Assessing the vulnerability of traditional maize seed systems in Mexico to climate change

Mauricio R. Bellon[a,1], David Hodson[b], and Jon Hellin[c]

[a]Diversity for Livelihoods Programme, Bioversity International, 00057 Maccarese, Italy; [b]Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, 00153 Rome, Italy; and [c]Socioeconomics Program, International Maize and Wheat Improvement Center, Distrito Federal 06600, Mexico

Edited by José Sarukhán, Universidad Nacional Autónoma de Mexico, Huixquilucan, Mexico, and approved July 1, 2011 (received for review March 3, 2011)

Climate change is predicted to have major impacts on small-scale farmers in Mexico whose livelihoods depend on rain-fed maize. We examined the capacity of traditional maize seed systems to provide these farmers with appropriate genetic material under predicted agro-ecological conditions associated with climate change. We studied the structure and spatial scope of seed systems of 20 communities in four transects across an altitudinal gradient from 10–2,980 m above sea level in five states of eastern Mexico. Results indicate that 90% of all of the seed lots are obtained within 10 km of a community and 87% within an altitudinal range of ±50 m but with variation across four agro-climate environments: wet lowland, dry lowland, wet upper midlatitude, and highlands. Climate models suggest a drying and warming trend for the entire study area during the main maize season, leading to substantial shifts in the spatial distribution patterns of agro-climate environments. For all communities except those in the highlands, predicted future maize environments already are represented within the 10-km radial zones, indicating that in the future farmers will have easy access to adapted planting material. Farmers in the highlands are the most vulnerable and probably will need to acquire seed from outside their traditional geographical ranges. This change in seed sources probably will entail important information costs and the development of new seed and associated social networks, including improved linkages between traditional and formal seed systems and more effective and efficient seed-supply chains. The study has implications for analogous areas elsewhere in Mexico and around the world.

adaptation | crop diversity | landraces | genetic resources | food security

Climate change is predicted to have major impacts on small-scale farmers in the developing world, but these impacts are likely be complex, locally specific, and hard to predict (1). Mexico and Central America is considered to be a region at significant risk from climate change (2). Maize is the most important crop cultivated in Mexico, being central to the diets of both urban and rural consumers, particularly the poor. It occupies the largest planted area in the country devoted to any crop and involves cultivation by a large number of small-scale farmers (3). The vast majority of these farmers operate under rain-fed conditions; hence, climate is one of the most important risk factors in their agricultural systems, and changes in climate can exacerbate those risks substantially (4).

Most small-scale farmers in Mexico recycle seed either by saving their seed from the previous harvest and/or obtaining it from fellow farmers (5, 6). Seed sourcing is embedded in well-structured traditional systems with rules and expectations based on family and local social networks and regulated by ideas of fairness and of respect for the seed (7, 8). Furthermore, the country is the center of domestication and diversity for maize (9, 10), and this diversity still is maintained and managed on-farm by many of these small-scale farmers (11–13). Traditional maize seed systems hence are important not only for farmers' livelihoods but also for the maintenance and evolution of Mexican maize landraces (14), one of the last reservoirs of maize genetic resources.

Given the importance of maize landraces and the seed systems that underpin them to farmers' livelihoods and maize genetic resources, it is fundamental to explore the potential impacts of climate change on traditional seed systems. We examine here the hypothesis that, in the face of climate change, traditional maize seed systems may be unable to provide small-scale farmers with appropriate genetic material because landraces and the seed systems that maintain them are too local relative to the spatial scope of predicted environmental shifts caused by climate change. We posit that if predicted environments are similar to current ones, the scope of current seed systems is adequate, because farmers could rely on the traditional geographical range of, and social relations embedded in, their seed systems. If, however, climate change leads to conditions very different from extant ones, farmers are likely to need to access seed from outside their traditional geographical ranges. The seed will need to be sourced from areas resembling the novel environments that farmers will face. Improved seed with climate-adapted traits also could be sourced from the formal seed system. Furthermore, farmers will have to overcome the transaction costs, including information and social costs, associated with obtaining the adapted maize seed.

We studied the structure and spatial scope of traditional maize seed systems in four transects across an altitudinal gradient from 10–2,980 m above sea level in five states of eastern Mexico. Our study was based on a survey of a stratified random sample of 20 communities with 20 households per community, giving a total of 400 households. We assessed the potential climate changes in the study areas through downscaled outputs from three major General Circulation Models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC): Hadley Centre Coupled Model Version 3 HadCm3, Commonwealth Scientific and Industrial Research Organisation (CSIRO), and Canadian Centre for Climate Modelling and Analysis (CCCMA) under the IPCC scenarios A2a and B2a (15) for 2050.

Results

The small-scale maize farmers in this study include both indigenous and Mestizo households. They have diversified livelihoods, producing multiple crops, fruit trees, and domesticated animals both for self-consumption and for the market. Farmers also engage in nonfarm activities. Maize, however, continues to play a key role in their livelihoods, having multiple uses, both for consumption and sale (Table S1).

Table 1 presents data on maize seed lots planted by sampled farmers in 2003. Landraces dominate across the four maize agro-climate environments studied: wet lowland, dry lowland, wet upper midaltitude, and highland; the presence of improved varieties is negligible. Seed lots are planted with seed from a farmer's own previous harvest for 10 years on average, suggesting that farmer selection plays an important role in the genetic composition of the maize that farmers cultivate.

On average farmers maintain more than one seed lot per farmer, and most seed lots across the four agro-climate environments are

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[1]To whom correspondence should be addressed. E-mail: m.bellon@cgiar.org.

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Table 1. Characteristics of traditional maize seed systems in communities studied

General characteristics	Maize agro-climate environment				
	WL	DL	WUMA	H	Total
Seed lots (SL)					
No. of SL	177	47	62	318	604
SL of landraces (%)	98.3	97.9	98.4	97.5	97.9
Average number of SL per farmer	1.3	1.2	1.6	1.8	1.5*¶
SL size (kg)	20.0	14.0	9.0	20.0	18.0*¶
SL saved by farmer (%, 2003)	75.7	85.1	82.3	72.6	75.5
SL obtained from family, friends, neighbors (%)	88.1	85.7	100.0	85.1	87.0
Median number of years that a SL is saved by a farmer	10.0	10.0	15.0	8.0	10.0‡§
SL obtained outside community, historical (%)	13.0	12.8	4.8	28.6	20.4†¶
SL obtained outside community 2003 (%)	1.7	0.0	0.0	6.6	3.7†¶
SL provided to other farmers 2002 (%)	25.4	23.4	29.0	18.2	21.9
SL provided outside the community 2002 (%)	1.7	4.3	0	3.8	2.8
Farmer experimentation					
Farmers who experimented (%)	19.3	22.5	12.5	34.1	25.6†¶
Number of experimental SL (historical)	30	13	5	79	127
Experimental SL of improved varieties	10	4	1	4	19
Experimental SL retained	6	1	0	9	16
SL of improved varieties retained	2	1	0	0	3
Spatial scope					
Seed lots obtained <10 km historical (%)	95.95	93.48	100	87.14	91.55†¶
Maximum distance historical (km)	38.5	50.5	2.5	321.8	
Seed lots obtained <10 km in 2003(%)	99.4	100.0	100.0	97.2	98.3†§
Maximum distance in 2003 (km)	18.4	0.0	0.0	0.0	76.4
Seed lots obtained within altitude range (± 50) m historical (%)	96.5	95.7	95.2	78.8	87.0†¶
Altitudinal range	−220/+280	−120/0	0/+560	−370/+700	
Seed lots obtained within altitude range (± 50) in 2003 (%)	99.4	100	100	95.2	97.3†¶
Altitudinal range	−20/+120	0	0	−180/+400	−180/+400
Seed lots distributed <10 km 2002 (%)	97.6	100	100	100	99.2
Maximum distance (km)	51.6	7.4	0	5.6	
Seed lots distributed within altitude range (± 50 m) in 2002 (%)	100	100	100	90.2	95.8†§
Altitudinal range	0	0	0	−280/+90	−280/+90

DL, dry lowland; H, highland; WL, wet lowland; WUMA, wet upper midaltitude.
*Statistical significance associated with a one-way ANOVA.
†Statistical significance associated with a likelihood-ratio χ^2 test.
‡Statistical significance associated with a Kruskal–Wallis equality-of-populations rank test.
§$P < 0.05$.
¶$P < 0.01$.

saved from their own farms. Seed obtained from outside the farm accounts for less than a third of seed in any of the agro-climate environments, and most of this seed is obtained from the farmers' social network of family, neighbors, and friends. Only a minority of seed sourced off-farm comes from stores, the government, or strangers. The role of the formal seed system, therefore, is minimal, even though there have been government programs to disseminate improved seed. The proportion of seed lots from which seed was given to other farmers roughly matches the proportion of seed lots that was acquired, indicating some sort of equilibrium by environment, although there is variation across environments. Very few seed lots are provided to farmers outside the community, many fewer than those obtained from other communities.

Traditional seed systems, however, are neither closed nor static; about 25% of the farmers said that they experiment with seed lots of landraces and, to a lesser degree, with improved varieties (especially in the highlands). The rate of retention is low, however, particularly for improved varieties, suggesting that farmers know about improved varieties, have tested some of them, and have found them wanting. Most seed is sourced within the communities where farmers live, with 90% of all of the seed lots obtained within 10 km of the community, although there is some variation across environments (Fig. 1). For seed lots sourced beyond the 10-km radius, the maximum distance of the source could be up to 300 km, although such distances are rare (Fig. 2).

In terms of altitudinal distances, the pattern is similar, with 87% of all seed lots obtained within a range of ±50 m, although there is variation across environments, with the percentage of seed obtained within the ±50-m range being as high as 95% in all environments except the highlands. (The range in the highlands also is much larger.) Similar patterns are observed in seed lots provided to other farmers: Except in the highlands environment, almost all the seed lots are provided within a 10-km radius and an altitudinal range of ±50 m. So apart from rare cases, the majority of seed lots in traditional maize systems studied, regardless of maize environment, tend to originate locally, within a radius of 10 km and ±50 m of altitude.

All three climate models predict a consistent drying and warming trend for the entire study area during the main maize-growing season (May–October), and this trend is predicted to increase with time. By 2050, all models predict decreased May–October rainfall in all 20 communities and substantially increased minimum (+1.4–2.6 °C) and maximum (+1.4–3.5 °C) average May–October temperatures. Fig. 3 shows the current and the predicted distribution of maize agro-climate environments for the study area for 2050 under the median values of six alternative future climates and an extreme future climate, overlaying 10-km radial zones around the communities studied (i.e., the likely seed lot-sourcing environments based on farmers' current seed-sourcing practices). (The 10-km radius used in our analysis was derived empirically from the observation that about 90% of

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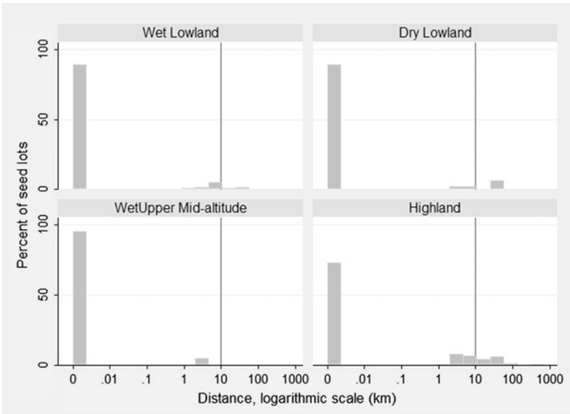

Fig. 1. Histogram of the distances from which seed lots were acquired historically, differentiated by maize agro-climate environment. Distances are in log scale. Bars near zero indicate seed lots obtained within the same community, and the vertical line indicates a distance of 10 km.

seed lots were obtained within that distance. The area thus is arbitrary, not because of the radius size but because of the choice of the cumulative percentage of seed lots included.)

Future models suggest substantial shifts in the spatial distribution patterns of the predominant maize agro-climate environments. Notable predicted trends evident under both median and extreme scenarios are (*i*) a drying of lowland environments, (*ii*) an expansion of lowland and midaltitude environments up the elevation gradient, and (*iii*) a substantial reduction of the highland environment (through displacement by warmer mid-altitude-type environments and an expansion of areas too dry for optimal maize production).

Table 2 shows that, for 8 of the 20 communities studied, the maize environment in which they currently are located may shift under the predicted median climate changes (Table S2). In 2003 most seed was sourced from within the environment in which it was planted. Another way of analyzing these changes is to relate predicted future climate shifts to the spatial scope of traditional seed systems by examining shifts in maize environments within the 10-km radial zones where most seed is sourced. We calculated the current and future proportions (%) of 1-km^2 cells (henceforth referred to as "pixels") classified by specific maize agro-climate environments within those 10-km radial environments for the 20 study communities. Table 2 shows that in the median and extreme scenarios shifts would occur in all maize environments. Changes in the overall distribution of maize environments were found to be statistically significant for both scenarios using marginal homogeneity tests ($P < 10^{-4}$ in both cases; Table S3). Major shifts would occur particularly in the highland and dry midaltitude environments, with the former shrinking and the latter expanding substantially. The highland environment is the only one where suboptimal conditions for maize production may increase (Table S2). Also, the number of communities with uniform maize environments within the 10-km radial zones (i.e., >90% of the pixels classified within the 10-km radial zones corresponding to a single maize environment) increased substantially in the lowland environments and decreased dramatically in the highland environment, indicating the possibility of future reduction and fragmentation in the highland environment.

Table 2 also shows that, for all communities except those in the highland environment, the predicted future maize environments already are present within the 10-km radial zones and that the average distances to the predicted novel environments are relatively short. Thus farmers should have relatively easy access to planting material adapted to the agro-ecological conditions predicted under climate-change scenarios. In the highland environment, however, predicted changes are such that traditional seed systems are unlikely to provide farmers with planting material suited to changed agro-ecological conditions. Farmers in the highland environment, however, have higher rates of acquisition of external seed lots and of experimentation with novel seed lots.

Discussion

Although much attention has been given to crop breeding and the development and diffusion of improved varieties with traits appropriate for coping with climate change (16, 17), small-scale maize farmers' adoption of this improved germplasm has been

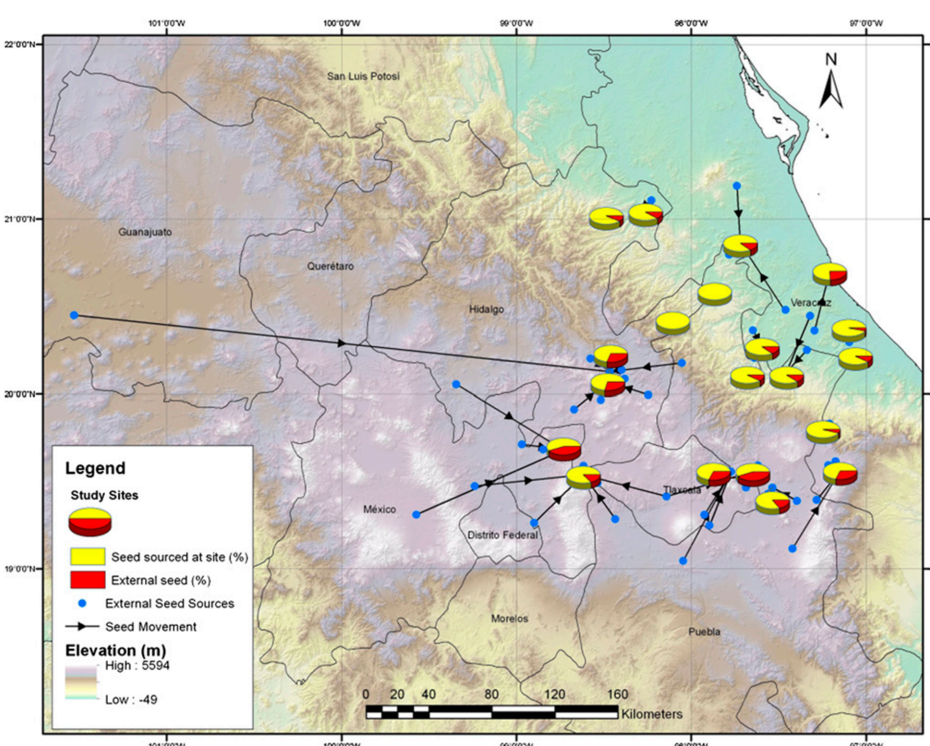

Fig. 2. Geographical distribution of the origins of the seed lots planted in the 20 communities studied and their associated source frequencies. Pie charts indicate the percentage of seed lots sourced within the community (yellow) or imported from outside the community (red). Lines with arrows indicate the movement of seed from external locations into the study communities.

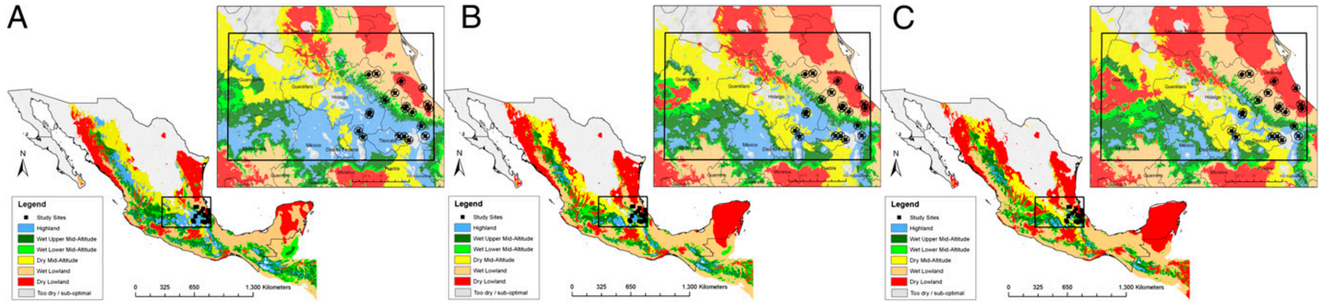

Fig. 3. Predicted changes in maize agro-climate environments (current situation vs. 2050, median of six possible future scenarios as well as the extreme scenario HadCM3 model A2a scenario). (*A*) Distribution of maize agro-climate environments under current climate condtions within Central Mexico covering an area that encompasses the geographical distribution of the origin of the seed lots planted in the studied communities. Points in black indicate the communities studied, and the circles around them indicate the 10-km radial zones where most seed lots originate. (*B*) The same information as in A, but modeled for maize agro-climate environments under the median scenario of the six scenarios for 2050. (*C*) The extreme scenario (HadCM3 model A2a scenario) for 2050. These figures show substantial potential changes in the distribution of maize agro-ecological environments associated with climate change.

minimal to date. This lack of adoption suggests that adaptation to climate change may have to rely on local practices and institutions available to farmers. Our results indicate that traditional maize seed systems are spatially very local, with farmers relying largely on seed lots sourced from community and associated social networks. This phenomenon, together with a relatively low influx of outside seed (although with differences by environment) suggests stable and consistent selection pressures on maize populations, both from farmers and the environment, and hence strong selection for local adaptation.

Contrary to our hypothesis, all studied communities except for the highland environment already have access to predicted novel maize environments within the traditional spatial scope of their seed systems (10-km radius), suggesting that traditional seed systems may be able to provide farmers with landraces suitable for agro-ecological conditions under predicted climate-change scenarios. Seed systems of studied communities located in the highlands may be the most vulnerable to climate change because of the absence of local material adapted to predicted climate changes. An estimated 18% of total maize production in Mexico occurs in the highlands (Table S4), making it an important maize agro-climate environment. In the areas we studied, highland seed systems have the highest seed turnover and the broadest spatial scope for seed flows (although this trend may not hold true

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Table 2. Predicted impacts of climate change on the maize environments of studied communities under median and extreme scenarios

	Maize environment					
	WL	DL	WLMA	WUMA	DMA	H
Total number of communities by current maize environment	7	2	0	2	0	9
Seed lots currently sourced within the same environment (%)	94.7	98.7	—	95.2	—	95.6
Number of communities predicted to shift maize environment by 2050						
Median scenario	2	0	—	2	—	4*
HadCM3-A2a	2	0	—	2	—	5*
Percentage of 1-km^2 pixels within 10 km radius of studied communities by maize environment†						
Current	33.7	12.0	4.4	5.1	0.9	32.8
2050						
Median scenario	31.6	18.3	2.7	4.7	8.5	24.8
Change	−2.1	6.3	−1.7	−0.4	7.6	−8.0
HadCM3-A2a	33.4	18.6	2.5	4.4	14.3	16.9
Change	−0.3	6.6	−1.9	−0.7	13.4	−15.9
Number of communities with homogenous environment within 10-km radius‡						
Current	3	1	—	0	—	7
2050						
Median scenario	5	4	1	—	0	2
HadCM3-A2a	5	4	1	—	0	2
Number of communities with predicted climate already present within 10-km radius in 2050						
Median scenario	7	2	—	2	—	8
HadCM3-A2a	7	2	—	2	—	6
Average straight-line distance to existing "new 2050" maize environment (km)§						
Median scenario	1.0	0	—	0.8	—	13.0
HadCM3-A2a	1.0	2.0	—	0.8	—	13.0

WL, wet lowland; DL, dry lowland; DMA, dry midaltitude; H, highland; WLMA, wet lower midaltitude; WUMA, wet upper midaltitude.

*Includes two communities for which maize production may not be viable because of suboptimal environmental conditions.

†Percentages do not total 100 because there were pixels classified as suboptimal (either too dry or too cold) for maize production.

‡Homogenous environment defined as >90% of pixels classified within the 10-km radial environment corresponding to a single maize environment; pixels in the highland environment classified as having suboptimal environments were excluded.

§Distances are to the nearest pixel of the new environment under current conditions.

throughout Mexico). Nonetheless, farmers in the highland environment are likely to need to source seed from outside their traditional geographical ranges, and this requirement may entail important information costs and the development of new social networks. Fragmentation of the highland environment suggests that access to wider landrace diversity may become even more important, leading to seed sourcing from more locations.

Maize landraces in Mexico show remarkable diversity and climatic adaptability, growing in environments ranging from arid to humid and from temperate to very hot (18). This diversity raises the possibility that Mexico already has maize germplasm suitable for predicted environments, i.e., that there are current analogs in the country for the "novel" crop climates predicted by 2050. However, environments that are likely to be extant in 2050 may include ones that are not currently represented in Mexico (e.g., ref. 19), suggesting that farmers will require germplasm with new adaptive traits. Furthermore, even if suitable germplasm does exist within Mexico, it may not be currently sourced by those farmers who are going to need it.

The impact of climate change on maize farmers' livelihoods will depend not only on their seed systems but also on the capacity of their local landraces to evolve and adapt to new conditions—a complex topic that needs further research (14) and depends not only on genetic factors but also on ecological processes (20). For example, historical evidence of plant responses to climate change under natural conditions shows that environmental tolerances evolve very slowly (niche conservatism), because plants can track favorable conditions in space and time and not experience strong selection (20). How these processes may affect a cultivated species like maize, in which the tracking of environmental conditions depends on human decisions and which, from a population genetics perspective, shows a metapopulation structure (21), remains to be studied. Already, however, there is evidence of greater local adaptation of highland than of lowland landraces in southern Mexico, and the former do not seem to express the plasticity necessary to sustain productivity under warming conditions (22). Highland Mexican races, which show introgression with teosinte (*Zea mays* subspecies *mexicana*) (23) and have a high genetic diversity among New World maize races (24), may be the most threatened because of their strong local adaptation. This strong local adaptation, coupled with shifts in climate (14), suggests that highland landraces are more vulnerable to climate change and merit special attention to assure conservation of genetic resources. Furthermore, ecological adaptation is not enough to guarantee successful adoption and adaptation by farmers: Germplasm also must have the necessary traits to make maize populations competitive for specific uses in these environments, such as consumption preferences and suitability for the niche markets for maize landraces that are important for farmers' livelihood security (25, 26).

This study focused only on maize in 20 communities in Mexico; however, it has important implications for other parts of Mexico and also for other regions of the world. An estimated 6.3 million hectares of highland maize are grown in the developing world. Almost half this area is in Mexico, but significant areas also are located in Central and South America, Eastern-Southern Africa, and Asia (27). Equivalent potential reductions in future highland maize environments are observed in these regions when the climate models and scenarios in the current study are used (Fig. S1).

Many small-scale farmers, and particularly those in centers of crop diversity, still rely on traditional seed systems (28), e.g., for potatoes in the Andes (29, 30), durum wheat (31) and sorghum (32) in Ethiopia, and millet in India (33). In the case of maize, estimates for 2006/2007 indicate that 65% of the total maize area in Eastern and Southern Africa (excluding South Africa) was planted using farm-saved seed (34); for Latin America and Asia (excluding China) at the end of the 1990s, these percentages were estimated at 55% and 35%, respectively (35).

Climate change is global, so these systems will be affected world wide. Yield losses associated with climate change depend on the vulnerability of these farming systems (36). Vulnerability, in turn, depends not only on exposure to climatic stressors but also on sensitivity to those stressors, which is determined by a complex set of social, economic, and institutional factors that collectively determine adaptive capacity (1, 37). Research has suggested that many countries throughout the developing world will remain highly vulnerable to climate change over the next 50 y (37). The impact of climate change in Mexico probably will differ from that in other countries, given Mexico's level of development and hence endogenous capacity to adapt (37); nonetheless, climate change is expected to have major implications for Mexico's agriculture and rural population (38).

Although the results presented here are quite local, they point to an issue of global significance: Traditional seed systems, which are important for millions of small-scale farmers and for many crops around the world, will be affected by global climate change, as will the livelihoods of farmers who depend on these systems for their agricultural production. Farmers will respond to climate change by pursuing different livelihood strategies, including agricultural intensification, crop diversification, and exit from agriculture (1, 39). The importance of access to seed will vary considerably in various strategies for climate adaptation, but, barring a wholesale exit from agriculture, smallholder farmers throughout the developing world will require access to suitable germplasm. We have presented an approach to this global issue that allows researchers to assess the vulnerability of these seed systems to climate change. These assessments then can lead to the identification of interventions to help farmers cope with the effects of change. This approach, based on quantifying the spatial scope of traditional seed systems and relating these spatial scopes to potential climate shifts that would modify the distribution of growing environments and hence the fit between the germplasm to which farmers currently have access to and the one needed in the future, can be applied to different systems and circumstances, although the specifics probably will vary from one case to another.

Potential interventions will require the fostering of a well-functioning seed system, linking formal and informal seed systems and market and nonmarket transactions to stimulate and meet efficiently the demand of farmers for climate-adapted seed (29, 33, 40). This adjustment probably will require the establishment of new links within farmers' seed-source networks that go beyond their traditional spatial scopes to connect communities in current and future analog climates. In Mexico farmers in the highland agro-climate environment will have to link with communities in the dry midaltitude environment. In practice, the geographical reach of farmers' seed networks could be broadened through exchange visits; linking farmer groups in different locations; fostering the exchange of germplasm, knowledge, and practices among different locations; and encouraging cross-community experimentation with local and introduced crop varieties.

Methods

The spatial scope of traditional maize seed systems was studied in four horizontal transects across an altitudinal gradient from 10–2,980 m above sea level representing the main maize-growing environments present in Central Mexico in five states: Veracruz, Puebla, Tlaxcala, Hidalgo, and State of Mexico. Transects included 46 municipalities; in each transect all communities with a population between 500 and 2,500 inhabitants and with maize production were identified (400 communities). From these 400 communities, 20 were selected randomly, and in each of these 20 communities 20 households were chosen randomly, for a total sample of 400 households. A survey was carried out from October–December, 2003, eliciting information on household demographic, socioeconomic, and agricultural characteristics. To analyze farmers' traditional seed systems, we used the seed lot as the basic unit of analysis. [A seed lot is defined as "all kernels of a specific type of maize selected by a farmer and sown during a cropping season to reproduce that particular maize type" (12).] An inventory of seed lots planted by the households, with information on the origin and history of the seed and its management—including experimentation—was obtained, with detailed information on the location of communities from which seed lots were obtained originally and to which seed lots were distributed. These movements were mapped, and distances between seed sources and their destinations were calculated.

Maize agro-climate environments in the study area were defined using the methods and criteria described by Setimela et al. (41). Differing ranges of maximum temperature and precipitation during the growing season were the defining factors of the agro-climate environments. These factors accounted for most of the genotype × environment interactions in an extensive multilocation, multiyear trial set, and the agro-climate zonation has proven a robust framework for germplasm deployment (42). A 5-mo optimal climate model (i.e., the five consecutive months with greatest water availability based on the ratio of precipitation to potential evapotranspiration) was used as a surrogate for growing season. Spatial distribution of current maize agro-climate environments was determined using the WorldClim climate database (43). The WorldClim data represent the long-term average climate for the period 1950–2000 and are used as a representation of current climate conditions. The current spatial scope of traditional seed systems in the study area was analyzed based on maize agro-climate environments.

Previous work relating rural poverty to maize environments in Mexico (44) found that 74% (n = 30,161) of the rural communities predicted to be below the food poverty line in 2000 occurred in just three maize environments—wet lowlands (37%), wet upper midaltitude (19%), and highland (18%). Future climate variation was assessed through the use of three IPCC GCMs. Downscaled data (30-arc seconds) from the WorldClim database were used for the HadCM3, CSIRO, and CCCMA models under the IPCC A2a and B2a scenarios (45) for 2050. The spatial distribution of potential future maize agro-climate environments was generated using these scenarios. To address some of the uncertainties from GCMs and emission scenarios, median values for the six alternative future climates in 2050 (three GCMs times two scenarios) were used to represent a likely future scenario (46). The extreme future climate (HadCM3, scenario A2 for 2050) was included also for reference. Climate parameter ranges and the growing season model applied were identical to those used for current climate conditions.

The calculated start month for the 5-mo optimal growing season remained constant under all future climate scenarios, implying no temporal shifts in growing season under future scenarios. Monthly current and future climate variables (minimum/maximum temperature and precipitation) were extracted for all study communities and were used to classify these communities and the associated 10-km radial zones (determined to be the likely sources of seed) into maize agro-climate environments. Potential environmental shifts in these environments were compared with the current spatial scope of traditional seed systems by measuring changes in the distribution of 1-km^2 pixels within the 10-km radial zones across maize environments between current and 2050 situations for both scenarios. These changes were tested statistically using marginal homogeneity tests (47) with Stata/SE 10.0 for Windows (48) with the procedure "symmetry." This approach was used because the data consist of matched pairs of pixels; hence, the data are not independent.

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