TORTILLAS ON THE ROASTER SUMMARY REPORT

CENTRAL AMERICAN MAIZE-BEAN SYSTEMS AND THE CHANGING CLIMATE

CRS
CATHOLIC RELIEF SERVICES

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

CIMMYT
International Maize and Wheat Improvement Center

THE HOWARD G. BUFFETT FOUNDATION

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Maize tortillas cook on a pan at a roadside cafe in El Salvador, Neil Palmer

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TABLE OF CONTENTS

Figures

Tables

FOREWORD

Our Foundation has been working in Latin America for over 10 years, with over $100 million invested in the region as a whole, and more than $75 million in Central America alone. The majority of that investment has been focused on efforts to provide a more food secure future for the most vulnerable rural populations in the region.

When we started, we funded many “traditional” development projects. These were projects that might improve the lives of the individuals participating, and perhaps their family members, but in most cases did not provide opportunities that could be taken to scale – and too often they failed to provide exit strategies. In the last several years we have taken a different approach and focused in areas that could have a broader impact, leading to changes in policy to bring permanent and substantive change to scale.

We funded Tortillas on the Roaster because the information it reveals is critical to understanding how this region can achieve long-term food security in the face of extreme challenges. Climate change raises the vulnerability and resiliency stakes for the more than one million subsistence farmers in Central America who depend upon maize and bean production for their survival. Until this report, it was impossible to understand the specific implications of climate change and what it will mean for the kinds of crops that can be grown and under what conditions.

I have met with hundreds of farmers in the course of my many trips to the region over the past several decades; they already understand climate change is affecting their livelihoods, they just need help getting the information and learning new techniques to mitigate its effects. We hope the stark predictions presented in this report will be a wake-up call to all—farmers, extension agents, governments, aid organizations—that we need to take a fundamentally different approach to farming.

That’s why our Foundation promotes biologically-based conservation practices that improve soil quality and water use, while mitigating soil erosion and nutrient run-off. We can’t completely stop the effects of climate change but we can significantly reduce its impact on farming by adopting these improved practices, which I use on my own farms in the U.S. and South Africa.

Food security is a choice, not for those who are hungry but for those who are in a position to solve the problem with the right solutions. I hope Tortillas on the Roaster can inform those solutions.

Howard G. Buffett
President
The Howard G. Buffett Foundation

EXECUTIVE SUMMARY

Climate change is occurring at an accelerated rate and its impacts are being acutely felt in Central America, one of the world's most vulnerable regions. Agriculture is highly sensitive to the temperature and precipitation changes associated with climate change, and smallholder farmers in Central America are already experiencing the impacts, first hand. Until now, climate change projections for Central America have been general, covering wide geographic areas. Given the heterogeneity of the climate, landscapes, and agricultural systems in the region, it is hard to use general trends for decision making at the farm or landscape scales. As a result, smallholder farmers and other decision makers have been slow to adapt adequately to the threats of climate change. They know that climate change is occurring, but they do not have enough detailed information to act on it.

To fill this gap, CRS,[1] CIAT,[2] and CIMMYT[3] carried out the Tortillas on the Roaster study (TOR). Funded by the Howard G. Buffett Foundation, the study provides detailed, actionable information for specific areas in four Central American countries: El Salvador, Guatemala, Honduras, and Nicaragua (CA-4). TOR provides detailed climate projections at a resolution of 5 km^2 or higher across all four countries for two distinct time frames—the near term (2020s) and the mid term (2050s). It predicts the potential impacts that climate change will have on the production of maize and beans, the two most important food crops in Central America. The study measures impacts in terms of changes in maize/bean production and related economic value. Important among the outcomes are maps that illustrate how different geographic areas within the CA-4 will be affected. Finally, recommendations are made for climate change adaption strategies tailored to specific geographic areas.

TOR applied state-of-the-art climate models and GIS tools and combined these with field-based agronomic research and detailed socioeconomic analyses at the household level in selected communities in each of the four countries.

There is an urgent need for maize/bean smallholder farmers to deal with the impacts of climate change. The study finds that the impacts of climate change on maize/bean production systems are significant, and they could be felt as soon as the next decade.

The TOR model projects that mean temperatures will rise by 1 °C by the period 2010 to 2039 (2020s), and by 2 °C by the period 2040 to 2069 (2050s). Minimum and maximum daily temperatures will rise, and water deficits will increase due to less precipitation and higher evapotranspiration rates.

The modeling shows that maize production will decline severely in the long term, primarily because of the compounding effect of widespread soil degradation. Smallholder farmers located on poor soils will see greater losses than those on good soils. For example, in El Salvador, where land degradation is most severe, losses in maize production could be as high as 32% in areas with poor soils and as low as 1% in areas with good soils by the 2020s. Bean production will also decline because higher nighttime temperatures will impede flowering. Projected reductions in bean production are as high as 25% in all four countries.

Maps produced by TOR identify three classes of climate impact areas: areas where it will be impossible to continue growing maize/beans (Hot Spots); areas where it is possible to continue with maize/bean cultivation if adaptation strategies are implemented and action is taken now (Adaptation Areas); and areas that are not currently cultivated but which become attractive to smallholder farmers due to changing climate conditions (Pressure Areas), many of which are high-elevation forests, wetlands, and other sensitive ecosystems.

The results of the study fill a critical gap in our knowledge of the impacts of climate change on maize/bean production in Central America. With this new information, stakeholders can now shift from a position of uncertainty to a position of risk management. The study shows there is reason for optimism: if action is taken now, the most severe impacts can be managed.

The technical strategies for adaptation are well known. TOR provides recommendations about which adaptation strategies are most appropriate for specific areas. Among the critical areas for investment are soil and water management; education and training to build agronomy, soil management and water management skills; protection of forests, wetlands, and other sensitive ecosystems and understanding the appropriate role for plant genetics. The key is to strategically focus investments for smallholder maize/bean farmers, and to tailor the investments to unique conditions.

What is needed now is political commitment and long-term investment in agricultural production in Central America. Governments urgently need to invest in education and training to build institutional and human capacity, and to rebuild extension services that re-emphasize basic agronomy, soil, and water management. Because more than 80% of Central America's maize and beans are grown on rainfed land, agriculture investments should be targeted to smallholder farmers in these areas. Production, which is low now, could be increased—even in the face of climate change—through improved agronomic practices and water management. National and local governments, together with communities and civil society, will need to work to protect forests, wetlands, and other sensitive ecosystems from encroachment and unsustainable agricultural practices. Research priorities should include breeding new varieties for heat and drought stress, as a critical part of an integrated adaptation strategy, although we need to be wary of over-relying on this strategy.

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1 Catholic Relief Services

2 International Center for Tropical Agriculture

3 International Center for Improvement of Maize and Wheat

1 MAIZE AND BEANS ARE THE MOST IMPORTANT FOOD CROPS FOR CENTRAL AMERICA

In the Central American countries of El Salvador, Guatemala, Honduras, and Nicaragua—here referred to as the CA-4 countries—more than 1 million smallholder farm families depend on the cultivation of maize[4] and/or beans[5] for their subsistence. The maize/bean production system, which dates back to the pre-Columbian period, is the foundation of the Central American diet and is integral to the regional culture. The annual consumption is as much as 170 kg/person of maize, and 25 kg/person of beans (CEPAL 2005). It is the most important agricultural production system in the region.

The production system in the CA-4 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/year of maize and 475,000 t/year of beans. The annual gross values of maize/bean production are greater than US$700 million and US$400 million, respectively (IICA 2007). Nicaragua produces more than 30% of the regional harvest and exports to neighbor countries.

Maize/bean cultivation 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/beans.

2 MAIZE/BEAN SMALLHOLDER FARMERS FACE ONGOING AND "NEW" CHALLENGES

Climate change is intensifying the existing challenges of growing maize/bean production in Central America.

Most smallholder farms are located on sloping terrain, using traditional slash-and-burn methods. For example, in Honduras, 80% of farms are found on slopes. Soils are shallow, fragile, and soil degradation is becoming a major constraint for production.[6]

For smallholders dependent on agriculture for their livelihoods, degradation of natural resources and low maize/bean 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

4 Corn.

5 The *Phaseolus vulgaris* bean is a small, dark red, Mesoamerican bean, native to Central America.

6 Oldeman et al. reported in 1991 that 75% of all agricultural land in CA-4 countries is degraded. Lands have been further degraded since then, but there has not been a comprehensive survey for 20 years.

MAIZE/BEAN PRODUCTION SYSTEMS IN CENTRAL AMERICA

The maize/bean production system in Central America has evolved as a relay intercropping system to match the climatic conditions and agro-ecology of the region.

Central America, generally, has a bimodal rainfall pattern. There is a 6-month dry season from December to April (Figure 1), followed by the wet season (May to November), which is interrupted by a short dry period (July to August).

The year's first rainy season takes place from May to July. The first planting season—called primera—occurs at this time. Maize is primarily planted in this first planting season, and it is harvested in September/October.

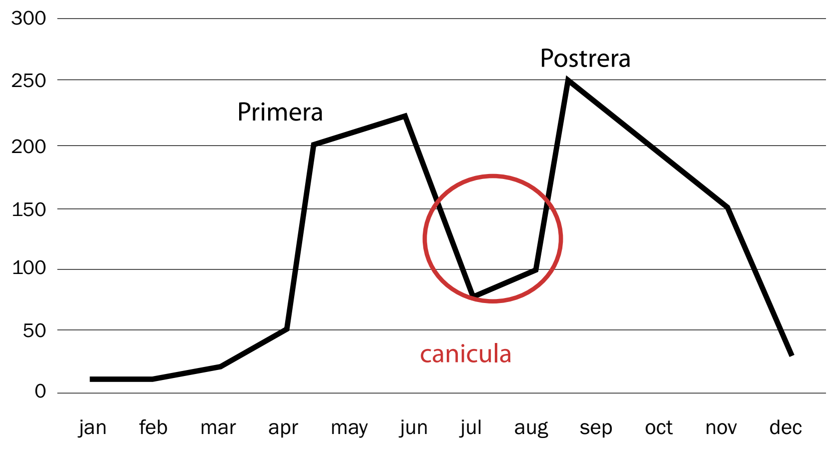
Pimera is followed by a short dry spell from July to August. The short dry spell following the primera is called the canicula.

After the canicula comes a second rainy season, called postrera, which lasts from early September to November. Beans are inter-panted amongst the mature corn.In most areas a second crop of maize may also be planted during the postrera. Beans are harvested at the end of the postrera.

In some more humid areas a third planting season—apante—is possible. Planting occurs in December/January, and harvesting takes place in February/March. Maize or beans, or both, are grown in apante.

The timing and severity of the canicula is perhaps the most serious climate risk factor to smallholder farmers, and is a major factor for smallholder farmers' cropping decisions (Magaña et al. 1999). When the canicula is very dry, starts early, or extends longer than usual, it threatens crops in both the primera and postrera seasons. Maize planted in primera can become stressed by an early onset of the dry period. Beans planted at the normal time in postrera can be stressed by the reduced availability of moisture during the initial growth period; or, bean planting could be delayed until the end of the extended canicula, thus shortening the bean-growing season.

Typical rainfall pattern in Central America (mm)



smallholders are highly vulnerable to climate variability, including droughts and severe storms.

3 MAIZE/BEAN SMALLHOLDER FARMERS NEED SPECIFIC INFORMATION TO UNDERSTAND AND ADAPT TO CLIMATE CHANGE

There is an urgent need by CA-4 smallholder farmers and decision makers, both nationally and regionally, for detailed information about where and how to focus activities for climate change adaptation and mitigation of the most important agricultural production system in Central America—maize/beans.

The added impacts of climate change, in the form of higher temperatures and less precipitation, will significantly affect crop viability or prevent production altogether. Therefore strategies for protecting the future of maize/bean production in the CA-4 must be implemented promptly. While the technologies for adaptation are, for the most part, already known, what is missing is the ability to know exactly where to apply the technologies strategically.

In order to adapt to climate change, maize/bean smallholders in the CA-4 will have to know what type of climate-related changes to expect, how these changes are likely to affect yields, and when and where changes will occur. Adaptation is possible only if predictions of global climate impacts are known at local levels, so that smallholders know what to adapt to.

Sufficiently detailed information about the extent of climate change and its effects in specific areas is needed so that actors can focus their decisions, policy, coordination, and interventions. However, the current outputs of climate prediction models are too coarse to allow effective decision making and strategy implementation at the smallholder farm level.

4 PURPOSE AND OBJECTIVES OF THE STUDY: PROVIDE DETAILED, ACTIONABLE INFORMATION FOR DECISION MAKERS

This study was carried out to provide specific and actionable information about the projected impacts of climate change of maize/beans, and to provide smallholder farmers with recommendations for adaptation. There is a gap between knowing that the impacts of climate change are imminent, and knowing that mitigation and adaptation strategies should be applied—but not knowing when and where to apply them. This study was undertaken to predict and analyze expected climate change impacts on maize/bean production at the smallholder farm level in El Salvador, Guatemala, Honduras, and Nicaragua.

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


A farmer in Honduras takes a break from digging irrigation channels in Alauca, Honduras


Farmer Juan Gonzalez checks his irrigated dry season bean crop in Jamastran, Honduras


Maize farmer Luis Cortés in his farm in Jamastran, Honduras

All photos by Neil Palmer

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

4.1 Objectives

1. Use existing global and regional climate models to create outputs that are specific to local scales (ranging from 1 to 5 km^2) across the CA-4 countries.
2. Predict how climate change will affect the production of maize/beans in the CA-4 countries.
3. Predict how the effects of climate change on maize/bean production in the CA-4 countries will affect smallholder farmers economically.
4. Identify and map, at a local scale, areas related to maize/bean production that will be affected by climate change, and classify these areas.
5. Identify and describe strategies that are most appropriate for specific geographic areas and socioeconomic conditions of smallholders.

5 METHODS

5.1 Providing climate projections for the CA-4, at the local scale

Historical climate data for Central America were derived from WorldClim's database.[7] WorldClim uses a combination of data from weather stations and interpolated data to provide estimates of temperature and precipitation at a high resolution (30 arc-second resolution, or about 1 km^2).

To generate climate projections for the CA-4, we applied 19 different global circulating models (GCMs).[8] The resolution of currently available GCMs ranges from 300 to 1000 km^2 at the global level, and from 50 to 60 km^2 at the regional level. These scales are too large for analyzing impacts at the smallholder level.

To downscale projections to the local scale—i.e., to achieve a resolution of 5 km^2 or better—researchers used a combination of WorldClim (which was cross-referenced with locally available climate data), and the delta method, which is a common tool that improves the resolution of GCMs by using a combination of climate data and mathematical interpolation.[9] The results of these climate projections were validated during field visits to 12 sites across four countries.

7 See www.worldclim.org.

8 In the literature, the abbreviation GCM is used to refer to "general circulating models" as well as "global climate models". In this paper, GCM refers to "general circulating models". GCMs are complex mathematical models that are key components for simulating climate and projecting climate change. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report used 21 GCMs. We used 19 of these GCMs to make our projections for the CA-4.

Climate projections were run for two time frames.

The first is a near-term scenario covering 2010 to 2039. This paper uses the shorthand term "2020s" to refer to the average for this period.

The second time frame is a mid-term scenario covering 2040 to 2069. In this paper the shorthand term "2050s" is used to refer to the average for this period.

Once the detailed climate projections were obtained, we clustered the results based on the outcomes of 19 bioclimatic variables, all of which were related to temperature (minimum/maximum) and precipitation. The results of this bioclimatic analysis were then overlaid on the Köppen climate classification map (Köppen 1936, Peel et al. 2007), which divides Central America into three main climatic zones.[10]

Our study did not include estimates of the frequency of extreme weather events such as hurricanes. Honduras, Nicaragua, and El Salvador are all top-ranking countries at risk of severe natural disaster according to the latest Climate Risk Index 2011 (Harmeling 2010). Although recent publications indicate "that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms" (Knutson et al. 2010), more information about the relationships between climate change and the frequency, intensity, and pattern of tropical cyclones is needed so that such data can be included in the modeling.

5.2 Predicting the effects of climate change on maize/bean production in CA-4

Next we made predictions of future maize/bean production. We used known physiological characteristics of maize/bean varieties, and their responses to heat and drought stress, to determine the effects of our climate projections on the crop performance of maize/beans. The main parameters analyzed were temperature (minimum/maximum), rainfall, and soil quality.

The tools used to predict maize/bean crop performance included:

- FAO's Ecocrop database[11] which is a spatial model that uses a range of environmental parameters to define a crop suitability index with a range of 0 to 100. These results were calibrated for the CA-4 countries.[12]

- Decision Support for Agrotechnology Transfer (DSSAT).[13] DSSAT is a well-tested tool for predicting crop performance. DSSAT requires the soil-water characteristics and genetic coefficients of each crop cultivar; relevant agronomic inputs such as fertilizer and irrigation; plus daily maximum and minimum temperatures, rainfall, and solar radiation.

9 For background on the delta method see Bader et al. 2008 and Jarvis and Ramirez 2010.

10 See Section 3 of the full-length report for details on the clustering methodology.

The DSSAT tool requires daily weather information, but our climate modeling methods above provided only monthly data. The availability of daily weather data is very limited for CA-4 countries. To fill this gap, we used MarkSim,[14] a weather-simulation model that uses 9200 weather stations in tropical and subtropical areas of the world and mathematical interpolation to generate maximum and minimum temperatures, rainfall, and solar radiation data.[15]

About 10 new bean varieties recognized for drought tolerance were field tested as part of this study, and their data were added to the database used for the crop performance models.

We simplified soil quality estimates by dividing soils into two broad categories: silts were used as a proxy for good soil, and sandy soils were used as a proxy for degraded (poor) soil. The poor soil scenario (low fertility, low water-holding capacity) is representative of current trends in soil degradation for Central America. The good soil scenario (higher fertility, more organic matter, good water-retention capacity) assumes better soil management. Soil degradation, which is characterized by nutrient depletion and loss of organic matter, is closely related with water limitations in two ways: degradation reduces water availability for crops by reducing rainfall infiltration, and it reduces plant water uptake due to weak roots (Rockström 2007).

Data on pests and diseases are scarce and the underlying interactions are not yet fully understood, so this factor was dropped from the study.

5.3 Predicting how the effects of climate change on maize/bean production in CA-4 will impact smallholder farmers economically: household vulnerability to climate change

Socioeconomic analyses were carried out on two levels.

First, we gathered socioeconomic information from smallholder farmers in 12 communities across the four study countries. The information we collected included main agriculture activities and trends, main sources of food and income, an analysis of household and community capital (assets), and a general perception of future communal strengths and threats.

Second, based on the initial socioeconomic information gathered and the results of the climate and crop modeling, we designed and carried out a detailed survey that involved 120 smallholder households in each country. The survey tool was designed primarily to determine a vulnerability index score for each household.

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11 See http://ecocrop.fao.org/ecocrop/srv/en/home.

12 See Section 3 of the full-length report for details.

13 See http://dssat.net/.

14 See http://gisweb.ciat.cgiar.org/marksim/.

15 See Section 3 of the full-length report for details.

The household vulnerability index is composed of three composite indices including: the level of exposure of the maize/bean cropping system to changes caused by climate change, the level of sensitivity of the household to the change in maize/bean production, and the resilience or adaptive capacity of the household. During these surveys, we also held focus-group discussions in all four countries. Through these discussions we were able to validate our identification of crop production areas and the importance of maize/bean production at these locations.

5.4 Mapping the climate impact areas in the CA-4

We used the results of climate modeling, the predicted effects on crop performance and aggregate yields, and the analyses of household vulnerability to produce detailed GIS maps that illustrate how specific geographic areas will be affected by climate change. The areas of impact were determined to fit into three classes, which are described in section 6.3.

6 RESULTS: THE EFFECTS OF CLIMATE CHANGE ON MAIZE/BEAN PRODUCTION IN THE CA-4

6.1 Climate projections at the local scale

We successfully downscaled the GCMs to higher resolutions—at least 5 km^2, and to 1 km^2 in some instances. These resolutions are significant improvements over existing ones. These downscaled models allowed us to generate future climate scenarios for the four countries included in the study—El Salvador, Guatemala, Honduras, and Nicaragua—in terms of a near-term time frame (2020s) and a mid-term time frame (2050s).

6.2 Projected effects of climate change on maize/bean production

Temperature: There will be an increase in annual mean temperatures (around +1°C by the 2020s and +2°C by the 2050s). Minimum and maximum daily temperatures will be higher. There will be an increased water deficit due to less precipitation and higher evapotranspiration rates.

Rainfall: Precipitation will continue to be minimal during the usual 6-month dry period (November/December to April), and may become even drier in some areas. There is a tendency towards a small reduction in precipitation in the month of May for most areas.

As an example, Figure 2 illustrates the projected changes in precipitation and temperature for one area in eastern Honduras, for the near-term scenario (2020s). For this particular area we predict no significant change in precipitation in the month of May. For the month of June, when maize is in an early and critical development phase, we predict less rainfall than the historic average.

The canicula (mid-summer dry spell that usually occurs in July and August), will be drier than it currently is and it will extend into September. The severity of the canicula in eastern Honduras will threaten maize that is planted in primera, and the prolonged canicula may make conditions unfavorable for the establishment and development of the postrera bean crop, which is normally planted in early September.

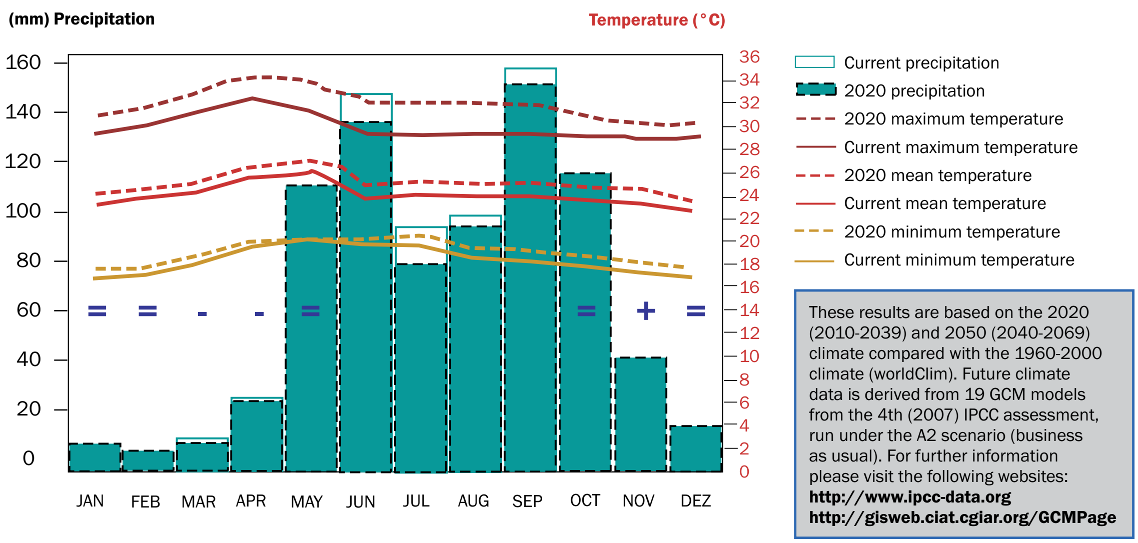

Figure 2 Temperature and precipitation changes predicted to occur by the 2020s (2010 to 2039), for one area in eastern Honduras.

For the second planting season, postrera, this community will receive less precipitation than the historic average during the month of September, which is when beans are normally planted.

The increases in the daily minimum, mean, and maximum temperatures will exacerbate water deficits: higher temperatures cause higher evapotranspiration rates of plants, triggering greater extraction of soil moisture by roots and thus leading to soil water deficits that will worsen the plants' heat stress. Dry conditions have substantial negative effects on biomass production and on the reproductive stages of both maize and bean plants.

Beans are particularly sensitive to high temperatures. When nighttime temperatures remain above 18°C, flowering is limited, thus significantly reducing bean yields.

During the months of October and November there is a risk of increased rainfall and flooding in eastern Honduras. In recent decades, severe storms have increased in frequency, often damaging agriculture and infrastructure.

6.3 Maps of the climate change impact areas

We produced maps for the CA-4 countries that illustrate the specific geographic areas related to maize/bean production that will be affected by climate change. The areas that will incur impacts, called climate impact areas, fall into the following three classifications:

- Hot Spot. An area where it will be difficult or impossible to grow maize/ beans in the future. Smallholder farmers will need to transition out of maize/beans.
- Adaptation Area. An area where it is possible for smallholder farmers adapt and continue to produce maize/beans if certain actions are taken now. Adaptation strategies would be focused on how to continue producing maize/beans.
- Pressure Area: An area that is not currently cultivated but where changing climate conditions will make an area more attractive for conversion to cultivation. Many of these areas are sensitive ecosystems, such as forests and wetlands. These areas were included in the analyses and on the maps (e.g., Figure 3) in order to illustrate the need to protect these areas from encroachment or degradation.

The map in Figure 3 shows the locations of the three classes of climate impact areas in the CA-4 countries: locations where beans should/can no longer be grown (Hot Spots, in red), locations where production systems need to be modified/adapted in order for production to continue (Adaptation Spots, in yellow), and locations where beans could, at least theoretically, be grown in the future (Pressure Areas, in green).

Most of the impacts to bean cultivation will occur in the 2020s, which is in the near-term scenario. This is because the predicted annual mean temperature increase of +1°C, in combination with higher minimum temperatures (night temperatures) will cause growing conditions to exceed the plants' physiological tolerances. Beans especially are affected because higher night temperatures impair their reproductive capacity and thus their ability to produce beans, i.e., their yield potential.

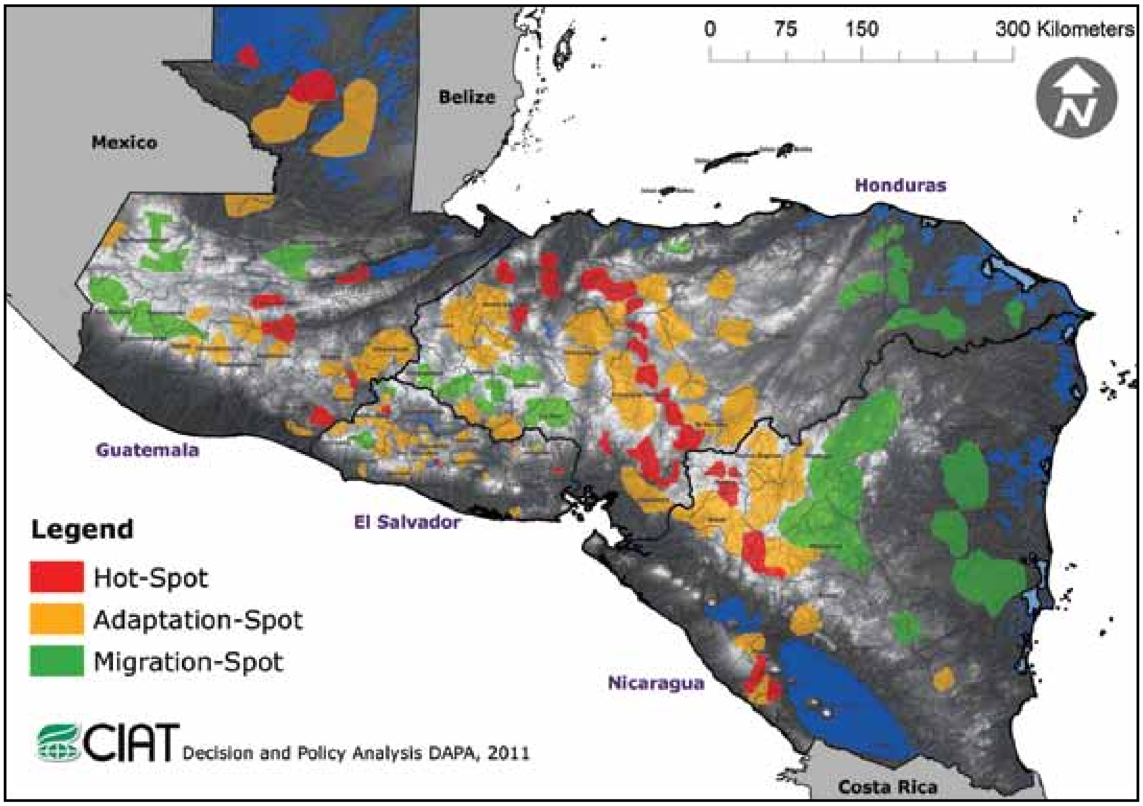

Figure 3. Predicted locations of climate impact areas, in four countries in Central America, for bean production in the 2020s.

6.4 Soil quality is a main determinant of effects of climate change on maize production

The DSSAT crop model revealed that the water-retention capacity of soil and soil fertility will significantly influence crop production, especially that of maize. This is critical for Central American countries, given that more than 75% of agricultural land has degraded soils (Oldeman et al. 1991).

Losses in maize production will be considerably greater for smallholder farmers located on poor soils than for those located on good soils (Table 1). For example, in El Salvador, climate change will cause a losses of about 30% in maize production on poor soils, but virtually no loss on good soils. Figure 4 illustrates the differences in yield reduction due to soil quality for the near-term scenarios and indicates the respective climate impact areas.

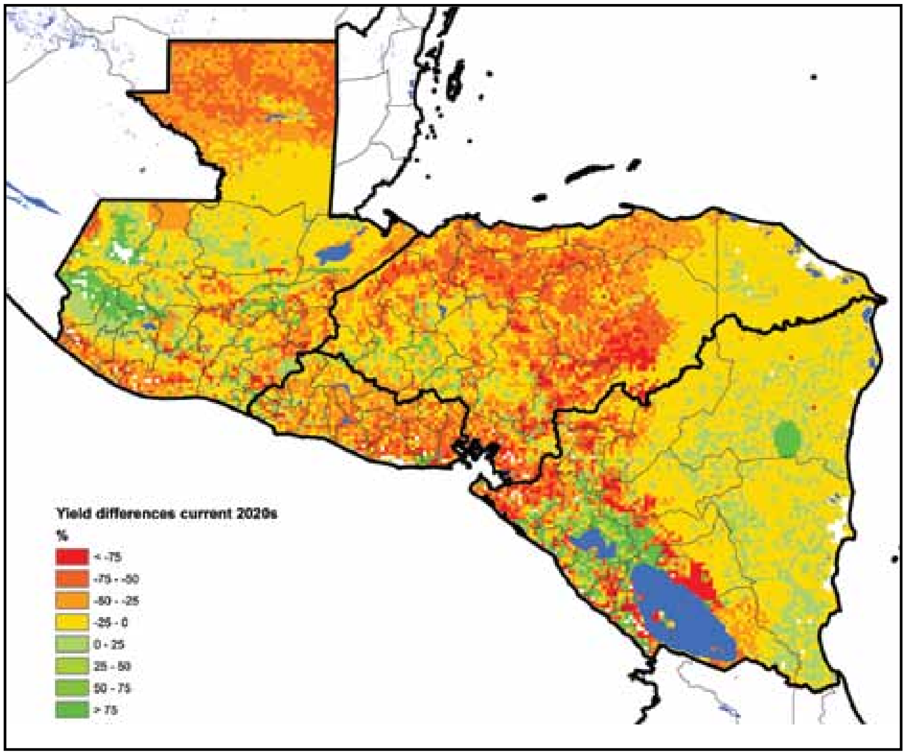

Figure 4a. Predicted differences in maize yields for 2020s under bad soil scenarios

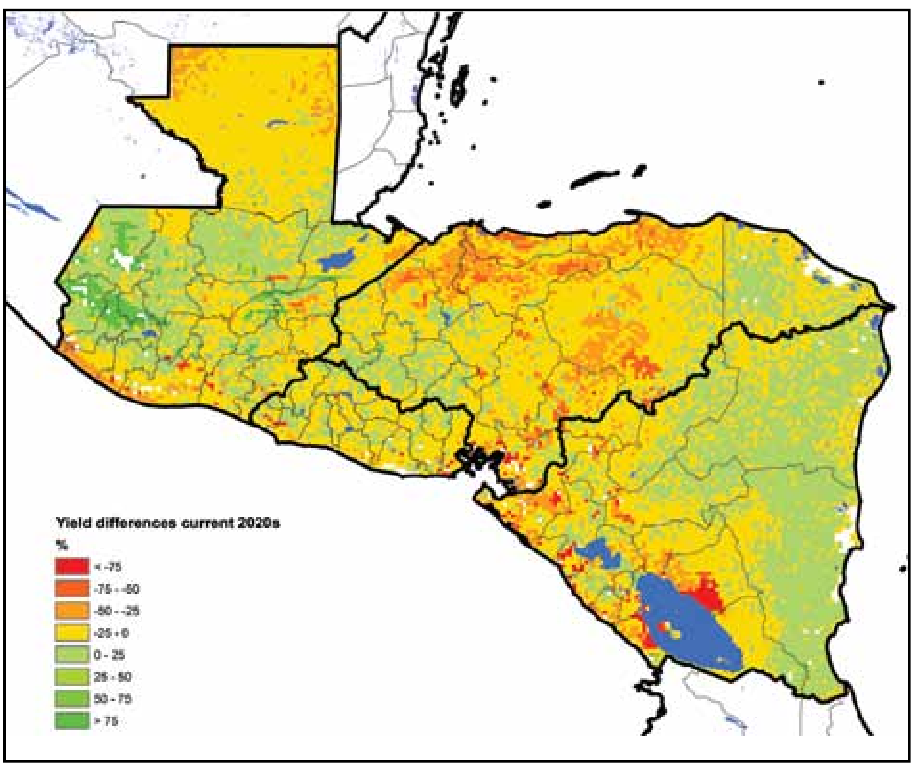

Figure 4b. Predicted differences in maize yields for 2020s under good soil scenarios.

Table 1. Predicted changes in maize production, in four countries in Central America, for two time periods, by soil quality.

Country	Poor soils		Good soils	
	2020s (% change)	2050 (% change)	2020s (% change)	2050s (% change)
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

An additional reason for greater differences in maize yield losses by soil scenario in El Salvador is that this country has very few remaining Pressure Areas (see section 6.3).

In all four countries, the negative impacts on maize production under the poor soils scenario are expressed at the country level. Honduras is worst affected (Table 1); losses in maize production will be almost 30% in poor soils for the 2020s and the 2050s, while losses in good soils will still reach 11.7% for both time frames. Second-most negatively affected for the scenario predictions is El Salvador, with slightly over 30% losses on degraded soils but minor losses on good soils. Nicaragua shows 11% losses for the poor soil scenario, but lower losses for the good soil scenario at 3.3% for the 2020s and 4% for the 2050s. Finally, Guatemala stands out with relatively low overall losses in production, at 10.8% for the poor soil scenario for the 2020s and 11% for the 2050s, but with a very slight increase in production under the good soil scenario overall.

These results take into account the potential for “annexing” land that is currently not suitable for maize/beans, but will become more suitable with the changing climate. We classified these lands as Pressure Areas. In many cases, these Pressure Areas are high-elevation (cool) forests, wetlands, and other sensitive ecosystems. The potential for Pressure Areas to be annexed into cultivation is a serious threat to natural resources and ecosystems in the region. In El Salvador, most land that can be cultivated is already cultivated, i.e., there is very little land that can still be converted. In the other three countries, Pressure Areas are more abundant, which, at least in theory, smallholder farmers could annex. The positive yield changes in Guatemala reflect the substantial amount of remaining mountainous forest cover in Guatemala that could be shifted to crop production, if environmental effects were ignored. Note: this study is not recommending conversion of forests or other sensitive ecosystems to annual crops.

The relationship between soil quality and bean production was also detected in

DSSAT, but beans did not show such dramatic results as maize.

6.5 Projected impacts on bean production

The impacts of climate change on bean production are also significant, with reductions predicted to be up to 25% of the CA-4's total production volume by 2050. Honduras will be the most affected country, with reductions in bean production expected to be 15% by 2020, followed by El Salvador at 8%, Nicaragua at 6%, and Guatemala at 4%.

6.6 Economic effects

Our conservative predictions indicate that reductions in maize and bean production will lead to economic losses for the region of about US$125 million per year, or 30% of current values, at or before the end of the 2020s (Figures 5 and 6). Note that these are rough estimates based on linear assumptions and do not take into account yield and price variability across time and regions.

In general, production losses for maize are much larger than for beans. This is true even when price differences tend to smooth the respective losses. Honduras and El Salvador have the largest maize production losses. For beans, Guatemala is the only country with relatively low predicted potential losses, but these low losses would occur only if smallholder farmers took the environmentally unsustainable approach of converting higher elevation forests into cultivated land.

For El Salvador, high potential losses in maize yields and the projected high price for maize are the main factors influencing high economic losses. However, changes in the variability of maize production over time and across jurisdictions are not a problem in El Salvador. In contrast, Nicaragua is predicted to have low changes in average production value but increases in production variability. Honduras is predicted to have the worst economic impact, with both high losses in average production and a substantial increase in variability of production across growing seasons. Guatemala is predicted to experience small changes in both average production and variability. Overall, the potential effects of climate change on maize/bean production in Guatemala will be less than in the other three countries.

6.7 Smallholder farmers are highly vulnerable to climate change

The vulnerability analyses reaffirmed the field observations we made through the focus groups and surveys in selected hot spots and adaptation areas. In all four countries, rural households have low adaptive capacity to climate change, as indicated by low physical, natural, and financial assets, and by limited human and social capital. Consequently, most of the CA-4 region can be classified as particularly vulnerable to climate change, with El Salvador showing the highest

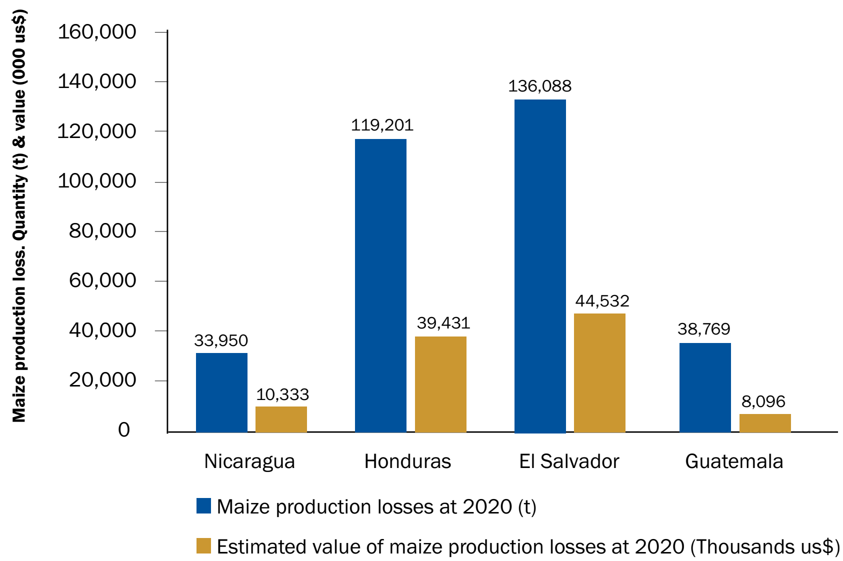

Figure 5. Predicted losses in maize production, in four countries in Central America, for the near-term scenario (2020s), by volume and value.

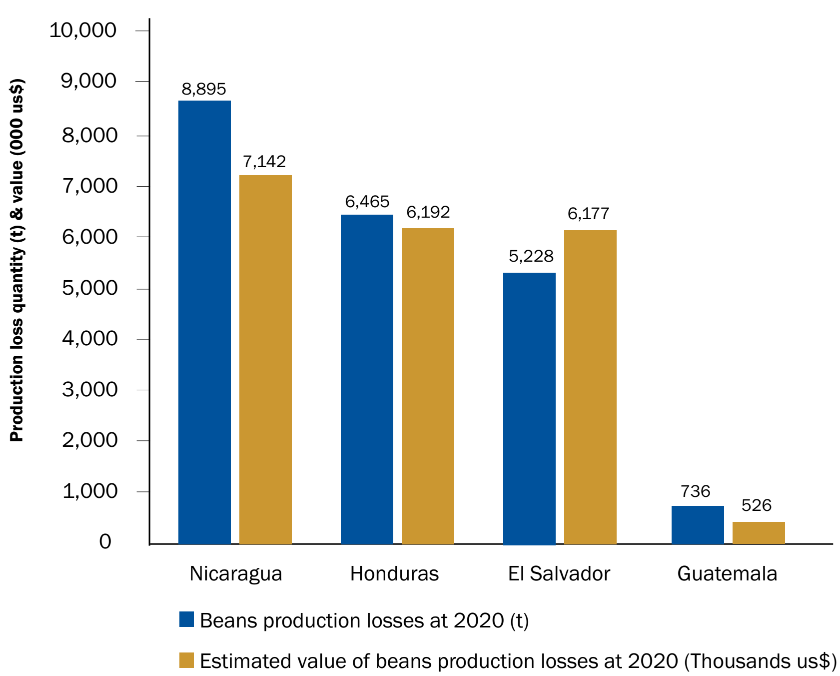

Figure 6. Predicted losses in bean production, in four countries in Central America, for the near-term scenario (2020s), by volume and value.

levels of vulnerability, followed by Honduras and Guatemala with medium levels and Nicaragua with a low level of vulnerability. This classification is somewhat arbitrary because we found high variability within the three classes of climate impact areas (Hot Spots, Adaptation Areas, and Pressure Areas—see section 6.3). Nevertheless the analysis provided valuable insights into smallholder farm assets (natural, physical, financial, human, and social), which are essential to developing location/farm-specific adaptation strategies.

The maps produced from this study provide a range of stakeholders, including smallholder farmers, government decision makers, development agencies, and the donor community, with information that will reduce the uncertainty of knowing how and where climate change is impacting smallholder farmers in the CA-4, and will guide the implementation of interventions. The maps indicate location and degree of predicted impacts so that countries can set priorities for policy, regulation, extension activities, adaptation, mitigation, and preparedness. This will allow actors from smallholder farm families to local authorities, and from donors to international agencies, to manage specific climate change risks in specific places.

7 STRATEGIC RECOMMENDATIONS FOR ADAPTATION STRATEGIES

The final objective of TOR was to identify and describe strategies that are most appropriate for specific geographic areas and socioeconomic conditions of smallholders. This section presents the five principal types of adaptation strategies identified by the study, and then provides a framework for recommendations tailored to specific conditions.

7.1 Five principal types of adaptation strategies

Over the course of the study, five principal lines of adaptation strategies emerged for implementation at the smallholder level, including: sustainable intensification, diversification, expansion of assets, increasing off-farm income, and diversification out of agriculture as a livelihood strategy.

Sustainable intensification and diversification both aim to increase soil fertility and water productivity, which are the two key elements for on-farm adaptation. All five of these strategies require serious investments in human capital (skills and knowledge).

7.1.1 Sustainable intensification

Sustainable intensification strategies are aimed at increasing crop productivity while preserving natural resources (land and water) in productive systems (eco-efficiency).

The cornerstone of adapting to climate change is for smallholder farmers to maximize the efficiency of natural resource use. While agriculture is a victim of climate change impacts, it is also a contributor, so sustainable intensification of production systems can increase productivity while simultaneously reducing greenhouse gas emissions. A series of strategies and management options for eco-efficient intensification of agriculture already exist, while others need to be adapted to local conditions. A central element for eco-efficient and sustainable intensification is to increase the efficient use of rainwater. Increasing the efficient use of rainwater is intimately connected to plant water availability, evaporation (from soils), transpiration, soil moisture, and plant water uptake capacity; these in turn are strongly linked to soil management, water harvesting, and plant nutrient management. These are the basic elements of agronomy; therefore it is critical that extension services, research, and university training re-emphasize basic agronomy.

In Central America, farmers are expanding the agricultural frontier through advances into more humid areas, such as the Atlantic coast in Honduras and Nicaragua. This is causing widespread deforestation, land degradation, social conflicts, migration, and increased greenhouse gas emissions. “Expanding” access to land could be done better through “climate smart” strategies. For example, there could be opportunities in the apante areas for converting deforested and degraded grazing lands into croplands and applying sustainable intensification to reverse land degradation. But this kind of strategy requires serious investments in knowledge, skills, and social organization (i.e., human and social capital)—see below.

7.1.2 Diversification

Strategies that diversify the production system lead to increases in the quantity and types of foods grown on land, and to more income from agriculture. Diversification should aim to keep vegetation over soils for as many months as possible to protect soils against erosion. Diversification can also maximize water productivity. Multi-story diversification—through agroforestry—can also increase soil water infiltration and is a key strategy for maximizing rainfall (water) productivity and reducing water stress.

While livestock and grazing systems were not explicitly studied in TOR, the topic emerged in the analysis for two reasons. First, grazing is often blamed for natural resource degradation in CA-countries, particularly soil degradation on sloping lands, and second, smallholder farmers are turning to livestock grazing as an alternative when soils are too degraded for cultivation. There is likely to be more grazing pressure with climate change. Therefore, the role of improved grazing practices and forages to mitigate, and adapt to, climate change is an important opportunity (Peters et al. 2000, Shelton et al. 2005). Peters et al. (2012, in preparation) identified opportunities in forage-based systems that are economically sustainable and socially equitable with the least possible ecological footprint.

7.1.3 Expand human and social capital/assets

As reported in the sections above, adaptive capacity for smallholders in almost all study sites was low. This highlights the need to focus on building human and social capital as an adaptation strategy, which underlies all other strategies. Information, knowledge, education, and social organization are important driving factors for successful implementation of all strategies for climate change adaptation.

7.1.4 Increase off-farm income, and diversify out of agriculture as a livelihood strategy

Strategies to increase off-farm income increase the importance of income sources from more-secure off-farm activities. Traditionally many Central American smallholders generate off-farm income as day labor—during coffee harvest, in processing facilities, or in maquiladoras (e.g. textiles for North American markets). These are predominately dry season activities associated with internal migration. Remittances are also an important source of off-farm income, which can help to develop new livelihood strategies when invested in value-generating economic activities.

Strategies to diversify out of agriculture mean that households will no longer depend on agriculture as the source of income and consumption. Diversifying out of agriculture requires training and education, particularly for young people, to succeed in other sectors. This has important implications for governments and the private sector in creating the conditions for education and job creation.

7.2 Targeting strategies based on climate change impacts and adaptive capacity

Identifying strategies that are most appropriate for specific geographic areas and socioeconomic conditions of smallholders proved to be complicated given the heterogeneity of how climate change would impact each location and the capacity of each smallholder to adapt to these changes. For example, climatic conditions vary considerably, soil quality is highly variable, and the mix of household assets (capital), and therefore their adaptive capacity, is also variable. The challenge for TOR was to provide assessments and recommendations that were meaningful at the farm or landscape level, while being more generally useful as decision-making tools across many different scenarios.

To do this, we classified the vulnerability of smallholder farmers based on the two main vulnerability indicators—impact and adaptive capacity. Each of these two indicators can be scored as high, medium, and low. Based on these scores, we determined a composite vulnerability class, ranked high, medium, or low. TOR then proposes a different set of objectives for adaptation strategies corresponding to each vulnerability class.

There are three basic strategic objectives: seek off-farm income; reduce the impact of climate change through sustainable agriculture, or increase assets (capital) to increase the smallholders' adaptive capacity. Table 2 summarizes these results.

Table 2. Classes of vulnerability, and the respective strategy objectives.

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

TOR presents three general types of vulnerability structures, and matches those to results of the climate models and socio-economic surveys in each community. Below, we describe the three general vulnerability structures:

1. Where the impact of climate change is high, but the adaptive capacity is low, the vulnerability class is scored high. In this case the general recommendation for smallholders is to seek income from non-agricultural activities and changing from maize/bean production to other livelihood activities.

2. Where the impact of climate change is high, and the adaptive capacity is also high, the composite vulnerability class is medium. In this case, the strategic objective for adaptation is to reduce the impact of climate change on-farm through *sustainable intensification* and *diversification* (these will be defined in the next section).

3. Where the impact of climate change is low, and the adaptive capacity is also low, the composite vulnerability class is medium. In this case, the objective should be to expand the assets (or capital) of smallholders, i.e., to increase their adaptive capacity, and to practice sustainable intensification on farm.

The results from TOR indicate that almost all smallholders have low or medium adaptive capacity, therefore a strategy to increase smallholder assets (i.e., to increase adaptive capacity) is common to all communities surveyed in all four countries, while a strategy to reduce the impacts of climate change on livelihoods is crucial, particularly in El Salvador.

Note, these strategy objectives should not be taken as absolute recommendations. Rather, they are intended to be guides, or starting points for discussion with stakeholders (smallholder farmers and their communities) in order to analyze results and design more specific strategies.

8 SUMMARY AND POLICY RECOMMENDATIONS

The information generated, the tools developed, and the strategies outlined in this study have the potential to create more resilient maize/bean production systems, while increasing the capacity of smallholder farmers to adapt to climate change in the CA-4 countries of El Salvador, Guatemala, Honduras, and Nicaragua.

The results of our project show that through the application of cutting-edge climate and crop modeling, uncertainty about the impacts of climate change on Central American maize/bean production systems and about how to respond can be alleviated. We successfully downscaled climate models to a useful resolution (5 km^2); quantified the impacts on maize/bean production and analyzed their socioeconomic consequences; identified specific climate impact areas; assessed household vulnerability to climate change; and presented principal adaptation strategies. Despite shortfalls in quantity and quality of available input data, we produced high-quality predictions about the influence of changing climate conditions on the production of maize/beans in El Salvador, Guatemala, Honduras, and Nicaragua.

The findings of the present study enable donors, development organizations, and decision makers at local, national, and regional levels to take appropriate action in the right locations and provide a policy and research framework for successful implementation of adaptation strategies in the rural sector. The tools and methodologies created for this study can also be applied to contexts beyond CA-4.

8.1 Recommendations

There is an urgent need for maize/bean smallholder farmers to deal with the impacts of climate change. Given the magnitude of changes predicted in the near-term scenario (2010 to 2039), climate change adaptation interventions must begin to take place now, without further delay. The study finds that the impacts of climate change on maize/bean production systems are significant, and they will be felt as soon as the next decade.

The results of the study fill a critical gap in our knowledge of the impacts of climate change on maize/bean production in Central America. With this new information, stakeholders can now shift from a position of uncertainty to a position of risk management. The study shows there is reason for optimism: if action is taken now, the most severe impacts can be managed.

8.1.1 Technical interventions

The technical strategies for adaptation are well known. TOR provides recommendations on what adaptation strategies are most appropriate for specific areas.

Among the critical areas for investment are soil and water management; education and training to build agronomy, soil, and water management skills; protection for forests, wetlands, and other sensitive ecosystems; and understanding the appropriate role for plant genetics. The key is to strategically focus investments for smallholder maize/bean farmers, and to tailor the investments to unique conditions.

What is needed now is political commitment and investment in agricultural production in Central America. Governments urgently need to invest in education and training to build institutional and human capacity, and to rebuild extension services that re-emphasize basic agronomy, soil, and water management. Because more than 80% of Central America's maize and beans are grown on rainfed land, agriculture investments should be targeted to smallholder farmers in these areas. Production, which is low now, could be increased—even in the face of climate change—through improved agronomic practices and water management. National and local governments, working with communities and civil society, will need to work together to protect forests and, wetlands, and other sensitive ecosystems from encroachment and unsustainable agricultural practices. Research priorities should include breeding new varieties for heat and drought stress, although we need to be wary of over-relying on this strategy.

8.1.2 Better data management

Improve Data Collection and Management: Governments also need to invest in their capacity to monitor climate change by collecting and sharing geo-referenced: (a) daily climate data, (b) yield data for maize and beans, and (c) updated detailed soils maps.

Crop Yields and Economic Data: Inconsistent or missing data made it difficult to provide model outputs at a 1-km resolution in most areas of CA-4. In particular, long-term yield and economic data (statistics) at the required level of resolution are not available. To better quantify impacts on maize/bean systems and their effects on socioeconomic factors, and to perform advanced economic analyses, much more and better local-scale economic data and harvest data are needed.

Climate Data: Climate data, particularly in Honduras and El Salvador, need improvement. The general lack of simple recording and management of key weather data at local and national levels impeded, and will continue to impede, the ability to carry out highly detailed data analyses, predictions, and simulation scenarios. Georeferenced data collection should be the standard—not the exception—in all public and private agriculture and natural resource programs.

Soils: There has not been a comprehensive soil mapping of the CA-4 for more than 20 years and this is urgently needed in order to better understand the changing conditions and the strategies that are required for climate change adaptation in each location. Based on the demonstrated importance of soil characteristics for climate adaptation and mitigation, there is a urgent need for georeferenced soil data throughout CA-4. While the variability in soil characteristics in hillsides in Central America is particularly challenging, new remote sensing methodologies tested can contribute to the data gap at local levels.

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A bumper dry season maize crop in Jamastran, Honduras, is produced thanks to irrigation.

A handful of maize seed, on a farm in Nicaragua.

A farmer in Honduras digs irrigation channels in Alauca, Honduras.

All photos by Neil Palmer

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