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Assessing current and potential rainfed maize suitability under climate change scenarios in México

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RESUMEN

Se evaluó la aptitud que bajo condiciones de temporal se tiene en México para el cultivo del maíz, así como bajo simulaciones de escenarios de cambio climático. El método aplicado consideró el factor más limitante a partir de diferentes variables que el maíz requiere para poder desarrollarse. Se compararon los factores y se obtuvieron zonas potenciales de distribución para el maíz, categorizadas en cuatro niveles de aptitud: apto, moderadamente apto, marginalmente apto y no apto. Los escenarios de emisiones de cambio climático aplicados fueron A2 y B2 para el horizonte de tiempo 2050, tanto para los modelos GFDL-CM2.0, UKHADGEM1 y ECHAM5/MPI. Los resultados muestran para el escenario base que un 63.1% de la superficie nacional presenta algún grado de aptitud para el cultivo del maíz. Específicamente, un 6.2% de la superficie nacional presenta condiciones aptas mientras que en 25.1 y 31.6% hay condiciones moderadas y marginales, respectivamente. De acuerdo a los modelos de cambio climático aplicados, se encontró que la categoría apto es la más vulnerable y será la más afectada al disminuir su superficie desde un 3% de acuerdo con UKHadley B2 y hasta un 4.3% de acuerdo con ECHAM5/MPI A2. La categoría marginalmente apto será la que más superficie nacional ocupe, desde un 33.4% según ECHAM5/MPI A2 y hasta un 43.8% de acuerdo con el modelo GFDL-CM2.0 A2. El modelo ECHAM5/MPI es el que señala las condiciones más adversas para el cultivo mientras que el modelo GFDL es el menos agresivo. Lo anterior denota que las condiciones naturales en el país para el cultivo de maíz serán más restrictivas, por lo que es urgente la aplicación de medidas de adaptación.

ABSTRACT

We conducted an assessment on the capacity to grow maize under rainfed conditions as well as under simulations of climate change scenarios in México. The selected method took into account the most limiting factor from different variables that maize requires to grow. These factors were compared, resulting in potential areas for maize distribution, classified in four different suitability levels: suitable, moderately suitable, limited suitability and not suitable. The emissions scenarios of climate change selected were A2 and B2 by 2050, including the GFDL-CM2.0, UKHADGEM1 and ECHAM5/MPI models. The results indicated that in base scenario, 63.1% of the national surface presents some degree of maize growing suitability. Specifically, 6.2% of the national surface indicated suitable conditions, while 25.1 and 31.6% had moderated and limited conditions, respectively. According to the climate change models, we were able to determine the full suitability level is also the most vulnerable one and as a consequence, this will also be the most aggravated one by decreasing its surface 3% according with UKHadley B2 and up to 4.3% in accordance with ECHAM5/MPI A2. This will make the limited suitability classification the one with the largest national territory, as much as 33.4%, according to ECHAM5/MPI A2 and up to 43.8% reflected by the GFDL-CM2.0 A2 model. The ECHAM5/MPI model indicates the most adverse conditions for maize growth, while GFDL model represents the less aggravating. All this clearly reflects that the natural conditions given for maize growing will become more restrictive, making it critical to implement environmental adapting measures.

Keywords: agriculture, adaptation, impacts, suitability, vulnerability.

1. Introduction

Maize growing is an ancient activity that goes back approximately 7000 years in history all over México and Central America. Its origin is not very clearly defined, but it is believed to be a long standing culturing tradition in the center and western areas of México, as the oldest existing records go back in those places (Ruiz *et al*., 1999; Nadal, 2000a). Its distribution is quite ample, as it ranges from 40º latitude in the south to 50º north latitude (González, 1984; Purseglove, 1985; Warman, 1995); this explains its remarkable adaptability to all kinds of environments, tropical, subtropical and mild regions (Doorenbos and Kassam, 1979). In México, maize growing occupies a surface that covers nearly 8 million hectares, and it is carefully grown under irrigation standard systems, in both, favorable and poor seasonal conditions (Oropeza *et al*., 2005).

In México, there are approximately 35 different kinds of maize (Reyes, 1990) and the distribution of certain indigenous groups coincides with some of these varietes of maize (Olivo *et al.,* 2004). As described by Benz (1997), this variety in maize is the result of a successful combination of natural and cultural processes for its selection and spreading. Out of this great diversity, Gómez and Esquivel (2002) took a closer look at the climate and agricultural requirements for all 35 different creole classifications of seasonal maize, providing a definition of seven agroclimatic regions for the seasonal maize in México. The breeds Vandeño, Tuxpeño, Tabloncillo, Chalqueño and Celaya (Reyes, 1990), represent commercial varieties, productive grain and fodder, which also have contributed in a remarkable way on different developmental national programs. All these breeds can be classified according to their main usage, as white maize for feeding purposes and yellow maize used to feed and fodder livestock. This variety of maize breeds has been established as the most essential nutritional base for millions of Mexicans historically, and it also has proven itself as a very resilient product against climate changes as well as agricultural policies in the country.

According to the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA, 2007) during the period 1996-2006, maize growing occupied 51% of the entire cultivated and harvested surface; generating 7.4% of the total agricultural production and representing 30% of the entire production value. The average base year production was 19.3 millions of maize tons, which included white, yellow and other maize types, with an approximated annual value of 29 090 million pesos. The most important variety was the white maize, which all by itself represented 94.6% in the total maize production in 2004 and 92.9% in 2005. This also represents an average annual production of 19.2 million tons, while 5.9% was represented by yellow maize, in the 2004 and 2005 period.

The entire agricultural industry in México has been severely affected by the climate variability, particularly by droughts (Conde *et al.,* 1999; Florescano and Swan, 2000; Jáuregui, 1995). Right along with all this, there have been events of hunger and a short maize supply, both in rural zones as well as urban. As described by the quoted authors, such phenomenon was only worsening during the most significant civil wars in México (towards the end of the Independence and the Mexican Revolution, for example).

Presently, seasonal maize producers are choosing to apply different strategies to face climate variability. These measures can involve extending the growing areas (in order to obtain the minimum required to make it sustainable), changing the maize variety onto something more resistant or with a shorter cycle, changing growing processes (they would very likely fall into debt with some expensive irrigation system), looking for short term jobs in other areas or in urban zones, or, finally emigrating to cities or different states, including the United States. According to Nadal (2000b), this migration process of rural manpower in México has increased since 1994, given the hostility in agriculture policy resulting from the North American Free Trade Agreement as well as other international agreements. This policy affects not only the maize producers, but also other agricultural producers that use to have a high income, such as coffee growers (Conde *et al.,* 2006; Gay *et al.,* 2006b) or producers with productive lands larger than 50 hectares that focused on exporting their products (Gay *et al.,* 2006a).

México has become an important food importer, particularly maize which has turn into one of the greatest investments of millions of dollars during the last decades. The great diversity of maize in México is now facing the threat placed by this massive grain importation, reducing the availability of different Mexican grains as well as the chances for the agricultural industry to adapt themselves to the climate changes and their consequences.

On top of this, the migration (internal or external to bordering countries) of producers, that are experts in the growing of these varieties, also represents yet another threat for the preservation of the "traditional" production (Kato *et al.,* 2009). Nevertheless, the greatest effort by the agricultural producers in México remains within maize production, which reflects the relevance of this activity in order to ensure food provisions for rural families.

Production of maize subsistence has become a household activity, either by family members or extended family. This activity for the most part is developed by elderly agricultural workers or even female members of the family. Given these circumstances, the family income has quickly diversified, depending not only in a great level of the remittances from emigrants, but also from the temporary labor of women, from the income generated from the leasing of land or even from government support (Ziervogel *et al.,* 2006).

Therefore, the studies conducted on the potential impacts brought by the climate changes affecting agriculture in México have been taking place for over a decade. An important precedent is reflected in the *Study Country: México facing Climate Change* (Conde *et al.,* 1997; Gay, 2000). In this study, there were two different methods selected for the assessment of the possible impacts. First, the Ceres-Maize model, which simulates maize growing and development under different climate conditions and estimates the possible agricultural yields applied to different crop management, given the varieties of maize, as well as the soil conditions. In the event of detecting reductions on the product´s yields from the climate change conditions, different adaptation measures were proposed, assessing their feasibility through a simple analysis of cost-benefit. The second method used optimal ranges of temperature and precipitation for seasonal maize production in order to generate theoretical agroclimatic maps (potential suitability maps) of appropriate regions for production during spring-summer.

Other studies (Conde *et al.,* 1998; Magaña, 1999) enable the evaluation of the importance of climate forecasting previously delivered to producers, with all the essential detailed climate information they needed in order to make decisions regarding possible adaptation measures. Having a greater knowledge on the inter-annual variability of weather, combined with early warning climate forecasting will allow them to face the potential increase in the inter-annual variability of rain caused by climate change.

Other studies (Conde *et al.,* 2006) have assessed the socioeconomic and climatic conditions that define the current vulnerability and adaptability of the seasonal maize producers in the Mexican state of Tlaxcala. Using climate change scenarios, they were able to project future vulnerability and adaptability, evaluating the possible actions that will allow them to increase their actual capacity to adapt themselves, analyzing the feasibility under climate change conditions.

With these precedents, the purpose of this study was to evaluate the possible impacts generated by climate change on the agricultural activities in the country, particularly on the maize growth, assessing its potential suitability and spatial distribution in the future in different climate change scenarios. In addition to this, the study also enabled the application of new and recent outputs of climate change scenarios for México (Conde *et al.,* 2008).

2. Methods

The chosen method was the one taking as a principle the limiting factor (FAO, 1978), which portrays the highest possible number of ecological variables; on the other hand it also provides the requirements that a certain species needs to grow up. All these factors were compared and as a result, it provides potential distribution zones for the species in the study, classified in different levels of suitability. Therefore, the applied method requires climate and environmental information for species requirements, in this instance, maize. Below we describe this information.

2.1 Climate data

The applied climate variables in order to estimate the maize suitability were the average annual temperatures and the total annual precipitation (Conde *et al.,* 2008), averages of the period between the years of 1950-2000. The slopes topographic map was created from the Digital Elevation Model by INEGI (2000), as well as the map of the soil depth (INEGI, 1998). Taking the total annual precipitation map as an initial reference, we were able to create the map of the growing period (Ortiz, 1987), applying the following:

$$GP = 0.24089\,(P) - 0.0000372 - (P^2) - 33.1019 \qquad (1)$$

Where GP indicates the growing period in days and P represents the total annual precipitation in millimeters. For the equation, the author appoints that R^2 equals to 0.7983.

2.2 Maize suitability

Suitability for the seasonal maize was established according to the agroclimatic and environmental requirements found in specialized literature (FAO, 1978; Ortiz, 1987; Reyes, 1990; Sys *et al.,* 1991; Flores *et al.,* 2000 and Gómez and Esquivel, 2002). Table I was created taking as an initial reference the analysis of the latter information; this table shows some of the environmental requirements associated with the seasonal maize phenology, particularly for the conditions in México. These values were expressed in ranges and were classified in four different groups according to suitability levels: suitable (S), moderately suitable (MS), slightly suitable or limited suitability (ls) and not suitable (NS). The selected agroclimatic variables were the following: annual average precipitation (mm), annual average temperature (ºC), average temperature during the coldest month (ºC), average temperature during the hottest month (ºC) and yearly dry period (months).

Table I. Agroclimatic requirements for seasonal maize growing in México.

Requirements		Suitability*						
		NS	ls	MS	S	MS	ls	NS
Temperature (ºC)	Mean	<14	14-18	18-22	22-26	26-32	32-39	>40
	Minimum	<7	7-12	12-16	16-18	18-24	24-30	>30
Precipitation (mm)	Total	<300	300-500	500-600	600-900	900-1200	1200-1600	>1600
	1st month	<60	60-100	100-125	125-220	220-295	295-475	>475
	2nd month	<70	70-150	150-175	175-235	235-310	310-475	>475
	3rd month	<70	70-150	150-175	175-235	235-310	310-475	>475
	4th month	<60	60-80	100-125	125-210	210-285	285-475	>475
Topography	Slope (%)	>30	16-30	8-16	0-8	8-16	16-30	>30
Soil	Depth (cm)	<20	20-75	75-100	>100	75-100	20-75	<20
Growing period (days)	Tropical	<90	90-119	120-149	150-224	225-284	285-365	
	Mild	<150	150-164	165-209	210-284	285-329	330-365	

* NS: not suitable, ls: limited suitability, MS: moderately suitable and S: suitable.

Finally, supported by the Geographical Information System ArcView (ESRI, 2006) the thematic maps were overlapped and we were able to create the aptitude map of seasonal maize for México, defined here as base map or base year.

2.3 Climate change scenarios

The general circulation models (GCM) selected were ECHAM5/MPI, UKHADGEM1 and GFDL-CM2.0, which will be named Echam, Hadley and GFDL, respectively; the emissions scenarios evaluated were A2 and B2 (Nakicenovic *et al.,* 2000) by the 2050. The models outputs were taken from Conde *et al.* (2008). Just like in the base map, after applying the suggested outputs for climate change, Table I was once again applied, running the new outputs of suitability for maize according to each scenario.

3. Results and discussion

3.1 Actual maize suitability

The current suitability map for maize growing in México is presented in Figure 1 while the occupied surface according to the different suitability levels is showed in Table II. In our findings, we detected the surface that is suitable for maize growing takes over 6.4% of the entire national land, 25.1% under moderately suitable conditions and 31.6% are marginally suitable for maize production. In 36.9% of the country, environmental and weather conditions are not suitable for maize, at all.

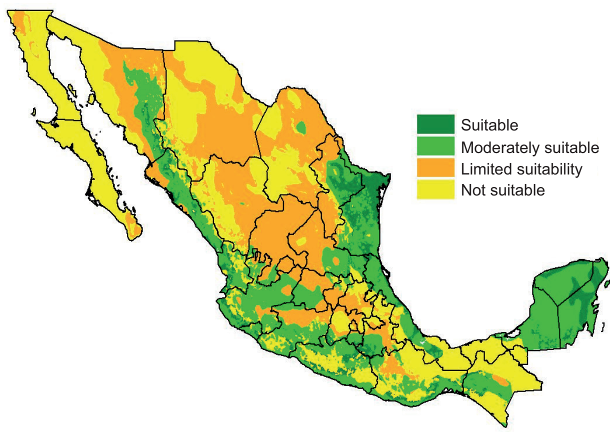

Fig. 1. Maize growing suitability map according to the base year (1950-2000 mean data).

These results turned out to be very similar to the ones indicated by the authors in the Third National Communication (INE-SEMARNAT, 2006), except for the "suitable" category. However, space distribution of the different levels of suitability for production presented the exact same tendency that was found in this study, the difference being on the occupied surfaces. This is due to the fact that the present document was supported by different data (1950-2000) in relation to the work previously mentioned (1961-1990). In addition, the current spatial information provides a much more detailed outsource than the one used for those years.

The surface within the suitable category is distributed in areas of the states of Tamaulipas, Nuevo León, Veracruz and Yucatán Peninsula (north and south of the Gulf of México), and in other zones of the states of San Luis Potosí, Puebla (northern center and center of the country), Guerrero, Jalisco, Nayarit, Sinaloa and Sonora (towards the Pacific coastlines), among others. In those states that make up the plains surrounding the Gulf of México, it provides an explanation for this tendency as they do not present steep slopes in sight, therefore they present all the necessary weather conditions as well as deep and well- drained soils (over 100 cm depth). The Yucatán Peninsula presents a similar environmental tendency, except that the soils tend to be thinner, however well drained, as

Table II. National surfaces (%) according to their suitability level for maize growing for the base year and climate change scenarios by 2050.

Suitability level for maize production	Base	Echam		GFDL		Hadley	
		A2	B2	A2	B2	A2	B2
Suitable	6.4	2.1 (–4.3)	2.7 (–3.7)	2.1 (–4.2)	2.5 (–3.9)	2.7 (–3.7)	3.0 (–3.4)
Moderately suitable	25.1	26.6 (+1.5)	26.7 (+1.5)	26.4 (+1.3)	30.2 (+5.1)	24.0 (–1.1)	24.6 (–0.5)
Limited suitablility	31.6	33.4 (+1.8)	35.1 (+3.5)	43.8 (+12.3)	39.7 (+8.1)	40.7 (+9.1)	40.4 (+8.8)
Not suitable	36.9	37.9 (+1.0)	35.6 (–2.3)	27.6 (–8.0)	27.6 (+0.1)	32.7 (+5.0)	32.0 (–0.7)

Note: The sign and percentage changes compared to the base scenario are shown between parentheses.

they originated from limestone. For the Pacific slope areas, suitable grounds for production are where there are no steep slopes, feature deep soils and have the correct weather conditions, this also coincides with finding mean annual precipitations higher than 600 mm.

The surface classified under moderately suitable for production covers 25.1% of the entire national territory and it is nearly on the same terms as the previous classification, except it covers a larger area. In the case of Yucatán Peninsula, we can appreciate a greater distribution of this classification, the coastline plains of the Gulf and the Pacific as well as the center and western region on the country. This tendency is due to the fact that this category presents the regions that feature a limiting environmental factor, such as grounds like the ones in the Yucatán Peninsula, and the slopes -capable of reaching a value as high as 20%.

The regions of the country that present marginal conditions for maize production are mostly observed where there are precipitations less than 600 mm, as in the case of the great northern center of the country or wherever there are two environmental restrictive characteristics, such as precipitations and slopes. A good example of this is found in the states located in the center of the country.

On the other hand, those regions in the country presenting no suitability for maize growing are mostly seen in the places where there is hardly any precipitation, like the Peninsula of Baja California and the desert of Chihuahua (northwest of México), or where rain is substantial, like in the states of Tabasco, Veracruz (Gulf of México), Chiapas and Oaxaca (Mexican Pacific); or just like the mountain system regions (*Sierras Madre*) in the country featuring steep slopes toward east, west and south.

3.2 Climate change scenarios

Those surfaces occupied by simulated scenarios of climate change are presented in Table II, its geographic distribution in Figures 2 and 3 as well as its description in the following points:

Scenarios A2 by 2050. The changes found in the different levels of suitability for this particular scenario group reflect even more restrictive conditions than those in B2. This tendency is clearly affected by the main arguments from the scenario group A2, as it considers a continuous growth in population, it presents a financial development oriented by regions and it also considers a

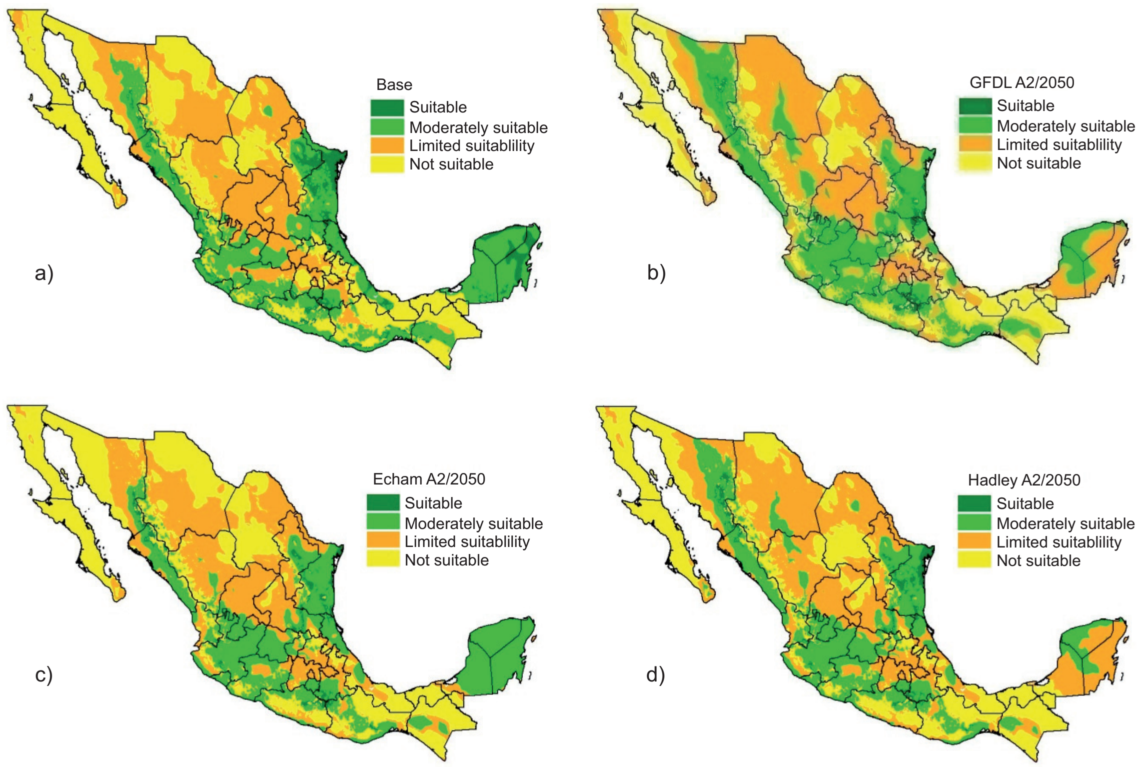

Fig. 2. Suitability for maize production according to a) base year and climate change scenarios A2 by 2050: b) GFDL, c) ECHAM and d) Hadley

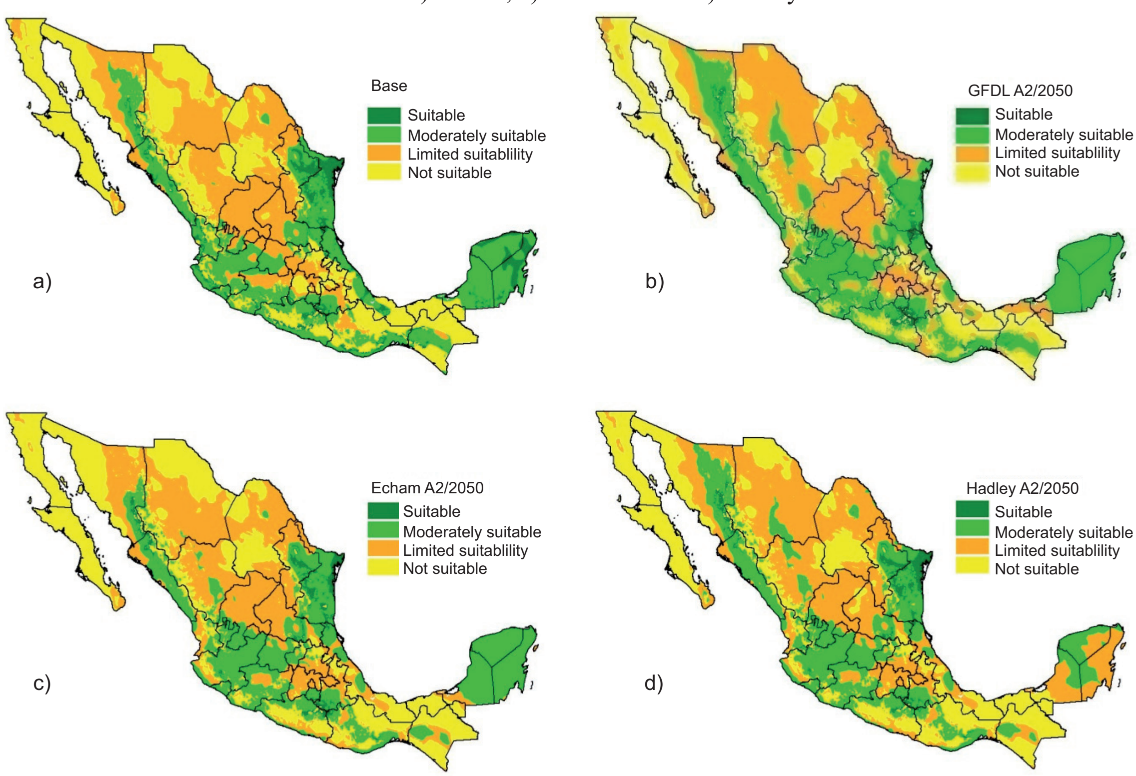

Fig. 3. Suitability maps for maize growing according to a) Base year and climate change scenarios B2 by 2050: b) GFDL, c) Echam and d) Hadley

middle - high emissions level. This is clearly reflected in the results of the models for this group of scenarios, forecasting a higher temperature increase for the entire country, while the B2 scenario suggests lower ones that A2.

The defined level suitable is the one introducing the most notorious surface changes, 4.3% in relation with the base scenario for the Echam model, 4.2 and 3.7% for the GFDL and Hadley models, respectively. The not suitable surface shows an increase of 5% according to Hadley model, but also decreases up to 8% according to GFDL model.

The possible geographic distribution (Fig. 2) of the regions that shows higher changes projected in the crop suitability is framed towards the Yucatán Peninsula, where the three models suggest that current suitability values will be decreased. A similar situation is shown in the states on the north plains surrounding the Gulf coastline.

In order to analyze the susceptible areas to the possible changes in suitability, all the different scenarios of climate change were compared against the base year through overlapping the cartography in a GIS. By placing this information over it, we were able to identify the possible direction of future changes for each one of the suitability levels within the base year: whether the suitability will increase, decrease, or remain the same (Table III). For instance, the base year indicated 6.4% of the national surface presents suitable conditions, and only 17% of this remains under this category according to Echam model (will not change its suitability rate), 58% will reduce its suitability to moderately suitable and the 25% remaining (of the total 6.4% of the national surface) could potentially experience a higher decrease whenever this becomes established, according to the model selected, as limited suitability.

All three models showed the suitable classification will be able to change its characteristics to even more restrictive conditions. According to GFDL model, 50% of the suitable class (in respect

Table III. Direction and change (%) on suitability levels for maize growing according to climate change scenarios A2 by 2050.

Model	Climate change scenario and suitability level	Base scenario %			
		Suitable	Moderately suitable	Limited suitability	Not suitable
Echam	Suitable	17	*4*		
	Moderately suitable	**58**	76	*12*	
	Limited suitability	**25**	**20**	71	*12*
	Not suitable			**17**	88
GFDL	Suitable	18	*4*		
	Moderately suitable	**32**	70	*21*	
	Limited suitability	**50**	**26**	77	*27*
	Not suitable			**2**	73
Hadley	Suitable	28	*4*		
	Moderately suitable	**30**	67	*17*	
	Limited suitability	**42**	**30**	77	*19*
	Not suitable			**6**	81

Note: The normal font on each model shows the national surface percentage (considering the base year) that will possibly have no change in the suitability level; changes that suggest suitability decrease are in bold and possible changes that would improve maize suitability are in italics.

with the identified total in the base year) could present marginal conditions. The intermediate suitability classes moderately and limited suitability, are the ones that will most likely be kept larger surfaces facing the climate change scenarios; for the first one, we can appreciate how the most remarkable changes will come from the suitable class, while the second one will provide a larger surface to the not suitable class.

The not suitable class (36.9% in the base year) will be the one keeping the highest percentage in its surfaces according to all three models: 88% out of this figure according to Echam model, 73 according to GFDL and 81% according to Hadley.

Scenarios B2 by 2050. This group suggests less restrictive changes in comparison with the previous one, since the factors in medium-high emission levels are considered as a result of local solutions in respect to economy, sustainability, as well as social and environmental atmospheres; it also considers a population growth lower than the one of A2 group. The result of this, particularly from outputs of the models, suggests lower increases in temperature when compared with A2 scenarios.

On the surfaces occupied by suitability levels, the “suitable” class is again the one presenting the most notorious changes, by reflecting 3.7% lower than the base scenario for Echam model, 3.9% for GFDL and 3.4% for Hadley models. The “not suitable” surface for maize production could decrease its surface to 2.3% according to Echam model, less than one percentage point according to Hadley model and practically similar to the current surface according to GFDL model (Table II).

In respect to the geographical distribution (Fig. 3), regions that indicate greater possible changes in the suitability for production are identified toward the Yucatán Peninsula and the northeast, where all three models suggest that current suitability will decrease. In the central plateau of the country, even more restrictive conditions are expected as the not suitable regions will increase. In the central region, we will be able to observe improvement in the suitability ranges, by suggesting that precipitation will increase, and as a result, this will fulfill the evapotranspiration requirements for maize growth.

Analyzing the change direction of the suitability of this group of climate change scenarios (Table IV), the “suitable” class is the most sensitive to predicted changes, and makes it vulnerable. Compared with the base year (6.4% of the national surface) and according to the ECHAM model, 30% of this number will remain as suitable, 18% according to GFDL model and 37% according to Hadley model.

In the three models results we can appreciate that the suitable class will be able to modify its characteristics to more restrictive conditions, just as suggested by the Echam model as it indicates that 47% of this class will be able to change into limited suitability, 57% according to GFDL model and 43% according to Hadley. On the other hand, the “not suitable” class will be able to hold a higher percentage of its surfaces in respect to the base year, since all three applied models indicated 12, 27 and 18% will present marginal conditions according to Echam, GFDL and Hadley models, respectively.

Summarizing, Echam model is the one presenting the most adverse conditions for maize production, since in the base year 63.1% of the national surface presents some degree of suitability for maize growing and the model suggests the surface will decrease by 62.1 and 64.5% of the total national

Table IV. Direction and change (%) on suitability levels for maize growing according to climate change scenarios B2 by 2050.

Model	Climate change scenario and suitability level	Base scenario			
		Suitable	Moderately suitable	Limited suitability	Not suitable
Echam	Suitable	30%	*3%*		
	Moderately suitable	**47%**	78%	*13%*	
	Limited suitability	**23%**	**18%**	78%	*12%*
	Not suitable			**9%**	88%
GFDL	Suitable	18%	*5%*		
	Moderately suitable	**57%**	84%	*17%*	
	Limited suitability	**25%**	**11%**	80%	*27%*
	Not suitable			3%	73%
Hadley	Suitable	37%	*3%*		
	Moderately suitable	**20%**	71%	*17%*	
	Limited suitability	**43%**	**26%**	79%	*18%*
	Not suitable			**4%**	82%

NOTE: The normal font on each model shows the national surface percentage (considering the base year) that will possibly have no change in the suitability level; changes that suggest suitability decrease are in bold and possible changes that would improve maize suitability are in italics.

land, according to scenarios A2 and B2, respectively, towards year 2050. Hadley model suggests very similar conditions to the current ones, by determining that 67.3 and 68% of the national surface will have favorable conditions for maize production. GFDL model suggests that these conditions could possibly improve, since those surfaces with some degree of suitability for maize will reach 72.4% of the national surface under the two socioeconomic selected scenarios A2 and B2.

This tendency becomes agreeable with the defined reasons for change by each applied model (see Conde *et al.,* 2008). GFDL model indicates that temperature and precipitation will increase for the most part of the year, which will also increase the potential evapotranspiration levels, being covered by the highest precipitations suggested by the model. This is quite in opposition to the results obtained from the Echam and Hadley models, which indicate temperature will increase all over the country, while precipitation will also increase in some places and will considerably decrease in some others. Raising temperature will also be a responsible of the potential evapotranspiration increased levels; therefore, we could expect an increase in the dry period of the year as well as a decrease in the potential suitability under the influence of these climate-change scenarios.

The impacts brought by climate change on seasonal maize production represent potential impacts, since this study basically uses the hydric and thermic requirements in order to determine the possible suitability of maize production under the current or future weather conditions. However, it becomes necessary to take into account the actions taken by the maize producers facing these conditions, not to mention the agricultural policies applied to support these producers. The remarkable migration of the agricultural producers in México (the manpower taken over by the elderly or women workers in the Mexican fields), the lack of government supporting programs for maize production in México leading to maize tax free importation (Appendini, 2001), the impoverishment of the agricultural ground, among other factors, determine the high level of vulnerability of these agricultural producers in México, subject to a double exposure: global climate change and economic globalization (O'Brian and Leichenko, 2000).

The present study has analyzed the potential impacts brought by the climate change in the spatial distribution for maize production in México; its results could potentially lead into the sustainability of remediation measures or a higher support, as well as target the areas where migration could increase or the resignation of this activity.

4. Conclusions

A suitability map for maize production in México for current conditions as well as under climate change scenarios was created, results indicated 63.1% of the national surface present some degree of suitability for maize production. Specifically 6.4% showed suitable conditions as 25.1 and 31.6% indicated moderated and limited conditions, respectively.

The applied climate change models provide different results, derived from the reasons of change that each one suggests as well as its possible impact over the potential distribution of maize. The possible impacts on maize production are not constant among themselves, but in general Echam model is the one presenting less favorable conditions for maize production, followed by Hadley model, leaving the minor impacts to GFDL model. Out of all the considered scenarios, the most restrictive in the levels of favorable suitability was A2.

The "suitable" level is the one reflecting the most notorious negative changes on surface, indicating 4.3% less than the base scenario according to Echam model, 4.2 and 3.7% for GFDL and Hadley models, respectively. On the other hand, the surface "not suitable" for maize production will increase up to 5% according to Hadley model, but it will decrease as much as 8% according to GFDL model, for the scenario group A2.

According to B2 scenario, the impacts over the "suitable" level will present the most notorious changes on surface, but lower than scenarios A2, holding 3.7% less than base scenario for Echam model, 3.9 and 3.4% for GFDL and Hadley models, respectively. In addition to this, the surface "not suitable" for maize production could decrease by 2.3% according to Echam model, less than one percentage point according to Hadley model and practically similar to the current surface actual according to GFDL model.

The method developed in this article has been applied on a regional scale for other crops (Palma *et al.,* 2007), so this can be understood as a useful tool for new studies on climate change in the country.

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