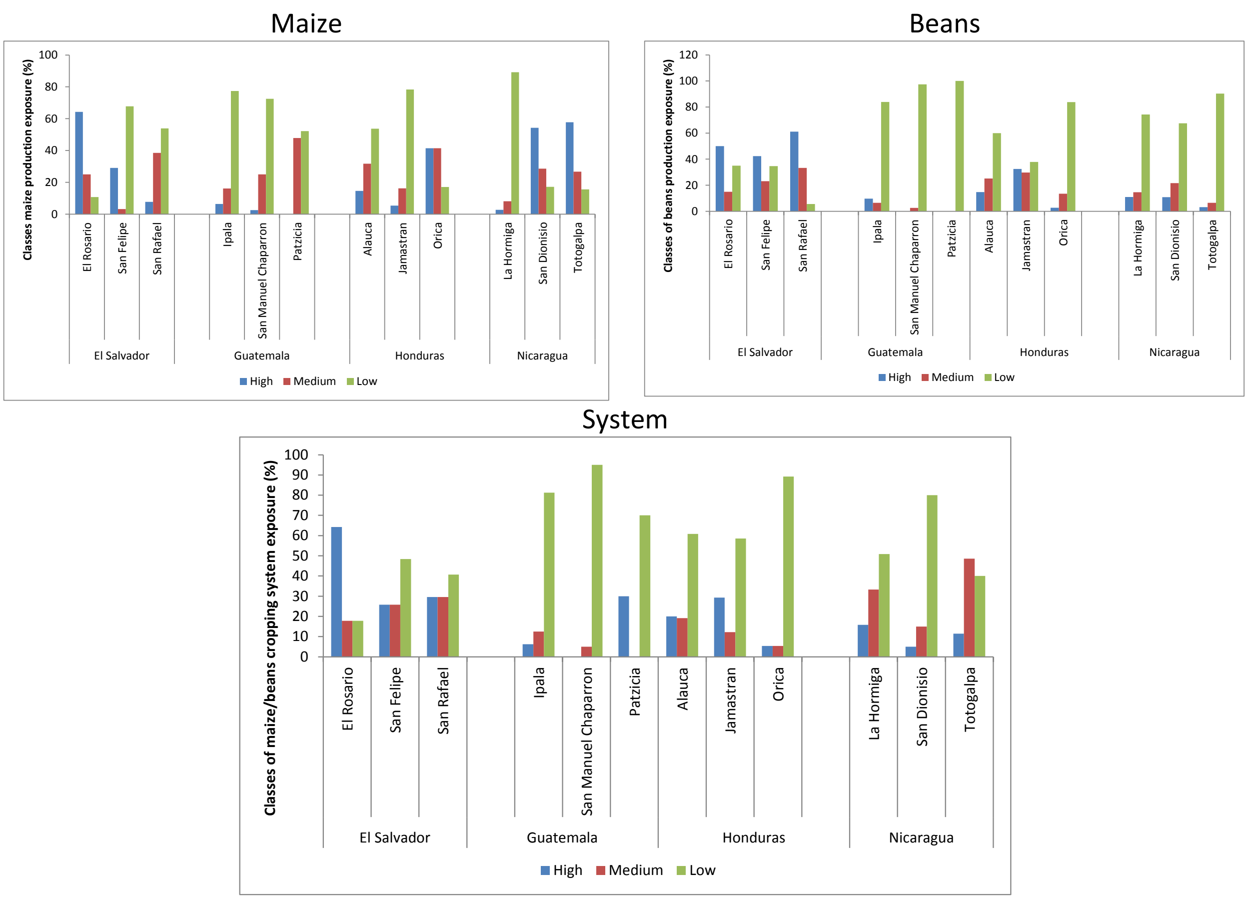


Figure 70: Exposure of maize-beans production system at the household level

6.8.4.2 Sensitivity level of the household livelihood

In the previous section the exposure of the maize and beans cropping system was analyzed in terms of changes in productivity and production at the household level. The analysis allowed the identification of focus areas with different numbers of households in different categories of exposure of their maize-beans production system to climate change. The next stage in the process of estimation of the index of vulnerability of the household consisted in the estimation of the level of sensitivity which reflects the potential impact of the change in the maize-beans production system on two important aspects with regard to the livelihoods of rural families: food consumption and income level. As in the previous case, the calculation is done in several steps. Figure 71 illustrates the process.

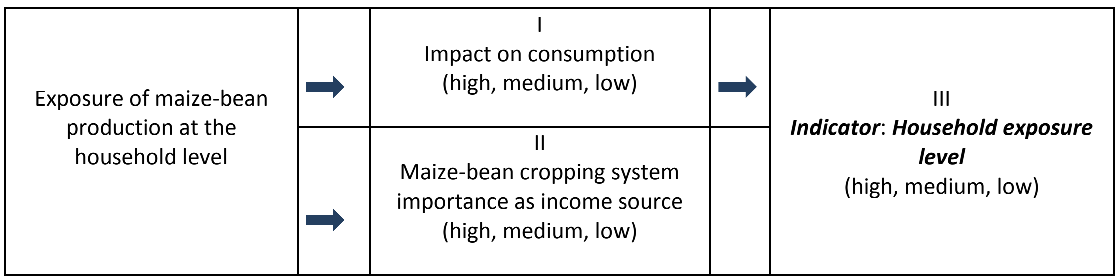


Figure 71: Stages in the estimation of the sensitivity of livelihood's sources indicator

Sensitivity of household consumption

The information gathered, in particular that relating to the consumption of animal proteins, did not allow estimation of the annual consumption of total calories with a reasonable level of confidence. Therefore it was decided to take the already estimated indicator of exposure of the maize-beans production system as an indicator of the level of sensitivity about consumption. This decision assumes a high correlation between both indicators; e.g., if the class of exposure of the production is high, i.e. that the household looses more than 66% of production, then the sensitivity of the level of consumption will also be the sufficiently significant for the household also belonging to the high class of sensitivity

Importance of the maize-beans system as a source of household income

In order to estimate the importance of maize-bean system in the family's income the following criteria were used:

1 = High. If the maize and beans are quoted between the first two main sources of income

2 = Medium. If the maize and beans are cited between the 3rd, and 5th main sources of income,

3 = Low. If the maize and beans are not quoted among the five more important sources of income

Results confirm information obtained through focal groups on the importance of maize (top panel of Figure 72) and beans (lower panel) in the generation of income. Maize is important as a source of income in the focus areas of El Salvador and Guatemala and is not in Honduras and Nicaragua, while beans are an important source of income in all focus areas except those of Nicaragua.

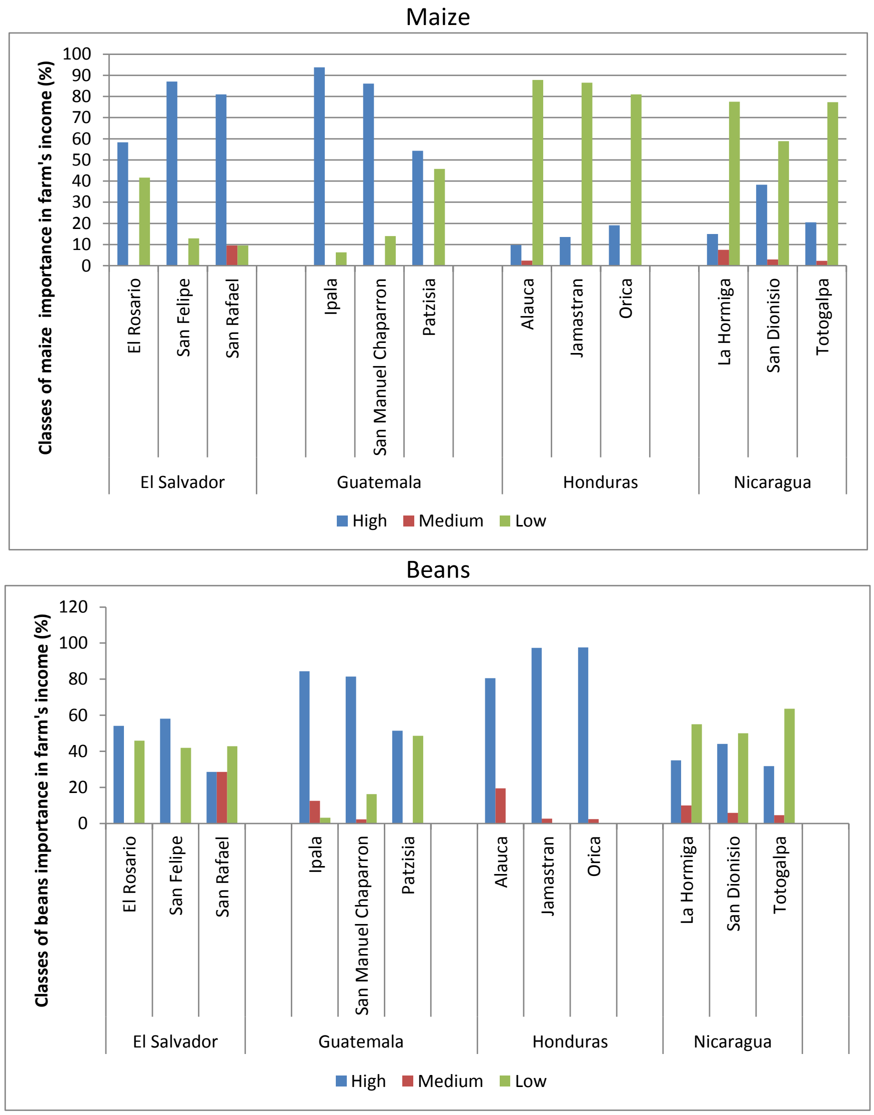


Figure 72: Importance of maize-beans production as a source of household income

Household sensitivity

The two indicators of sensitivity by crop were combined to form the final indicator of household sensitivity to the change in the production of the farm system. Figure 73 shows the results. In the case of maize a pattern differentiated by country emerges, with predominance of a medium/high sensitivity for El Salvador and Guatemala, and low/medium sensitivity in Honduras and Nicaragua. In the case of beans, a medium/high sensitivity level predominates in all focus areas except for Nicaragua where a low/medium sensitivity level prevails. When combined to form the indicator at the household level, the pattern that emerges is similar (bottom panel of the figure).

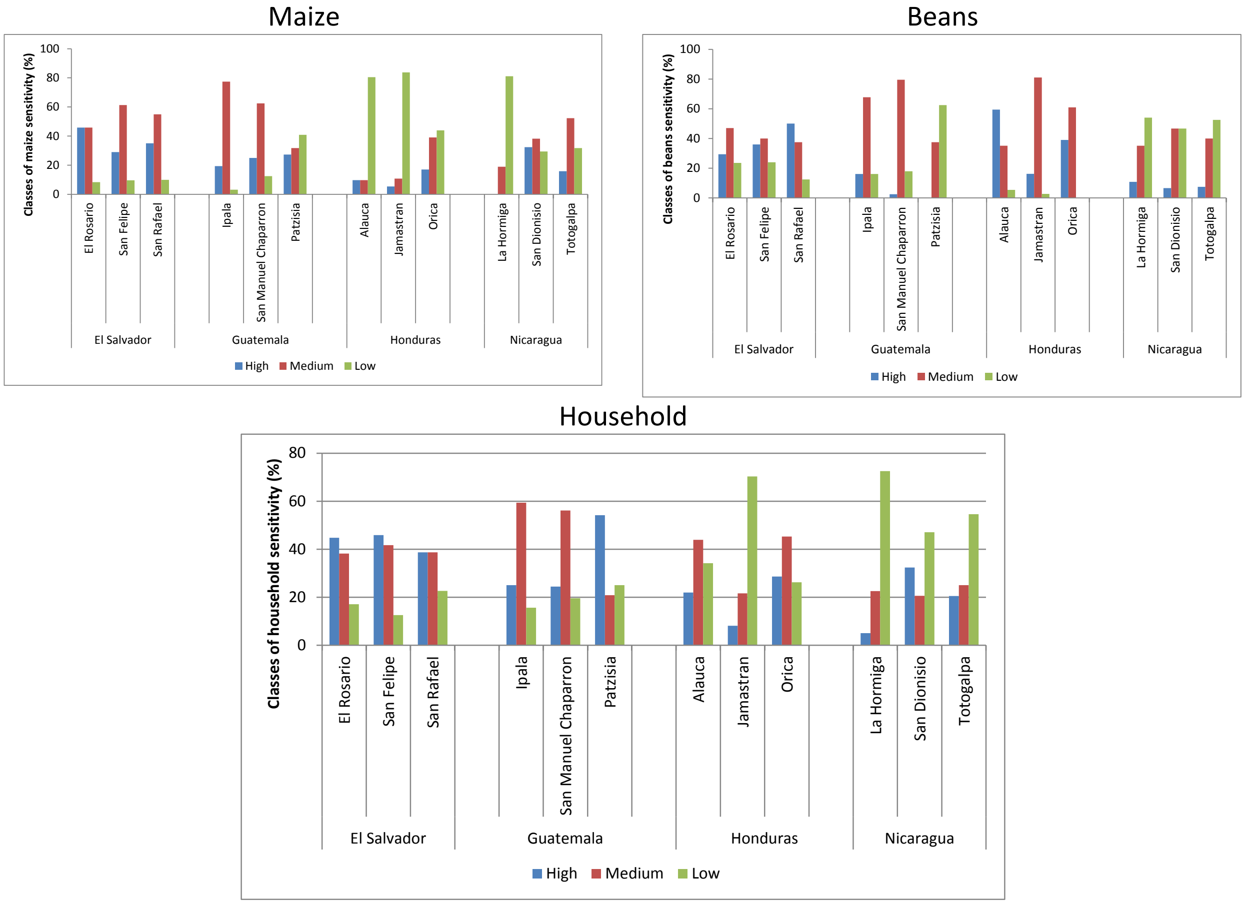


Figure 73: Household sensitivity to the change in maize-beans production

6.8.4.3 Household adaptive capacity

The third estimated component of the vulnerability indicator is related to the ability or capacity of the household to recover from the impacts caused by changes in the production of maize and beans. As in the two previous cases, it is a complex indicator, which depends on the quantity and quality of the endowment of the different types of capital that possess the family. The estimation procedure is illustrated in Table 41.

Table 41: Estimating household adaptive capacity

Base Indicator Availability: (Low, Medium, High)	**Intermediate Indicator Availability: (Low, Medium, High)**	***Final Indicator*: Household adaptive capacity Low, Medium, High)**
Land quantity and quality	I) Physical and natural capital	Adaptive capacity
Water quantity and quality		
Quality of farm access		
Farm/irrigation equipment		
Credit access level	II) Financial capital	
Family labor	III) Human capital	
Education level		
Social participation	IV) Social capital	
Information level and reactive capacity		

Availability of physical and natural capital

The combination by pairs of physical and natural capital required a sequence. In a first stage soil and water availability were combined to form an index of availability of natural capital, and likewise the availability of physical capital was obtained by the combination of the availability of equipment with the index of quality of the road access to the household. In a second stage, both indicators were combined to form the composite indicator of the availability of physical and natural capital.

Physical capital: Equipment and quality of road access

Figure 74 presents the results obtained in the different focus areas. With regard to the availability of heavy equipment (excludes light tools like machete and backpack sprayers) and irrigation equipment (left upper panel of the figure), the results indicate that the availability of this type of capital is low in all selected focus areas, but particularly low in El Salvador. The focus area Orica and Jamastrán in Honduras show better availability of this type of capital.

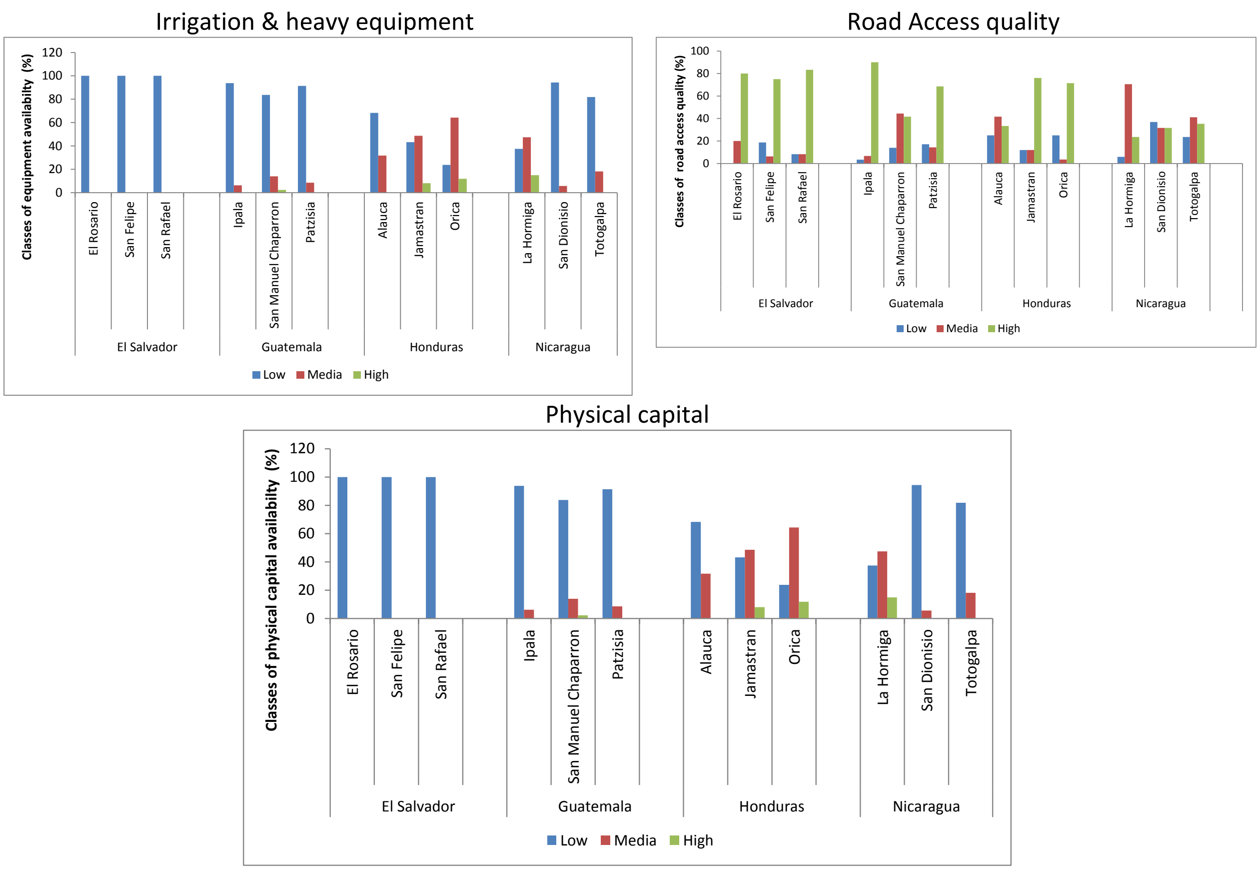


Figure 74: Classes of physical capital availability

The calculation of the quality of road access to the household, took into account two factors: the distance to the market, approximated by the time the farmer spends to reach the market, (***Long***, if the delay is more than one hour and ***Short***, if it is less than 1 hour), and the type of roads (***Bad***, if the road is sidewalk or dirt and ***Good*** if it is paved or mixed). The four possible combinations were divided into three classes of access quality: ***Good***, if the delay is short and the path is good. ***Medium***, if the distance is long, but the road is good, or if the distance is short and the road bad, and ***Bad***, if the delay is long and the road is bad. Results (left upper panel) show that access quality measured in those terms is good at the focus areas of El Salvador and two Honduras focus areas, but road access quality deteriorates in Nicaragua

The indicator of availability of physical capital (lower panel of Figure 74) was obtained as a result of combining both, the equipment and road access indicators. Results show that the limited availability of this type of capital dominates everywhere, but is particularly pressing in the focus areas of El Salvador and Guatemala. Honduras shows a distribution more balanced and Nicaragua presents La Hormiga with better availability than the other two focus areas in this country

Natural capital: Land and water

To estimate the availability of land, an indicator was sought that reflects the flexibility in land management. It was estimated by the number of additional cultivated plots grown in the year 2011, beside those used for maize and/or beans, categorized as: 1 = ***Low availability***, if not grown any additional plot; 2 = ***Medium availability***, if 1 additional plot was cultivated; and 3 = ***High availability***, if 2 or more additional plots were cultivated. Figure 75 shows a similar picture as in the case of the physical capital, the class of low land availability dominated in all focus areas.

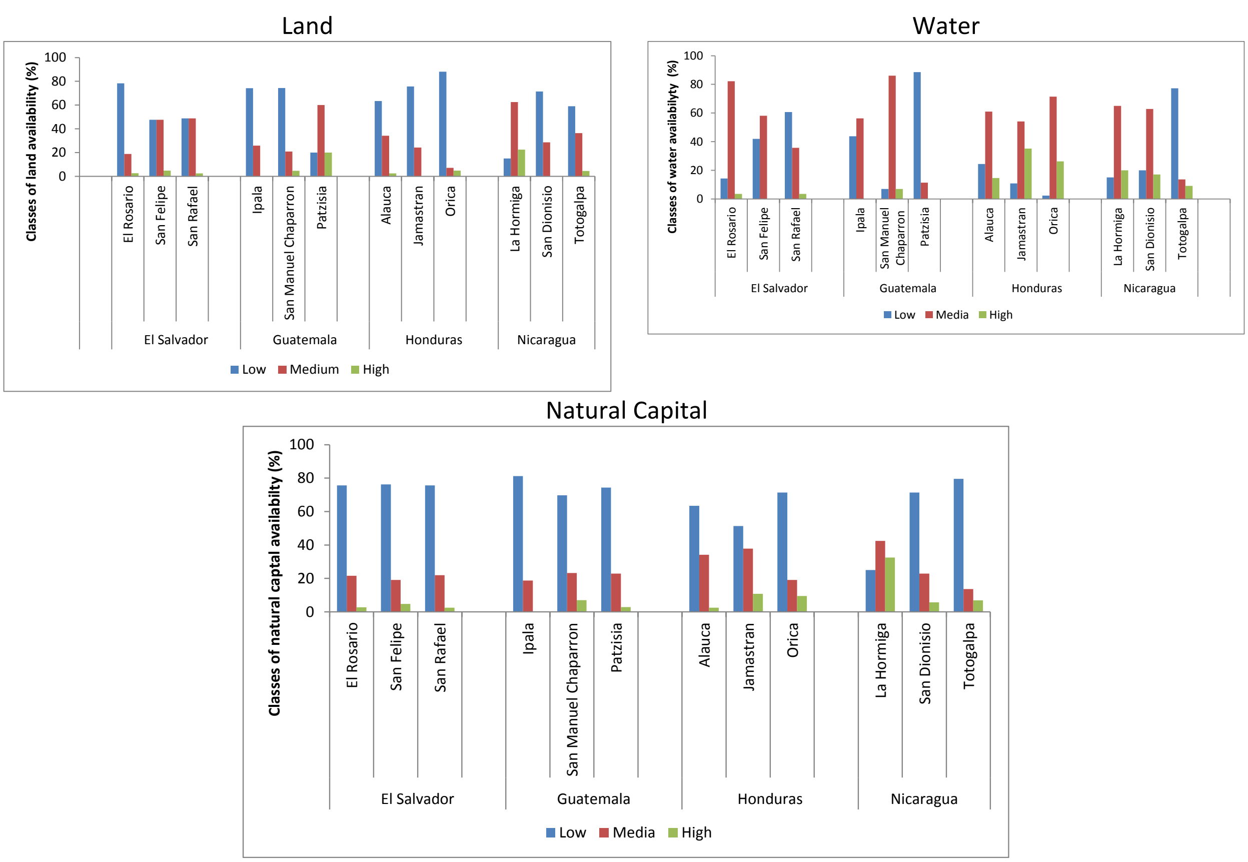


Figure 75: Classes of natural capital availability

The indicator of water availability was estimated by grouping the availability of irrigation water and the availability of safe drinking water into three classes: 1 = ***Low***, if the household doesn't have any, 2 = ***Medium***, if the household has one of the two types, and 3 = ***High*** if the household has both. Results (top right panel of Figure 75) show the class of medium availability predominates across hot-spots, but the lack of availability of drinking water is significant particularly in El Salvador and Guatemala. Good availability of water appears significantly in Honduras and Nicaragua.

The indicator of natural capital availability (bottom panel of Figure 75) was then obtained by combining the indicator of availability of land with that of water. Once again, results show that the pattern of the class of low availability predominates everywhere.

Physical & natural capital

The final indicator of Physical & Natural Capital availability was obtained through the combination of both indicators: availability of physical capital, and availability of natural capital. The results (Figure 76) reflect the predominant pattern among its components of low availability of this type of capital among the producers of maize and beans in the selected focus areas.

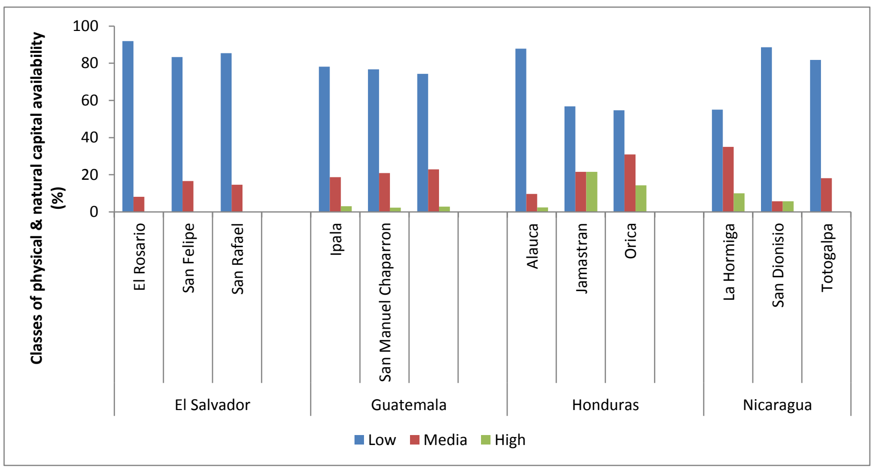


Figure 76: Classes of physical & natural capital availability

Financial capital

The availability of financial capital was estimated based on the availability of credit of some sort, as measured by the use of the credit in the year 2011. The results (Figure 77) show that access to financial capital is generally low in all focus areas, with two exceptions: Orica and Totogalpa in Honduras and Nicaragua, respectively.

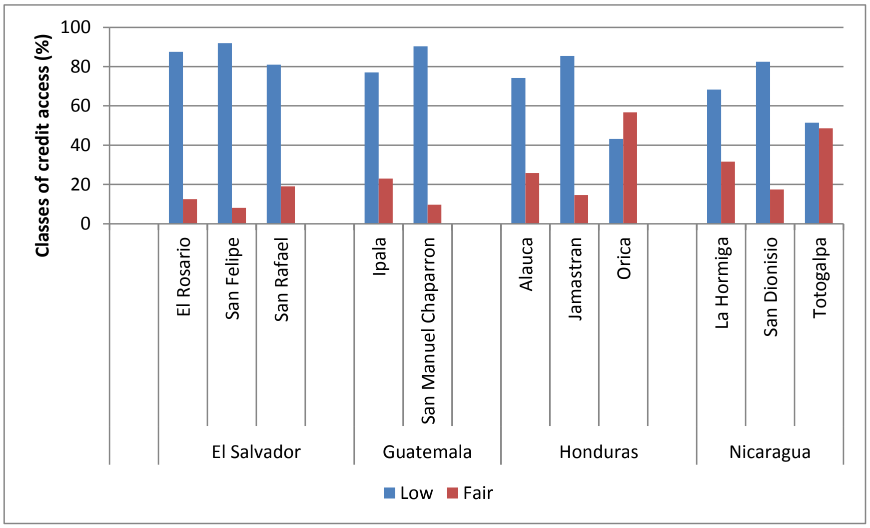


Figure 77: Classes of financial capital availability

Human capital

The educational level of household members was used as a proxy for human capital availability and classified into three classes: Low, Medium and High depending on the relative amount of members of the family with certain level of education. Classes to identify the level of education were defined as follows: Low, if no member of the household had attended high school (secundaria); Medium, if at least one member of the household had attended high school, and High if at least one member of the household had a technical, or had attended to higher or equivalent education. The results show that as in the cases of the natural and physical capital households in selected focus areas do not have a good endowment of human capital (Figure 78).

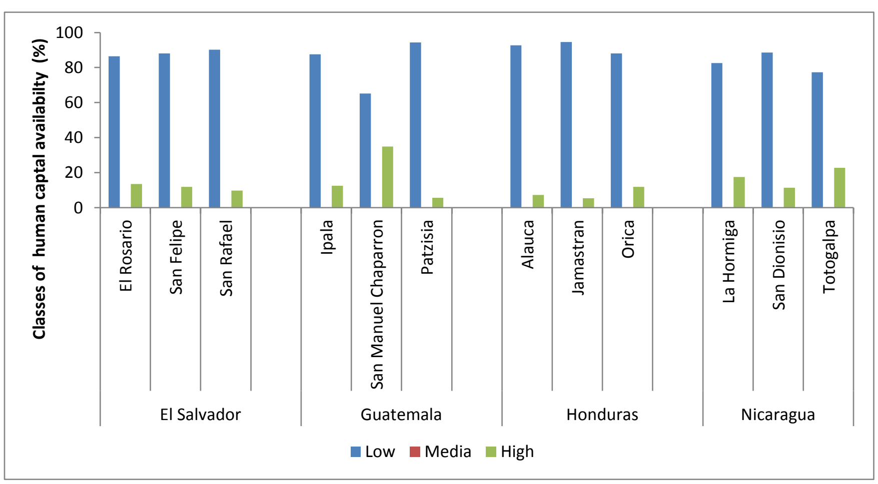


Figure 78: Classes of human capital availability

Social capital

For the indicator of social capital availability we used two components. On the one hand the extent of information on climate change and its consequences in the locality members of the household have, weighted by the level of reaction to these consequences (as measured by the number and age of activities taken in response), and on the other hand, a second component related to the level of participation of the members of the family in social organizations. Figure 79 shows the results for the different focus areas.

Information & reactive capacity

The indicator for the household level on information and reactive capacity was composed of two components: (i) a measure of the perceived and associated consequences of climate change classified as ***Low, Medium,*** *and* ***High***; and (ii) a measure of the number and age of activities taken in response to these changes classified as: ***Low*** = less than 3 activities and less than 5 years old; ***Medium*** = between 3 and 4 activities less than 5 years old; and ***High*** = more than 5 activities regardless their age.

The final indicator of the household information & reactive capacity was elaborated by combining both indicators, resulting in the following three classes:

Low = Household with little or no information on climate change, and therefore low reactive capacity

Medium = Household with some level of information on climate change but medium reactive capacity

High = Household with a good level of information on climate change and high reactive capacity in terms of activities

Results (upper left panel, Figure 79) show a pattern in which a low level of information and reactive capacity dominated across focus areas in El Salvador and Nicaragua, while in Guatemala and Honduras households have a better level of information & reactive capacity to climate change and its effects.

Level of participation in social organizations

The second component of the social capital was the level of household participation in organizations of different types. Three classes were estimated taking into account the number of organizations and household members involved: ***Low***, if no member of the family is involved, ***Medium***, if only one member participates in an organization, and ***High***, if more than one member participates in one or more organizations. The results (Figure 79) show a pattern of low participation in the focus areas of El Salvador and Guatemala, and a good turnout in Honduras and Nicaragua. This is important information for the implementation of any kind of adaptation strategy

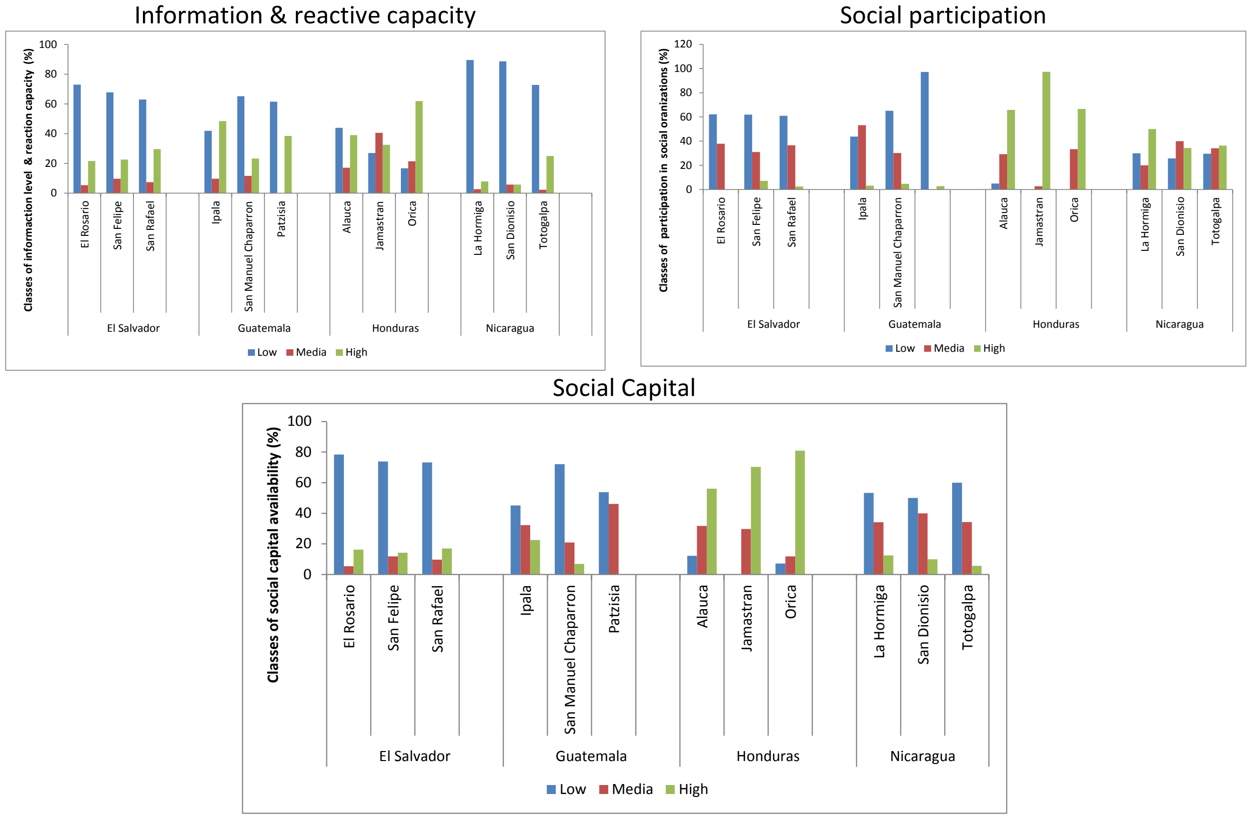


Figure 79: Classes of social capital availability

Availability of social capital

The indicator of availability of social capital was estimated by combining both indicators. Results (lower panel of Figure 79) reflect the pattern of its components: focus areas in Honduras show good levels of availability of social capital, followed by those in Nicaragua and Guatemala, which are dominated by low levels, but also reported significant medium and high levels of social capital. The worst situation is again present in the focus areas of El Salvador.

Adaptive capacity

The indicator of the household adaptive capacity combines by pairs the availability indicators corresponding to the four types of capitals in the following way:

Table 42: Indicators for Household Adaptive Capacity

Capitals	Intermediary	Final Indicator
Physical/Natural	Physical/Natural and Financial	Household Adaptive Capacity
Financial		
Human	Human and Social	
Social		

The results (Figure 80) show a predominant pattern of low adaptive capacity in all focus areas, with some relevant level of adaptive capacity in the focus areas in Honduras and Nicaragua.

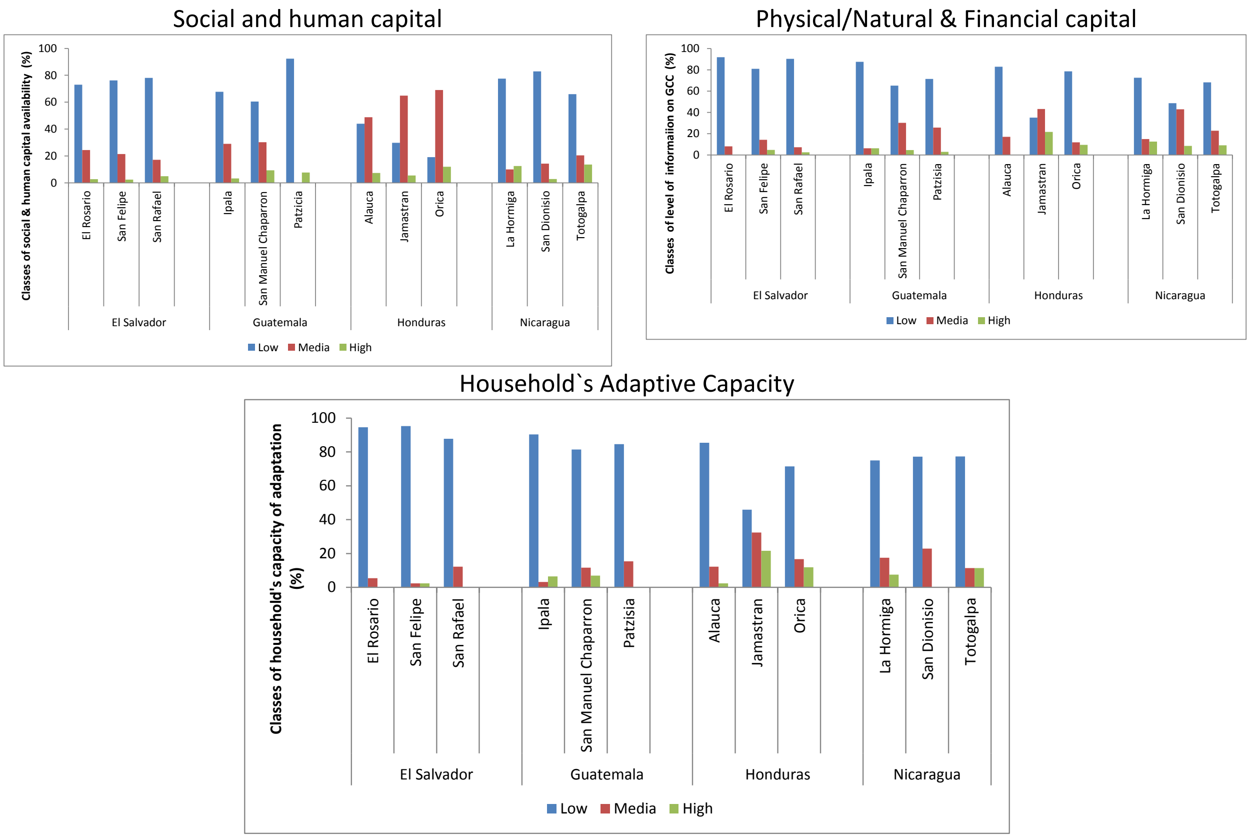


Figure 80: Household adaptive capacity

6.8.4.4 Household vulnerability

Finally, the indicator of household vulnerability was estimated by combining pairs of the three components as it is set out below:

Table 43: Components of the household vulnerability indicator

Components	Intermediary	Indicator
Household exposure	Impact on household livelihoods	Household vulnerability
Household sensitivity		
Household adaptive capacity		

The results (Figure 81) show the ample variability in the indicator between the selected focus areas. Focus areas in El Salvador seem to be dominated by a high level of vulnerability but with a somehow lower level in San Felipe. In Guatemala dominated a medium level of vulnerability in the selected focus areas. A better situation emerges for Honduras and Nicaragua, with a better level of response that propels medium and low vulnerability levels especially in La Hormiga in Nicaragua, and Jamastrán, and Alauca in Honduras.

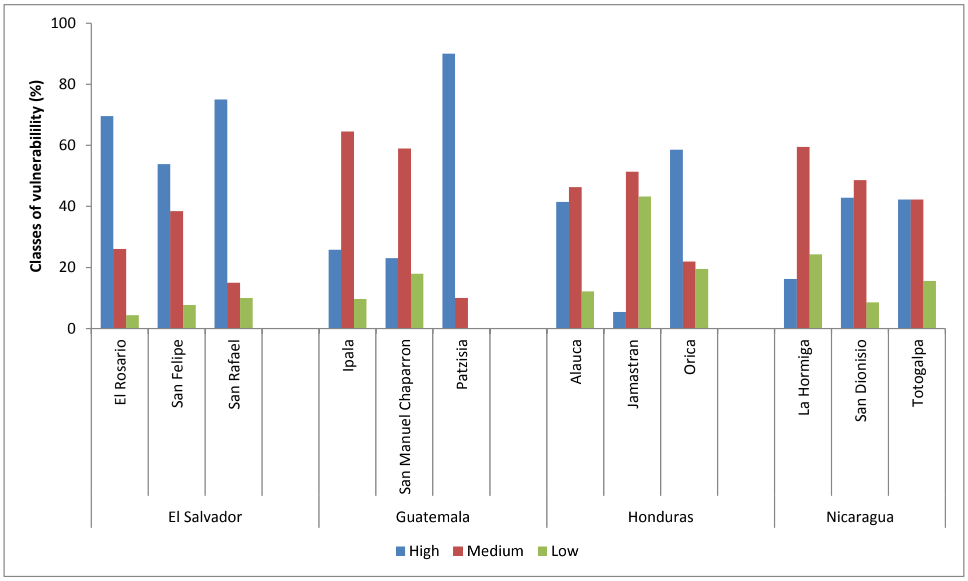


Figure 81: Classes of household's vulnerability

6.9 Local adaptation and mitigation strategies developed

The development and implementation of adaptation strategies to face progressive climate change depend on the participation of all actors in the Central American agriculture sector. Research institutions and policy makers should provide feasible strategies to farmer communities and specific pathways for adaptation. The results and recommendations below are addressed to prepare all participants to respond to Global Climate Change threats with adaptation measures. As adaptation strategies are most important as first reaction to possible impacts, we need to make these strategies also climate-smart and ensure furthermore that they will contribute to the mitigation of climate change in the future which requires a multidimensional farming-environment-system-approach.

From reviews and discussions with farmers, researchers and development practitioners we derived five principal strategies for adaptation at farm level:

i. ***Sustainable intensification:*** Aimed at increasing physical productivity while preserving natural resources (land and water) in productive systems (eco-efficiency).
ii. ***Diversification:*** Increases the amount of consumption sources and income from agriculture
iii. ***Expansion:*** Expands the endowment of different types of capitals
iv. ***Increasing off-farm income:*** Increase the importance of sources of income from more secure out-of-the-household activities.
v. ***Out of agriculture*** *as a livelihood strategy:* The household leaves agriculture as a source of income and consumption.

Sustainable intensification

The cornerstone of climate change adaptation is the maximization of natural resource use efficiency for agriculture production. Rising day and night temperatures and decreasing rain fall will force farmers to improve their efficiency in water and land use activities. Intelligent management of limited water and soil resources is required in order to produce more output for a growing, mostly urban population in the future. However, since agriculture is not only a victim of climate change, but also one of its main causes, **sustainable intensification** of agriculture production systems has to take into account the need to drastically reduce greenhouse gas emission from agriculture activities and increase potentials for effective measures to mitigate climate change.

While the eco-efficient intensification of agriculture production systems mounts a huge challenge on farmers, consumers, policy makers, researchers and development practitioners, a series of technologies and management options are already available for immediate implementation, others have to be adapted to local conditions to maximize their benefits. Finally, there are still knowledge research gaps which have to be filled as soon as possible.

Since most of the agriculture production in Central America relies on rain-fed conditions, a central element for eco-efficient and therefore sustainable intensification under the projected climate change scenarios for Central America is **to increase rain water use efficiency**. In order to increase rain water use efficiency three areas have to be addressed: plant water availability, evaporation and plant water uptake capacity. All three areas are intimately linked with soil management, water harvesting and plant nutrient management.

Soil management

The main objective of soil management in Central America in the future has to be the maximization of the water holding capacity (water retention) throughout the soil profile for increased plant water availability. In order to achieve increased water retention, soil organic matter contents and infiltration rates have to be improved through plant residue retention on the soil surface/ mulch management and minimal to zero tillage systems which also protect soils from erosion. Water should be used for transpiration by plants and not lost unproductively through evaporation. Therefore permanent soil cover is desirable to reduce evaporation from the soil. Again dry-planting, mulching, crop rotations, conservation agriculture, intercropping, windbreaks and agroforestry systems are management options to reduce evaporation rates and at the same time soil temperature. In general, best practice agronomy is required to adjust and manage adequate plant density structures, plant and row spacing and crop canopies. Unfortunately during the past two decades agronomy was not a priority in the national agriculture research systems in Central America neither at the international agriculture research centers. This gap on location-specific agronomy has to be filled.

Water harvesting

In addition to the possibilities to retain rain water in the soil profile, plant water availability can also be increased through water harvesting. In large areas of Central America annual precipitation, even with the projected reductions, will be sufficient to produce a wide range of crops (>1000 mm/a). With >80% of the annual precipitation running off without being used for any purpose, and with the vast amount of precipitation within a few months (distribution issue), intelligent water harvesting and water management are imperative. Water harvesting techniques are available for all scales and budgets.

Management of these stored water resources allows production of crops in times when the availability of light in the region is at its peak (dry season) with a significant push in biomass production and a reduction in pest and disease incidents. This in turn leads to an improved realization of crop production potentials and in combination with reduced losses to increased harvests in times when markets may offer higher prices; this includes also the production of high quality seed for the following cropping season. The integration of agua-culture in water harvesting projects is well documented offering additional sources of income. Supplement irrigation from water harvesting sources enable farmers to ensure establishment and maximum growth for their rain-fed crops especially in strategic growth stages. However, since resources from water harvesting are limited their use has to be strategically planned and decisions on the kind of crop to be irrigated have to be made. Obviously irrigation techniques should be implemented which guarantee maximum benefits of the harvested water for the crop.

All interventions that reduce superficial water run-off (water harvesting) or underground water resources (wells) are part of hydrological balances and should be part of an overall assessment of the hydrological capacities of a landscape. This assessment is fundamental for the planning of water distribution for human consumption and agriculture production in order to avoid social conflicts. Simulation models such as SWAT can help to generate information for decision making on water use in a landscape scenario.

Plant nutrient management

The plant nutrient status has an indirect effect on water use efficiency through the physiological efficiency of the plant. An optimal nutrient status ensures the highest biomass output per unit water used. Hatfield et al. (2001) estimated that water use efficiency can be increased by 15-25% through adequate nutrient management. Through soil management, as discussed above, water use efficiency can be further increased by 25-40%. Thus there is a huge potential for improvement through enhanced soil and nutrient management. This is corroborated by the results presented in the present report on maize production under future climate change conditions. The impact of climate change on maize production will be reinforced drastically by poor soil conditions which are already found throughout Central America. Soils are poorly managed and most of them show advanced signs of degradation. The magnitude of the potential impact of enhanced soil and nutrient management can be assessed by comparing maize production predictions of good soil vs. poor soil scenarios presented above.

Improved varieties

Proper nutrient management will not only help to reverse soil degradation but will also enable farmers to take full advantage of new improved drought and heat tolerant varieties which request advanced fertilization and agronomic management. Especially in areas with medium expected impact (adaptation areas) genetic improvement by breeding programs points out a viable adaptation strategy. As temperature seems to be the mayor constraint for future production in Central America breeding for heat-stress is therefore preferred over drought tolerance. CIAT is leading the genetic improvement of common beans towards heat stress tolerance. In Latin America, currently most areas are limited by maximum temperatures and worldwide 7.2 million hectares could benefit from heat tolerance (Beebe et al. 2011). There is also important breeding for drought tolerance (Katungi et al. 2011) but research is still not far. For maize CIMMYT is advancing fast on the development of new heat and drought tolerant maize varieties adapted also to low N environments, but in both crops farmer access to good quality seed at moderate costs is limited. There is an urgent need to improve seed availability through strengthening and encouraging the development of smaller local seed companies particularly in areas where larger commercial companies have not invested.

Diversification

Another principal strategy for adaptation at farm level is the diversification of the agriculture production system in order to increase the amount of consumption sources and income from agriculture. Integrated agua-agro-silvo-pastoral systems can produce a wide range of different products for consumption and markets. Nutrient cycling is enhanced through the integration of crops and animals resulting in higher crop yields. Further benefits include improved soil and water quality, increased biodiversity, as well as lower greenhouse gas emissions and increased carbon sequestration. In addition, alternate crop uses related to trees and shrubs offer sources of bio-energy, fruits, nuts, horticulture nursery stock, wood fiber and livestock shelter. Agroforestry systems offer furthermore opportunities for restoration of degraded lands, allow for livestock integration, and improve micro-climates considerably.

However, management of highly integrated systems requires skills and knowledge which only few farmers can provide; especially challenging in situations with low human capital indices as in Central America resulting in low household adaptability to climate change (see above). Furthermore there are still major knowledge gaps with regard to livestock integration/ management and water-livestock productivity.

Expansion

The word “expansion” in agriculture is synonymous to expansion of land occupation for agricultural purposes. In the present report, we use this word rather as the increase of the endowment of natural, physical, financial, human and social capitals on farm level.

In Central America we currently see the expansion of natural capital through advances of the agriculture frontier into the more humid areas of the Atlantic coast causing widespread deforestation, land degradation, social conflicts, migration and increased greenhouse gas emissions. A typical example is the shifting of bean production to “Apante” areas in Nicaragua. “Apante”, which is the third beans-crop cycle in Central America (starting in December and lasting until March), has its main extension in Nicaragua in the departments of Atlantico Norte, Atlantico Sur, Jinotega, Matagalpa and Rio San Juan (MAGFOR, 2011). These areas become more suitable to beans because of their climate pattern (see climate-cluster Figure 12). Farmer and experts confirmed during field work and analysis that this already happened during the last years and production is increasing in these areas. In Nicaragua during the cycle 2010-2011 roughly 26 thousand tons of beans were produced during the “Primera” season, 50 thousand tons during the “Postrera” season, and 30 thousand tons during the “Apante” season (MAGFOR, 2011). Of course shifting to “Apante” areas is an option to keep the yearly production volume constant and future climate is predicted to be favorable for these areas, but we need to take into account that these areas are mostly forests which would mean a change in land use (deforestation) to open up enough production areas. In our analysis we identified these areas as Pressure Areas with favorable climate conditions for bean production, but not enough land is available in these areas and additional deforestation will cause more negative impacts especially enhancing climate change.

Nevertheless there could be an opportunity in the “Apante” areas for converting deforested and degraded grazing lands into crop lands applying the concepts of sustainable intensification and reversing land degradation. Livestock production is closely associated to greenhouse gases and Latin America is contributing more than 20% of worlds total methane emissions through livestock (Key, N., & Tallard 2011). Despite the high demand for grazing land in Central America, the role of improved forages to mitigate climate change (Peters et al. 2000, Shelton et al. 2005) could be an important opportunity to reduce greenhouse effects and make some land available for crop production. Peters et al. (2012 in preparation) identified opportunities in forage-based systems that are economically sustainable and socially equitable with the lowest possible ecological footprint.

An important issue for climate change adaptation in Central America is the land tenure complex. Long-term land lease is not common, but without such long-term perspectives investments in sustainable soil and water management will not to be made. During the field interventions we came across several cases similar to medieval serfdom which will never allow smallholders to adapt to new climate conditions or even get out of poverty. Policy interventions are urgently needed.

While expansion of physical capital depends on public investments as in the case of access roads, expansion of financial capital (access to credits) for investments in equipment (e.g. irrigation) remains a challenge in Central America. We perceive no lack of financial resources for credit schemes, but credit conditions are increasingly complex, classified as high risk and thus elevated in costs so that only few smallholders can access these credits.

A very effective and powerful strategy for adaptation to climate change is the expansion of human and social capital. Information, knowledge, education and social organization are important driving factors for the successful implementation of all above mentioned principal strategies for climate change adaptation. Nearly all above mentioned suggestions are directly linked with management. Agriculture is getting more and more knowledge intensive and human resources have to keep up with these advances in order to implement resource management that allows maximum yields while sustaining their natural resource base. There is a growing need to update farmers, extension workers, technicians and university curricula. Training and extension models have to be reassessed and improved. While training is a constant and cost-intensive endeavor, without training all other solutions will not work. There is ample evidence that low human capital is one of the major factors for low technology adoption in the hillsides of Central America (Padilla, 2002).

But there is also a need to generate and manage appropriate knowledge for farmers, extension workers and students. Since agriculture is a location-specific activity blue print approaches did and will not work successfully in practice. Knowledge gaps have to be identified and closed, appropriate information has to be gathered including farmer information and observations and turned into valuable knowledge and principles. Human resources have to be able then to transform this knowledge into location-specific solutions.

In order to obtain the type of human resources needed, university curricula has to be updated and field experiences intensified. Closer collaboration between the scientific and academic sector on the one hand and the development sector at the other is also necessary to target real world problems. Investments should be made in a new young generation of field technicians to obtain the required education and knowledge levels. A good extension system is required where well trained technicians are able to provide support for a manageable amount of farmer clients. Such a system will make sure that farmers will have timely access to all the necessary tools and inputs for sustainable agriculture production under changing climate conditions.

Given the cost and the problems of establishing and keeping an extension system running direct transfer of knowledge and information to farmers with other means is becoming more and more important. With ever increasing coverage of mobile phones and increasing access of rural populations to mobile phones and other information sources like the internet these pathways of knowledge transfer need to be utilized more in the future (@adaptation). In countries like India or Kenya farmers already use mobile phones for getting daily updates and forecasts of climate information that allows them to optimize planting dates and thus utilization of rainfall and fertilizer applications. With climate variability predicted to increase in the future precise timing of soil preparation, planting and other activities will become increasingly important thus the need for simple and affordable means of delivering this information is growing.

The extension system should also provide a learning framework for farmer groups and their communities to generate their own solutions (expanding social capital and adaptive capacity). Discussions about adaptation- and mitigation options within communities make climate change a social learning process where best practice examples can then be pulled into similar climate and social locations.

Off-farm income and Out-of-agriculture livelihoods

A considerable part of Central American smallholders traditionally generate off-farm income during e.g. coffee harvest, in processing facilities or mostly for women the maquiladoras. These are mostly temporal activities during the dry season associated with migration. Remittances are also an important source of off-farm income and largely spent on consumption. In general, rural areas provide limited opportunities for income generation which leads to migration to urban areas or outside Central America. As climate change impacts become more evident, smallholders with very limited sets of resources and capitals (low adaptive capacities) under high climate change impact will be forced to generate more off-farm income and eventually drop out of the agriculture sector (see Table 45 for the examples from project focus areas). Leaving the agricultural sector can be considered a viable strategy to adapt to climate change leaving opportunities for the remaining farmers to lease additional land and improve their natural resource base for sustainable intensification. In the history of agriculture this is a well-known and recurrent process this time driven by changes in climate conditions. In stark contrast to other historical examples no significant industrial or service sectors exist to absorb the released work force. Migration to urban centers and subsequent social problems will be the consequences. Since climate change will impact on all sectors of a society, adaptation to climate change has to involve also all sectors. An integrated approach to climate change is needed.

6.9.1 Towards adaptation strategies in focus areas

Which of the above mentioned five principal strategic lines of action are adequate to a particular focus area depends not only on the respective levels of vulnerability, but rather on the relative importance of the two main indicators that it comprises (impact and adaptive capacity). To identify classes of appropriate strategies for different focus areas it is therefore necessary to identify classes of vulnerability according to the relative importance of each of the two components. Each of these classes gives rise to a different strategy to deal with the consequences of climate change. Table 44 shows different combinations of both components and possible strategic objectives for adaptation to climate change consequences.

Results from the focus areas indicate that almost all focus areas has low adaptive capacity, therefore a strategy aimed to increase the endowment of any form of capital is common to all, while a strategy aimed to reduce the climate change impact on livelihoods appears to be crucial for the focus areas of El Salvador, and to a lesser extent to those in Honduras and Nicaragua.

Table 44: Classes of vulnerability and the respective strategy objectives

Impact	Adaptive capacity	Vulnerability class	Objectives of the strategy
High	**Low**	**High**	*Increase income originated outside the household* - Actions aimed primarily at change of activities (maize/bean) as sources of livelihoods including migration to non-agricultural activities
High	**Medium**	**High**	*Increase income originated outside the household* - Actions aimed primarily at change of activities (maize/bean) and *Expansion* - Activities aimed at increasing the household capitals endowment
Medium	**Low**	**High**	*Sustainable intensification* - Actions aimed mainly at reducing the impact of the consequences of climate change *Expansion* - Activities aimed at increasing the household capitals endowment
High	**High**	**Medium**	*Sustainable intensification* - Actions aimed mainly at reducing the impact of the consequences of climate change *Diversification*
Medium	**Medium**	**Medium**	*Sustainable intensification* - Actions aimed mainly at reducing the impact of the consequences of climate change and/or at increasing the household capitals endowment *Diversification*
Low	**Low**	**Medium**	*Expansion* - Activities aimed at increasing the household capitals endowment
Medium	**High**	**Low**	*Sustainable intensification* - Actions aimed mainly at reducing the impact of the consequences of climate change *Diversification*
Low	**Medium**	**Low**	*Expansion* - Activities aimed at increasing the household capitals endowment
Low	**High**	**Low**	*Any type of strategy is fine*

Results also show three types of dominant structures presented in Table 45 and ordered from higher to lower level of vulnerability.

Table 45: Dominant structures in focus areas and associated strategies

Type of predominant structure	Focus areas (country)	Strategy
Impact: High ***Adaptive capacity***: Low ***Vulnerability***: High	El Rosario (El Salvador) San Felipe (El Salvador) San Rafael (El Salvador)	*Increase in the income originated outside the household.* Actions aimed primarily at change of activities (maize/bean) as hot-spot livelihoods including migration to non agricultural activities.
Impact: Low - Medium ***Adaptive capacity***: Low ***Vulnerability***: Medium - High	Orica (Honduras) San Dionisio (Nicaragua) Totogalpa (Nicaragua) Patzisia (Guatemala)	*A*ctivities aimed at increasing the household capitals endowment, including soil conservation investments that increase de value of the resource, together with: *Sustainable intensification*. Actions aimed mainly at reducing the impact of the consequences of climate change
Impact: Low ***Adaptive capacity***: Low ***Vulnerability***: Medium	Ipala (Guatemala) San Manuel Chaparron (Guatemala) Alauca (Honduras) Jamastran (Honduras) La Hormiga (Nicaragua)	*A*ctivities aimed at increasing the household capitals endowment, including soil conservation investments that increase de value of the resource, together with: *Sustainable intensification*. Actions aimed mainly at reducing the impact of the consequences of climate change

The above strategies should be interpreted as focus or predominant strategies for focus areas, this mean that the strategy has the potential to benefit at least 50% of households in the focus area. However, there may be a significant number of households in each of the focus areas for which adjustments are needed. The strategies may also be used as guidelines for the discussion in the communities to design more specific strategies.

6.9.2 Opportunities for Mitigation

Agriculture is not only one of the largest contributor to greenhouse gas emissions causing climate change, but offers also opportunities to mitigate the effect of climate change through both sequestering carbon and reduced emissions. The main strategies are a) enriching soil carbon, b) promoting climate-friendly livestock production systems, c) minimizing the use of inorganic fertilizers and d) restoring degraded lands and preventing deforestation. Since this issue has been widely discussed and documented in literature (e.g. Smith et al. 2007, Scherr and Stahpit 2009) we will not extend this section by providing detailed descriptions. Nevertheless it is worthwhile to mention that elements presented under the sustainable intensification section of this chapter are also main instruments for climate change mitigation generating a win-win situation for farmers in Central America. Key factor is enhanced soil & plant management because soil and plants hold close to three times as much carbon as the atmosphere. Even small changes in carbon stored in the soil could thus have a significant impact on the global carbon balance.

7 Conclusions

The successful downscaling of global climate models to local resolutions (1km) allowed the generation of future climate scenarios for all location in the four countries included in the study for the time frames 2020 and 2050. This is a prerequisite for development of rational adaptation strategies. In general terms, precipitation in the future will be low or even lower in the first 4 months of the year which is the typical dry season in the region. For the month of May (planting time) we predict no significant changes in precipitation although there is a tendency towards reduction in all 4 countries. For the important month of June (establishment and early development of maize) we see a reduction of rainfall followed by a more severe and extended dry spell, the so called "*canicula"* in July and August into September putting the first planting season *"la primera"* under serious threat. For the second planting season *"la postrera"*, which is the more important season for beans, there will be less precipitation for the planting month September. Together with the deficit from the prolonged *canicula* climate conditions might be very unfavorable for the establishment of beans especially in areas with sandy soils. During the month of October and November there is a risk of increased rainfall causing flooding similar to the ones experienced in 2011 with huge damages on agricultural production and infrastructure in Central America. The water deficit is further increased through the increase of the minimum, mean and maximum temperature. Higher temperatures cause higher evapotranspiration rates of plants triggering soil water deficits and heat stresses. High temperature stresses especially high night time temperatures (> 18 °C) and drought conditions have substantial effects on biomass production and reproductive stages of maize and bean plants. We can summarize that in the future there will be higher mean temperatures (around +1°C by 2020 and + 2°C by 2050), higher minimum and maximum temperatures and an increased water deficit due to less precipitation and higher evapotranspiration rates which means that maize and beans farmer in Central America will have to cope with far less favorable climate conditions for agriculture production in the future. We did not include frequencies of extreme weather events such as hurricanes in the study since the relationship between climate change and its impacts on the frequency, intensity and pattern of tropical cyclones is highly complex and still subject to active research. However, recent publications indicate "that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms" (Knutson et al., 2010). In particular the higher-class hurricanes are those which bring about the most severe impacts and overwhelm poor countries´ capacity to adapt and respond, and in the worst cases can throw back countries for years in their development progress. This was the case in Honduras and Guatemala through Hurricane Mitch in 1998. Honduras, Nicaragua and El Salvador are all top ranking countries according to the latest Climate Risk Index 2011 (Harmeling 2010).

Feeding the future climate scenarios into DSSAT crop model resulted not only in yield predictions but revealed also a significant influence of soil water retention capacity and soil fertility/fertilization on yields, especially in the case of maize. We therefore included two contrasting soil scenarios in the study, the poor soil scenario representing the current trend of soil degradation in Central America while the good soil scenario assumes better soil management. Yield predictions differ considerably between the two scenarios.

The impact on maize yields under the poor soil condition scenario can be considered as more drastic and pronounced in all project countries, a serious issue considering the wide spread soil degradation in the region. The modeled maize yield changes also differ between high reductions of yields in drier lowland areas and considerable increases for highland areas particularly in Guatemala. At country level the most affected country is Honduras which showed almost 30% losses under the worst case scenario for 2020s and 2050s while the predictions show that under the good case scenario losses would still reach 11.7% for both future time frames. Second most affected for the worst case scenario predictions is El Salvador with slightly over 30% losses. Losses for this country for the good soil scenario were very minor underlining at less than 2% the importance of soil management. Nicaragua showed losses of just over 11% for the poor soil scenario for 2020s and 2050s and lower ones for the good soil scenario at 3.3% for 2020s and 4%. Guatemala stood out as it showed also relatively low overall production losses for the poor soil scenario at 10.8% for the 2020s and 11% for the 2050s, but a very slight increase in production under the good soil scenario overall.

Climate change impact on bean production can be considered drastic as well with reductions of up to 25% of the total production volume in Central America by 2050. Once more Honduras and El Salvador are the most affected countries with 15 and 8% yield reduction by 2020, respectively, followed by Nicaragua with 6% and Guatemala with 4% losses in bean production.

In value terms our conservative predictions indicate production losses for the region around US$ 125 million per year by the 2020s. These are rough estimates based on linear assumptions and not taking into account the variability across time and regions. In general, production losses for maize are by far larger than those for beans. This is also true in value terms even when price differences tend to smooth the respective losses. Honduras and El Salvador are the two countries with larger maize production losses while in terms of beans only Guatemala differentiates from the other three countries with a relatively low level of potential losses.

In the case of El Salvador, high potential maize losses together with high maize prices are main factors influencing this result. On the other hand, changes in variability seem not to be a problem in this country. On the contrary, Nicaragua presents low changes in the average production value but a substantial increase in production variability (increased risk level). Honduras presents the worst situation presenting both high losses in average production together with a substantial increase in variability (increases risk level). Guatemala presents small changes in both average production and small change in variability. Consequently, the potential impact of climate change over maize-beans production in Guatemala seems to be much less important than for the other three countries included in the analysis.

Most of the impact will occur in the 2020s which indicates that the predicted annual mean temperature increase of +1 degree Celsius in combination with also higher minimum temperatures (night temperatures) passes an important physiological tipping point where especially beans are affected in their reproductive capability (see above) and thus in their yield potential. Future reductions by the 2050s will not have the same magnitude. As a consequence and given the magnitude of changes predicted climate change adaptation interventions should take place now without any time delay.

On the country level Guatemala with its diversity of climatic zones seems to be able to balance climate change impacts, showing multiple areas with increased yield in maize and beans, however, drier lowland areas and Petén will also be harder hit in the future. In general, there is a significant variability within countries for both crops. For the useful and effective targeting of climate change adaptation interventions information on the degree of impact in particular areas is crucial for decision makers at all levels. Therefore we worked on the identification of “focus areas” (hot-spots, adaptation and pressure areas) across the four countries. We identified areas with more than 50% predicted decrease of crop yields for 2020 as hot-spots and areas, where actions need to be take in place immediately to avoid increasing vulnerability of farmers livelihoods in this areas. Other areas were identified as adaptation areas. In this areas crop production do have a good possibility to adapt to a changing climate but need well coordinated adaptation strategies. As third category we identified pressure areas. These are areas with increasing bean yields by changing climate patterns and a higher risk for uncontrolled agriculture frontier shift. These pressure areas deserve mayor attention by the respective authorities. Past and current experiences in the region, however, raise fears that these areas might be lost in the next decade due to the described climate change impacts and other factors such as population increase and land tenure problems. The condensed information in the respective map generated in this study is very useful for a number of different stakeholders and decision makers, development agencies and the donor community. The maps indicate location and degree of the predicted impact and thus reduce the uncertainty with regard to climate change. The respective areas can now manage their specific climate change risks.

The above reported predictions aim to reduce uncertainties about future conditions and turn these uncertainties into risks. Risks can then be managed. However, given the available data, their type, quality and resolution we do not pretend to forecast exact yield distributions throughout the four countries over five decades. We rather see these model results as useful indicators of how future scenarios will most properly look like. Since we applied several calibration stages, ground checks and feedback loops with crop experts and focal groups across the region, we are very confident that the cutting edge application of scientific tools such as DSSAT enabled us to deliver a robust decision making base. Our objective to provide model outputs at a 1km resolution could not be reached throughout the project due to inconsistent or missing data. Especially long-term yield and economic data (statistics) at the required level are not available. Also in the case of climate data there is still a need for improvement particularly in Honduras and El Salvador. Geo-referenced data collection should be a standard and not the exception. With regard to crop pests and diseases, data are even scarcer and the underlying interactions not yet fully understood. We therefore decided to drop this factor from the study for the time being. Research is currently under way to clarify the complex interactions between pests and diseases and the changing climate.

Through discussions with focal groups across the four countries we were able to reconfirm our focus area selection and the importance of maize and bean production at these locations. However, a general trend towards shifting to more livestock and sorghum (dry land agriculture) was noted. This trend seems to be driven by economic and climate events in the recent past. Nevertheless people in Central America are still maize and bean eaters with a close cultural affiliation to both crops, confirming the importance of the present study.

The performed vulnerability analyses reaffirm field observations in the focal groups and during the field survey. In all four countries households have a rather low adaptive capacity to climate change. Subsequently, the region can be classified as particularly vulnerable to climate change with El Salvador showing high levels of vulnerability, followed by Honduras and Guatemala with medium levels and Nicaragua with a low level of vulnerability. The presented classification is somewhat arbitrary since we found high variability within focus areas. Nevertheless the analysis provided valuable insights on farm endowments of natural, physical, financial, human and social capitals which are essential to develop location/farm-specific adaptation strategies to climate change.

Since it is not possible to develop a large number of location/farm specific adaptation strategies within the framework of the present study we summarized our recommendations in five principal adaptation strategies: sustainable intensification, diversification, expansion, off-farm income and out-of-agriculture. All principles strategies contribute to a central goal: efficient use of limited water and land resources to maximize output. In order to achieve this goal, enhanced soil and plant nutrient management is required in combination with water harvesting schemes and improved varieties. The expansion of human and social capitals (education, information, knowledge) is a prerequisite for the successful implementation of all above mentioned principal strategies for climate change adaptation.

Agriculture is getting more and more knowledge intensive and human resources have to keep up with these advances in order to implement resource management that allows maximum yields while sustaining their natural resource base. There is a growing need to update farmers, extension workers, technicians and university curricula. Training and extension models have to be reassessed and improved. But there is also a need to generate and manage appropriate knowledge for farmers, extension workers and students. Since agriculture is a location-specific activity blue print approaches did and will not work successfully in practice. Knowledge gaps have to be identified and closed, appropriate information has to be gathered including farmer information and observations and turned into valuable knowledge and principles. Human resources have to be able then to transform this knowledge into location-specific solutions.

Given the cost and the problems of establishing and keeping an extension system running direct transfer of knowledge and information to farmers with other means is becoming more and more important. With ever increasing coverage of mobile phones and increasing access of rural populations to mobile phones and other information sources like the internet these pathways of knowledge transfer need to be utilized more in the future (@adaptation). In countries like India or Kenya farmers already use mobile phones for getting daily updates and forecasts of climate information that allows them to optimize planting dates and thus utilization of rainfall and fertilizer applications. With climate variability predicted to increase in the future precise timing of soil preparation, planting and other activities will become increasingly important thus the need for simple and affordable means of delivering this information is growing. The extension system should also provide a learning framework for farmer groups and their communities to generate their own solutions (expanding social capital and adaptive capacity). Discussions about adaptation- and mitigation options within communities make climate change a social learning process where best practice examples can then be pulled into similar climate and social locations.

As climate change impacts become more evident, smallholders with very limited sets of resources and capitals (low adaptive capacities) under high climate change impact will be forced to generate more off-farm income and eventually drop out of the agriculture sector. Leaving the agricultural sector can be considered a viable strategy to adapt to climate change leaving opportunities for the remaining farmers to lease additional land and improve their natural resource base for sustainable intensification. In the history of agriculture this is a well-known and recurrent process this time driven by changes in climate conditions. In stark contrast to other historical examples no significant industrial or service sectors exist to absorb the released work force. Migration to urban centers and subsequent social problems will be the consequences. Since climate change will impact on all sectors of a society, adaptation to climate change has to involve all sectors as well. An integrated approach to climate change is needed.

By producing the proposed project outputs we could show that through the application of cutting edge climate and crop models uncertainty about climate change impacts on maize-bean production systems in Central America can be turned into manageable risks. Climate models were downscaled to a useful resolution (1km), the impacts of climate change on maize and bean production was quantified and their socio-economic consequences analyzed, hot-spots, adaptation- and pressure areas were identified, household vulnerability to climate change assessed, and principal adaptation strategies developed. Despite shortfalls on quantity and quality of necessary input data we managed to produce high quality prediction about the influence of changing climate conditions on the production of maize and-beans in Nicaragua, Honduras, El Salvador and Guatemala. The findings of the present study should enable decision makers on local, national and regional levels to take appropriate action in the right locations and provide an adequate policy framework for successful implementation of adaptation strategies in the rural sector. Emphasis must be given to the development of human resources and social capital especially in the identified focus areas, pressure areas have to be protected from migration, and we should start today.

(Photos: Courtesy Neil Palmer, CIAT)

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