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Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study

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RESUMEN

Los eventos climáticos extremos (como los asociados con eventos fuertes de El Niño) afectan de manera importante a la agricultura mexicana, ya que más del sesenta por ciento de ella es de temporal, esto es, depende fundamentalmente de una buena temporada de lluvias para producir. El cultivo que se siembra es básicamente maíz, que todavía es la principal fuente de nutrientes para una gran proporción de la población rural en el país. Dentro del proyecto *Fomento de Capacidades para la Etapa 2 de Adaptación al Cambio Climático en Centroamérica, México y Cuba* analizamos las estrategias que han desarrollado los productores de maíz de temporal en la región centro del país para hacer frente a los eventos climáticos adversos. Los impactos en el maíz de temporal debido a la variabilidad y al cambio climáticos son estudiados empleando un modelo de simulación agrícola. Varias medidas de adaptación se pueden evaluar usando este modelo. Sin embargo, el efecto de otros forzantes se debe considerar en una evaluación de la capacidad adaptativa de los pequeños productores al cambio y a la variabilidad climáticos. La participación de los actores clave de la región permitió decidir cuáles de las posibles medidas adaptativas podrían ser viables bajo las condiciones climáticas actuales y futuras. La construcción de invernaderos, el uso de composta, la aplicación de riego por goteo, fueron algunas de las técnicas seleccionadas con los actores clave. Las respuestas entusiastas ante estas medidas permiten considerar que éstas podrán prevalecer en el futuro ante condiciones de cambio climático. Sin embargo, la adaptación al cambio climático implica –además de las técnicas descritas– la generación de las capacidades para hacer frente a los eventos climáticos adversos, esto es, incrementar el conjunto de capacidades adaptativas al cambio climático entre los actores clave.

ABSTRACT

Climate extreme events (such as those associated to strong El Niño events) highly affect Mexican agriculture, since more than sixty percent of it is rainfed. The basic crop cultivated is maize, which is still the main source of nutrients for a large portion of the rural population in the country. Within the project *Capacity Building for Stage II Adaptation to Climate Change in Central America, México and Cuba*, we analyze the strategies developed by maize producers in the central region of the country to cope with climatic adverse events. Impact on rainfed maize due to climate variability and climate change conditions are studied using a crop simulation model. Several adaptation measures can be evaluated using that model. However, the effect of other stressors must be considered in an assessment of the adaptive capacity of small farmers to climate variability and change. Key stakeholders' involvement in the region helped us to decide which of the adaptive measures could be viable under the current conditions and under future climatic conditions. The construction of greenhouses, the use of compost, and dripping irrigation, were some of the techniques selected with the participation of the stakeholders. The enthusiastic responses to these measures allow us to consider that they can prevail in the future, under climate change conditions. However, the adaptation to climate change includes –besides the stated techniques– the generation of the capacities to cope with climatic adverse events, that is, to enhance the adaptive capacities to climate change among the key stakeholders.

Keywords: Climate variability and change, rainfed agriculture, vulnerability and adaptation.

1. Introduction

Rainfed maize production is the most important agricultural activity for the majority of subsistence farmers in México. During 2000, 11,175,842 hectares of the total national agricultural production were rainfed in the spring-summer period (SEMARNAT, 2000) and 53% of it was maize. Similar numbers can be found since 1990, illustrating the great importance that a good rainy season has for the Mexican agriculture and also the value that Mexican farmers give to maize production.

Maize has been planted in the country for more than 500 years (Nadal, 2000), and it constitutes the basic food in the Mexican nutritional regime. The scarcity of maize grains and famine can be found in the history of México associated with severe and long lasting droughts, which social effects increased during the most important civil wars in the country: the War of Independence (1810), that was probably influenced by drought conditions that prevailed in the country since 1809 and lasted until 1812 (García-Acosta *et al.*, 2003), and the Mexican Revolution (1910), for which some authors (Florescano and Swan, 1995, Jáuregui, 1995) have documented the drought conditions that persisted since 1908 to at least 1913.

It is then clear that climatic extreme events have affected severely maize production; particularly drought events have forced farmers to apply different strategies to cope with it. The relation between those droughts in México and El Niño events has been discussed in several previous papers (Jáuregui, 1995; Liverman; 1990, Magaña, 1999), and strong El Niño events and their impacts in the last forty years on rainfed maize production in the central highlands of the country, have also been reported by the authors of this paper (Conde *et al.*, 1999a, 1999b).

Based on these studies, it can be stated that the strategies to cope with climatic extreme events applied by farmers include changing planting date, switching to more resistant maize varieties, applying agrochemicals and changing cultivars. All of these measures could be seen as strategies inside the agricultural activity, but also there have been strategies that farmers have developed outside their agricultural sector, such as seeking for temporary jobs in urban areas, renting their fields or even migrating to the capital city of the state, cities in other states or to the United States of America. It has been calculated that almost 50,000 Mexicans migrate each year, so that by 2004, 10.23 million Mexican migrants lived in the United States, a population that has grown at an annual rate of 4.2% since 1994 (CONAPO, 2004). However, this migration has allowed the subsistence of rural families, since migrants have sent millions of dollars to México (in 2004, more than 13,000 billion USD; Banco de México, 2005).

During the year 2003, 200,500 agricultural producers that were affected by climatic adverse events (climatological contingencies) were supported by the Mexican government. A survey applied to a representative sample of those producers showed (Cortés, 2004; Gay, 2004) that the majority of them produced maize and that the major climatic event was drought. Also, the averaged age of those producers was more than 50 years, and one third of them were women, showing a social composition shift towards those that are more vulnerable to climatic, socioeconomic and political changes.

The current situation of Mexican agriculture has become quite unstable, since Mexico is a country with an increasing food importation. More than 90,000 million USD were invested during the last decade for this purpose (Pérez, 2005), and were particularly directed to purchase maize from the United States of America. For some authors (e.g. Appendini, 2001), the policy related to food security issues changed since the nineties to guarantee people's capacity to acquire food, instead of seeking an agriculture that could produce most of the food for its population. The massive importation of maize also threatens the high genetic diversity of Mexican maize varieties (forty-one racial complexes and thousands of corn varieties (Nadal, 2000)) and could become more dangerous under the new laws of biodiversity that do not clearly protect the native seeds from transgenic ones.

Maize prices have dropped dramatically, being now 45% less than those in 1988. In contrast, the *tortilla* price (nutritional basic element in México) has increase in almost 279% (Nadal, 2000), accelerating the malnutrition conditions and poverty of the rural and urban population.

Considering all of these factors, it is possible to say that the adverse climatic events are now a more acute source of vulnerability in the Mexican agriculture than before, since multiple socioeconomic stressors are now in action.

In response to the described situation, rainfed maize producers have expanded the planted surface, using areas where soils are not favorable to agriculture and increasing the pressure on forests and other ecosystems. Even though yields have then decreased, and that the lack of governmental support are important agricultural disincentives for rainfed maize production, Mexican total production of maize is more or less constant since 1988, except for 1998, when national corn production was affected by a severe drought (Nadal, 2000b).

Adaptation measures aimed to reduce the impact of climatic events such as drought, must then consider the economical and social barriers described above.

2. Methods

During the project Capacity Building for Stage II Adaptation to Climate Change in Central America, México and Cuba (UNDP, PIMS # 2220), the method proposed by the Adaptation Policy Framework (Lim *et al*., 2004) is being applied. This method is stakeholder driven, implying that each step of the project must include stakeholders' active participation.

An important feature in this project is that it deals with current climate vulnerability and adaptation, in contrast with previous studies, such as the country studies (Gay, 2000), more focused on climate change scenarios than on the current and past impacts of climatic variability.

For México, a case study is being developed in three municipalities in the state of Tlaxcala, with the objectives of analyzing and implementing options to increase the adaptive capacity of rainfed maize producers to adverse climatic events, which can be seen as possible adaptation measures to climate change. It is expected that those farmers, and also decision makers and regional experts (key stakeholders) will be involved in the assessment of current and future vulnerability and adaptation options.

Climatic threat spaces are proposed (Conde, 2003a, 2005a) as a tool to visualize those years when temperature and precipitation anomalies (with respect to the average values from the period 1961-1990) might constitute a climatic threat to maize production. These climatic threat spaces are constructed using the averages (which are used in climate change studies as the ''base scenario''), and a measure of variability (the inter-quartile range), which represent the normal climatological conditions. Years outside these ranges can be seen as possible threats to the specific system that is being under study. To address if in those years there might have been negative impacts, thresholds related to the system must be depicted in that space to visualize the most threatening years.

In this phase of the study, we are deciding the coping ranges and thresholds at different phenological stages of the crop, to construct the threat spaces specifically related to maize climatic requirements.

To address the possible impacts of climatic variability and change, crop simulation models, such as the Ceres-maize model (Jones and Kiniry, 1986) is being used, particularly to determined maize sensitivity to diverse climatic conditions. Also, social scientists are analyzing the current agricultural policies and programs that might be implemented in the state and that could support future projects in this field.

Climate change scenarios for the years 2020 and 2050 are constructed using the outputs of three general circulation models (GCM), and two socioeconomic special report on emission scenarios SRES A2 and B2 (Nakicenovic, 2000). These scenarios are introduced in the Ceres-maize model, so projections of future yields can be obtained.

Finally, after one year of applying participatory techniques (Conde and Lonsdale, 2005), the project team (researchers, students and farmers) decided that three practical methods will be applied: the use of compost to organic cultivation of tomatoes and chile, construction of greenhouses, and dripping irrigation, to optimize the use of water. For that purposes, new members of the research team were incorporated (i.e. architects, chemists); particularly, it was considered that students and teachers from the local school of Environmental Studies could guarantee the future sustainability of the project.

3. Results

The case study that is being carried out in three municipalities of the Mexican state of Tlaxcala (Fig. 1), is supported by a continuous stakeholder communication, facilitated by the participation of several researchers and the authors of this paper in different studies since 1997 (Orozco, 2000, Ferrer, 1999, Conde *et al*., 1998, Magaña *et al*., 1998). These conditions favored the flux of information of stakeholders' needs, perceptions and agreements with the research team, so that the stakeholder driven requirement can be achieved. All members of the project team (researchers, students and producers) have participated in several workshops and focal groups.

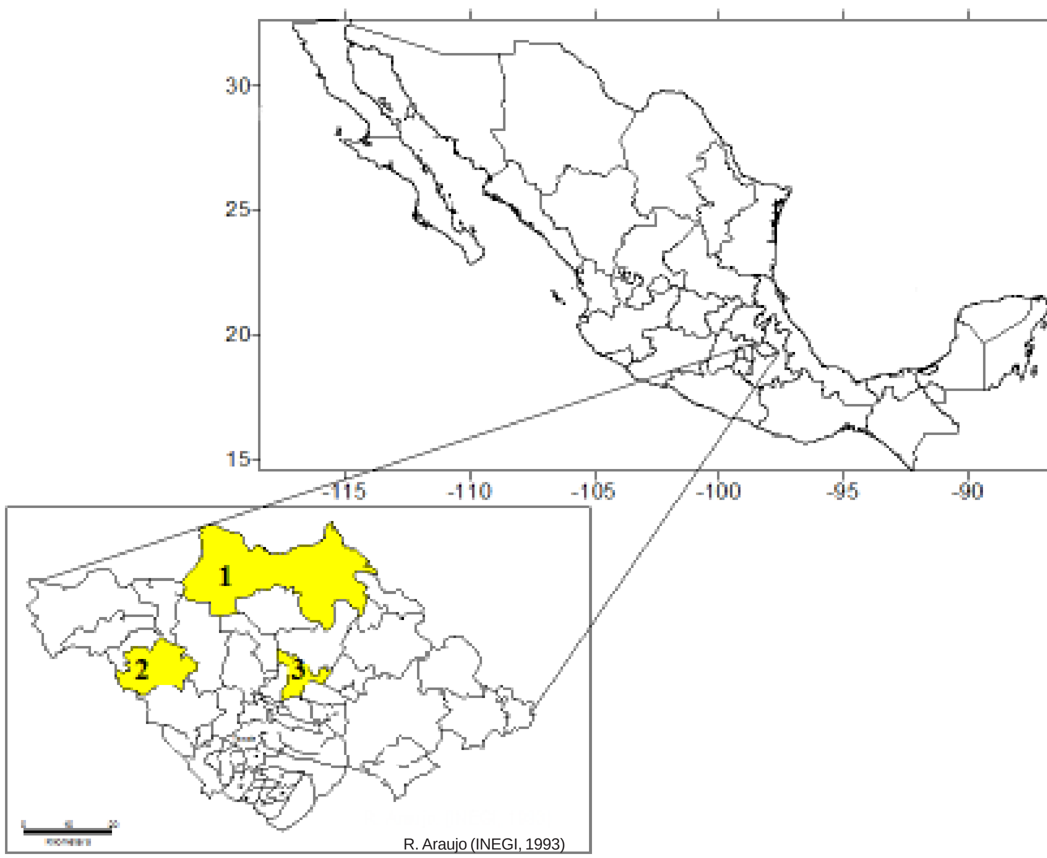

Fig. 1. Tlaxcala state and the 3 municipalities (1. Tlaxco, 2. Españita, 3. Apizaco), were the project is being developed.

During the first workshop of the project (10/6/2004), it was agreed that the most vulnerable group in the agricultural sector was the rainfed maize producers. Also, drought, frost, hail and strong winds were considered the most important climatic threats in the state. Soil degradation was the most important environmental factor that could reduce the coping capacity of maize producers. Socioeconomic conditions, such as the lack of economical support (particularly the disappearance of subsidies) and of technical support, have highly reduced the access to resources that usually farmers applied to cope with climatic adverse events. Finally, young farmers are migrating to other regions, or changing their occupational expectations.

The main conclusion of this workshop is that the project should focus in those soil enrichments and water optimization techniques that could also support adaptation conditions in the future. For that purpose, the construction of greenhouses, the use of compost, and dripping irrigation were agreed as the possible techniques that could reduce the current vulnerability of rainfed maize producers. These measures might allow farmers to cope with current and future climatic events. Also, farmers can obtain an extra income, which indirectly improves the agricultural conditions of maize production.

After that workshop, several fieldwork campaigns have been developed (from January to December, 2005), discussing the design and cost of greenhouses, the manufacture of compost and selecting the cultivars that will be grown in the greenhouses.

In the focus groups participatory techniques were applied; their main objectives were: a) to draw maps to agree where the natural resources are allocated and where land use changes have been relevant; b) to classify soils and their possible current use; c) to construct a calendar of farmers' activities and incomes d) to prioritize the climatic adverse events.

In previous studies we were also able to learn about the farmers' perceptions and needs of climatic information (Ferrer, 1999, Conde *et al.*, 1999a, 2003c), particularly considering small proverbs (sayings) such as: ‘‘Flowering in March, (*represent a*) lost year’’, ‘‘April rains, a thousand grains’’, or ‘‘What has not been born by St. John's (June, 24) is lost by St. Peter's (June, 29)’’. These perceptions are still documented as an important feature of the ongoing project, since they describe the fears and hopes of farmers related to current climate, and can also indicate the future climatic risks associated to possible changes during certain months or seasons.

Soils in Tlaxcala are the less fertile in the country (SEMARNAT, 1996), so maize yields are less than 2.5 tons per hectare, and 40% of the productive units have less than 1 hectare (Plan Estatal de Desarrollo, 2005). Rainfed agriculture is practiced in 89% of the cultivated surface, being then highly affected by climate variations.

The agreed adaptive measure to soil conditions was to support the use of compost for cultivating. The National Autonomous University of México (UNAM) donated 5 tons of compost at the beginning of the project, while researchers and students from the University of Tlaxcala began learning the processes to manufacture compost from manure and/or organic wastes.

The general conditions of maize producers follow those described previously: low prices of maize grains and forage, high prices of tortilla, malnutrition and increasing poverty. Also, rural migration and farmers aging reduce the strategies that farmers have adopted in the past for food security, like diversifying cultivars (Altieri, 1987) or soil conservation techniques (Ziervogel *et al.*, 2005; Conde and Ferrer, 2003a).

The project team decided that the possible adaptive measure for this situation was to cultivate chiles and tomatoes (cultivars selected by the farmers and their families), that could be consumed by families involved in the project, but also that could be sold with a much better price in the market than maize.

As an example of the climatic threat spaces (Conde and Ferrer, 2003a, Conde *et al.*, 2005a), in Figure 2 a combination of the minimum temperature and the precipitation anomalies are shown for the spring season (March, April, May; MAM). These variables are chosen since frosts (associated with lower values of minimum temperature), and/or a delay in the onset of the rainy season, are two of the most worrisome climatic events for maize producers in Tlaxcala. The anomalies are calculated with respect to the median value (1961-1990) for precipitation and with respect to the average value (1961-1990) for minimum temperature. The limits of box 1 (Fig. 2) are determined using the quartile range for each variable. The limits of box 2 (Fig. 2), that lies above the inner one, are defined in terms of the physiological requirements of temperature and precipitation for maize. As an example, minimum temperatures below 6.5 ºC represent the lower threshold at any stage for maize in Tlaxcala, where frosts can affect the crop.

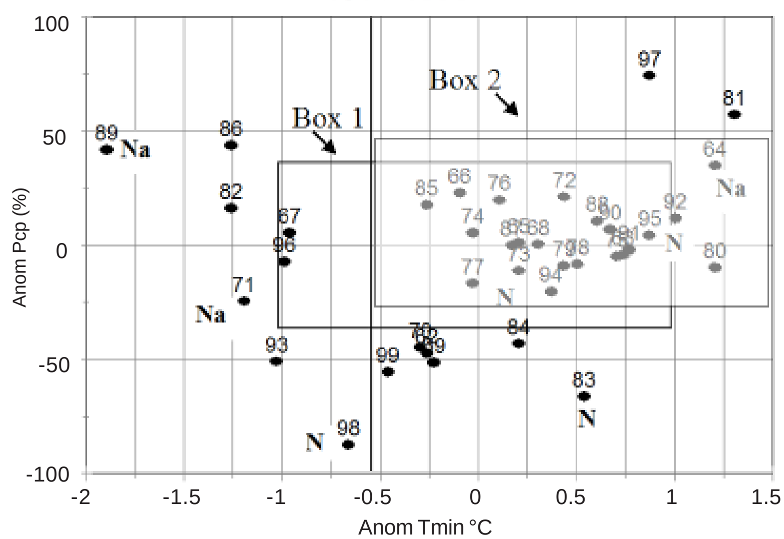

Fig. 2. Example of climatic threat space for 1961-1999 springs (March, April, May; MAM) for Apizaco, Tlaxcala. Box 1 depicts the quartile range of the temperature and precipitation. Box 2 is related to the climatic requirements of maize during this season.

To prevent losses from severe frosts events, the project team decided to construct small greenhouses that could protect the tomatoes and chiles from these events. The team learned to plant in seedbeds (using a combination of bio-fertilizers, local soil and compost), and then to transplant the most developed plant into the greenhouse. These measures would increase the limits of the coping range related to frosts, and would give the maize producers an important income, without which is difficult to apply adaptive measures to their main activity.

The delay in the onset of the rainy season in spring represents a highly risky drought. Also, heavy precipitation implies a high risk of lixiviation of nutrients and hydrological erosion.

The agriculture of Tlaxcala is very dependant on summer rainfall, since 92% of the rural production units are rainfed (INEGI, 1996) and more than 50% of those units are dedicated to maize production. Tlaxcala is the smallest state in the country, with a complex topography that gives the state a significant spatial climatic variability. The late onset of the rainy season and a decrease in the amount of summer rain are the two conditions that farmers define as "drought", both phenomena are present during strong El Niño events (Conde and Heakin, 2003b; Conde *et al.*, 1999b), and can reduce maize yields in Tlaxcala (Figs. 3 and 4).

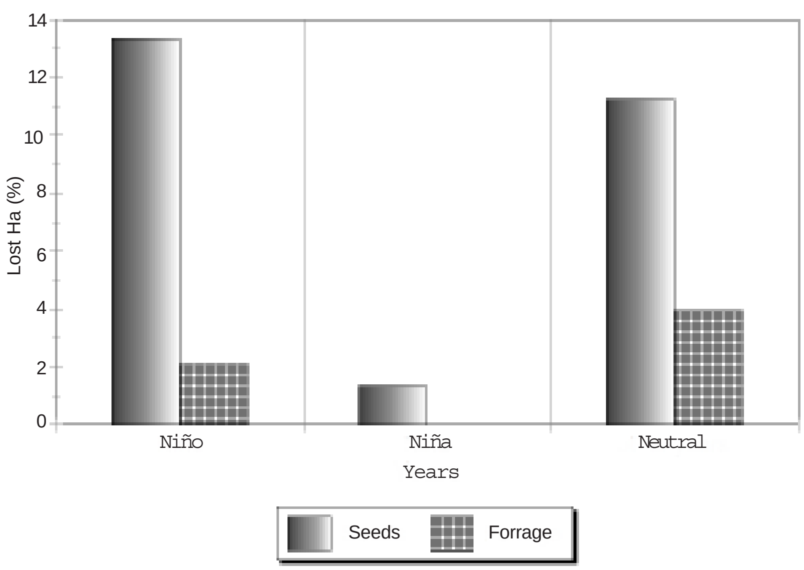

Fig. 3. Impacts of El Niño, la Niña and neutral years in rainfed maize production in Tlaxcala, obtained for the average yields for the period 1979-1996. *Source*: Apoyos y Servicios a la Comercialización Agropecuaria (ASERCA, SAGARPA); (Personal communication).

In this context, the project team agreed that dripping irrigation could be a solution, not only during drought conditions, but also due to the scarcity and cost of this resource for agricultural activities. It could also be a precaution if climate change conditions develop to a drier scenario.

La Niña conditions usually lead to normal or above normal summer rains, which could have positive effects on maize yields (Fig. 3). However, La Niña events have eventually been associated to floods that have affected severely Tlaxcalan agriculture, since this state is the most affected in the country by hydrological erosion (SEMARNAT, 1996). If the climate change conditions could imply an important increase in the amount of rain, then this could also represent a risky scenario for maize production in the state.

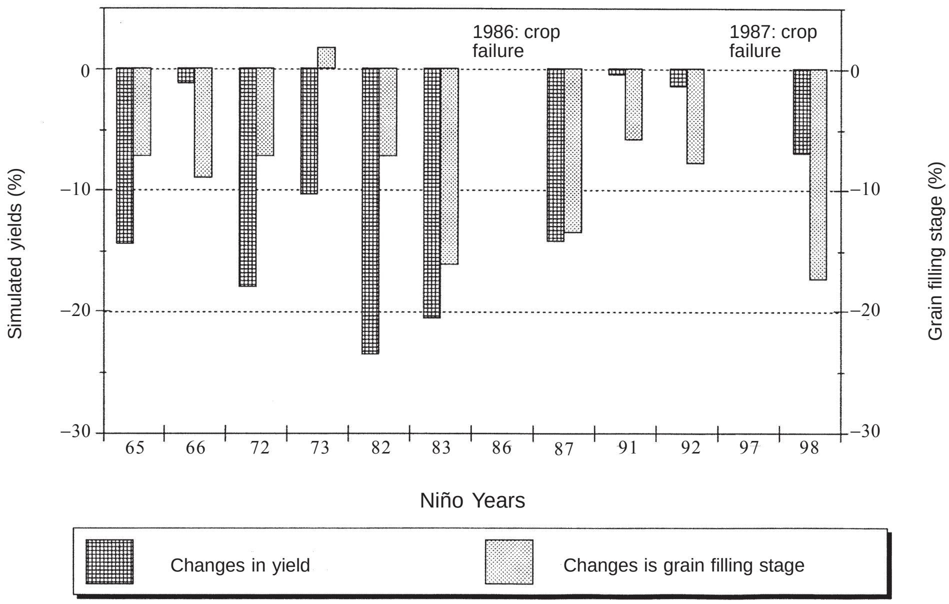

Fig. 4. Changes in simulated yields (%) and on the grain filling stage for Apizaco, Tlaxcala, Differences are calculated using the Ceres-maize model (Conde *et al.*, 2003) and comparing the expected results with normal climatological conditions (climatology) with the strongest El Niño events since 1965 to 1998.

Several climate change scenarios can configure an El Niño or La Niña analogue condition for the state of Tlaxcala. These scenarios were constructed using three general circulation models (Echam4, HadCM3, GFDL) under the A2 and B2 SRES scenarios (Nakicenovic, 2000), and for the years 2020 and 2050. In Figure 5, the possible changes in temperature and precipitation are shown as an example for the month of July, and for the Tlaxcalan municipality of Apizaco.

The possible impacts of climate change calculated with the Ceres-maize model showed an increase in maize yields (Fig. 6), for the emission scenario B2 and using the outputs of three general circulation models. This situation is related mainly to the reduction of frost threats, associated to the increase in minimum temperature.

One important issue that must be considered in the climate change scenarios is that the changes in the basic climatic variables are related to changes in the mean values, but nothing is established in relation to extreme climatic events. If the future climate will be associated to an increase in the duration or intensity of El Niño events (Intergovernmental Panel on Climate Change, Working Group I, IPCC, WGI, 2001), the positive results obtained with the Ceres-maize model then should be taken with precaution (Conde and Heakin, 2003b).

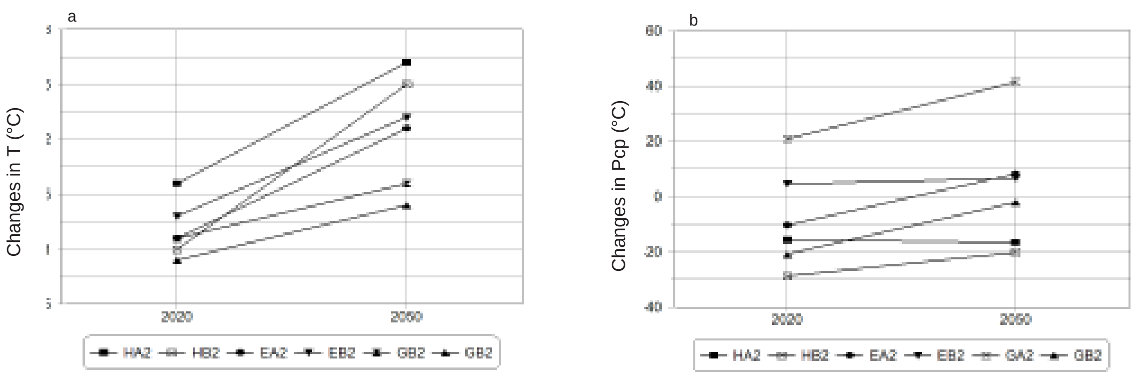

Fig. 5. Climate change scenarios for Apizaco, Tlaxcala. The variables shown are temperature (a) and precipitation (b) for the month of July for the years 2020 and 2050 using three GCM outputs (H: hadCM3, E: Echam4, G: GFDL) and two SRES scenarios (A2 and B2).

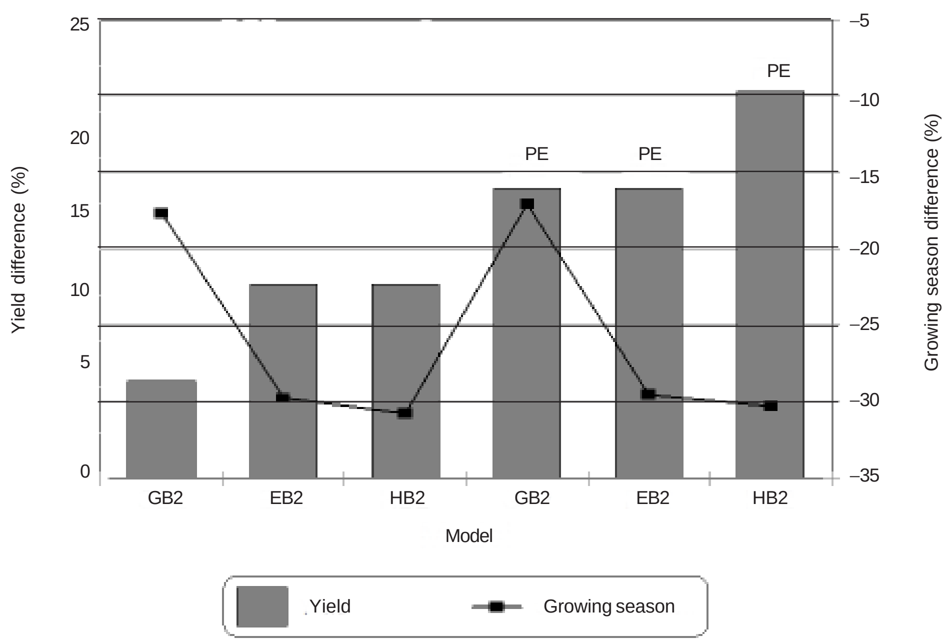

Fig. 6. Impacts on rainfed maize production in Apizaco, Tlaxcala, considering the changes in yields (%) and the changes in the growing season (%). The climate change scenario uses the B2 SRES scenario, the outputs of three GCM (HadCM3, ECHAM4, and GFDL; notation as in Figure 5). PE in the figure refers to the physiological effect of the increase in atmospheric CO_2.

There are now high expectations and enthusiasm among the farmers involved in the project for those techniques that are being implemented. However, the most valuable issue in the project is the capacity building to conduct, participate and implement the selected adaptative measures.

The enhancement of the adaptive capacities includes the multidisciplinary research team, the new knowledge that farmers will acquire to manage the greenhouses, the compost, and the dripping irrigation, and finally the support and follow up that the University of Tlaxcala will provide to these new processes, since the monitoring and evaluation of the project's results need to be performed and documented.

4. Conclusions

Rainfed maize agriculture has been and will be severely affected by climatic events. The producers' socioeconomic conditions (producers age, migration, malnutrition, poverty, low maize prices, increasing prices in tortillas, lack of economical or technical support, etc.) have decreased the coping capacity of farmers to climatic adverse events, particularly to drought.

Impacts of El Niño climatic conditions, simulated with the Ceres-maize model, differ in sign with those obtained with climatic change scenarios, which report an increase in yields. These differences could represent a window of opportunity in the future, but the latter results should be taken with precaution, since the climate change scenarios only address changes in the mean values of the climatic variables, but do not account for the possible changes in the extreme climatic events (such as El Niño).

The possible advantages of the selected strategies during the project Capacity Building for Stage II Adaptation to Climate Change in Central America, Mexico and Cuba (greenhouses, the use of compost, and dripping irrigation) proposed with the engagement of the producers in the region are: producers' aging will not affect the labor required, women can be integrated to these options, soil fertility can be coped with (using compost) and optimization of water consumption can be achieved. Also, these measures increase crop diversity and food variety for the producers and their families and reduce the current climatic risks. Finally, these options are considered viable adaptation measures for future climatic changes.

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