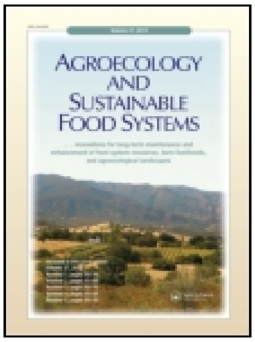

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Farmer Strategies for Dealing with Climatic Variability: A Case Study from the Mixteca Alta Region of Oaxaca, Mexico

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This study describes an interdisciplinary methodology for helping small farmers prepare for climatic variability. We facilitated workshops in the Mixteca Alta region of Oaxaca, Mexico, in which groups of small farmers described how they had adapted to and prepared for past climate challenges. Farmers reported that their cropping systems were changing for multiple reasons: more drought, later rainfall onset, decreased rural labor, and introduced labor-saving technologies. Examination of climate data found that farmers' climate narratives were largely consistent with the observational record. There have been increases in temperature and rainfall intensity, and an increase in rainfall seasonality that may be perceived as later rainfall onset. Farmers also identified 14 indicators that they subsequently used to evaluate the condition of their agroecosystems. Farmers ranked landscape-scale indicators

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as more marginal than farmer management or soil quality indicators. From this analysis, farmers proposed strategies to improve the ability of their agroecosystems to cope with climatic variability. Notably, they recognized that social organizing and education are required for landscape-scale indicators to be improved. This outcome suggests that climate change adaptation by small farmers involves much more than just a set of farming practices, but also community action to tackle collective problems.

KEYWORDS agroecology, climate change, participatory research, rainfed agriculture, small farmers

INTRODUCTION

Climate change is expected to disproportionately impact tropical regions where the majority of small farmers and pastoralists reside (Easterling et al. 2007). Small farmers that manage diversified and small-scale farms, that rely on family labor, and that produce both subsistence and commercial goods are a predominant mode of production in many regions of the world (Astier et al. 2012). One of the challenges for addressing twenty-first century climate change is scale. Climate models do not provide specific enough information for adaptation at small scales (Oreskes et al. 2010).

Effective adaptation to climate change requires location-specific understandings of climate variability (Gamble et al. 2010). This is especially true for small farmers, who often use local climate knowledge for decision making. While climate may seem an unlikely candidate for management, small farmers are not limited to reacting to it (Wilken 1987). Small farmers have developed innovative farming strategies for withstanding challenging climatic conditions (Altieri and Nicholls 2013). The recovery of traditional management practices from creative and motivated local stakeholders may in fact represent important strategies to prepare for climate change (Astier et al. 2011). Scientific and local knowledge must be bridged to contribute to the well-being of agricultural communities (Valdivia et al. 2010). Moreover, Roncoli (2006) recommends the use of ethnographic and participatory methods to move towards a climate vulnerability and adaptation paradigm led by farmers and institutions.

This article discusses participatory research in the Mixteca Alta Region of Oaxaca, Mexico that facilitated a process whereby farmers evaluated the ability of their agroecosystems to withstand the vagaries of climate. The proposed methodology documented small farmers' past strategies for dealing with climatic variability, developed local indicators to assess the ability of agroecosystems to withstand climatic variability, and placed the locally derived indicator framework in the hands of farmers for evaluating the current state of their agroecosystems. Additionally, we put the farmers' description of climate history in conversation with regional climate records. This latter step of original quantitative climate analysis was not essential to identifying farmer adaptation strategies, but rather may validate farmers' experiences to scholars, community organizers, and policymakers.

METHODOLOGY

Study Area

The Mixteca Alta Region of Oaxaca, Mexico is both a political entity and a part of the larger geographical area predominated by the Mixtec people. We collaborated with three communities from the Nochixtlán District of the Mixteca Alta Region: San José Zaragoza (Zaragoza), El Rosario, and San Pedro Coxcaltepec Cántaros (Coxcaltepec; Figure 1). Due to its high elevation (much of it above 2000 meters), the Mixteca Alta is largely classified as a subtropical dry winter climate (Cwb) according to the Köppen-Geiger system, although it lies within the tropics (Kottek et al. 2006). Most precipitation occurs from June through September, with a mid-summer decrease known as the *canícula* (Magaña et al. 1999). The highest average temperatures are in April and May, before the heaviest summer rains, and frosts are common from October through March at higher elevations. Figure 2 shows

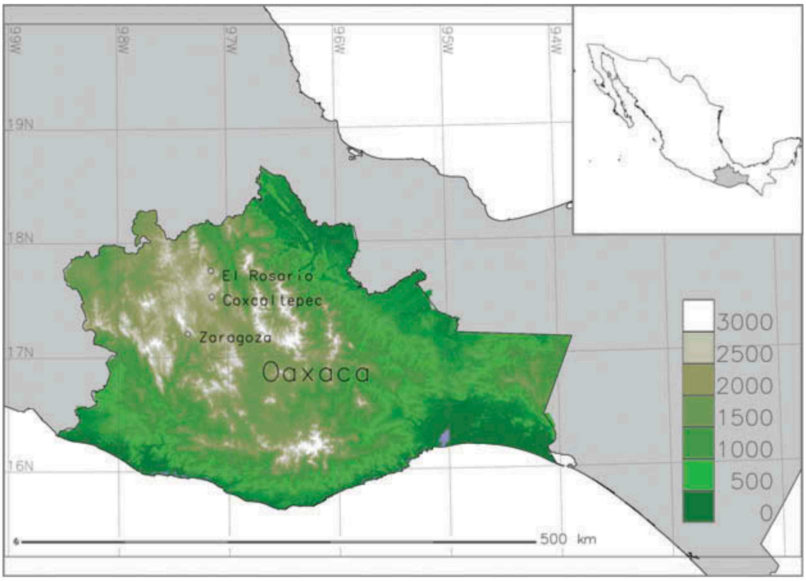


FIGURE 1 Map showing the communities from the Mixteca Alta region of Oaxaca, Mexico that participated in this case study: San José Zaragoza (Zaragoza), El Rosario, and San Pedro Coxcaltepec Cántaros (Coxcaltepec).

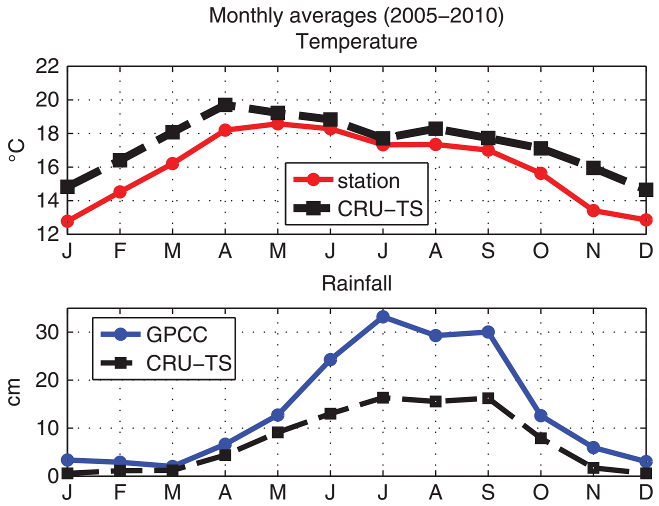


FIGURE 2 2005–2010 monthly averages based on data from the Nochixtlán meteorological station (17°26′ N, 97°15′ W, 2040 m) and gridded averages over 96.5–97.5°W, 17–18°N. Top: Temperature (°C) based on data from the Nochixtlán meteorological station (solid line with circles) and CRU–TS (dashed line with squares). Bottom: Rainfall (cm) based on data from GPCC (solid line with circles) and CRU–TS (dashed line with squares).

the monthly average temperature and rainfall from 2005–2010 for a 1°×1° region surrounding the communities (96.5–97.5°W, 17–18°N) in Figure 2.

Rainfed agriculture—particularly maize, beans, and wheat—is widely practiced in the Mixteca Alta (Altieri et al. 2006; Velásquez 2002). Two important rainfed cropping systems in the Mixteca Alta are cajete maize (*maíz de cajete*) and seasonal maize (*maíz de temporal*). The two maize systems differ significantly in their requirements for labor, technology, and social organization. Groups of farmers sow cajete maize at the end of the dry season between February and March, using a two-sided digging tool (*pico y coa*) to locate residual soil moisture. These sowing activities involve much of the community and require coordination throughout the winter months (Rivas Guevara 2008; García Barrios et al. 1991). In contrast, families individually sow seasonal maize in furrows along with beans and squash at the beginning of the rainy season between May and July.

The Mixteca Alta is also marked by a legacy of severe soil erosion and desertification, a crisis of food production and poverty, and an aging demographic due to increasing outmigration by youth (Boege and Carranza 2009). A group of farmers, with support from the international NGO World Neighbors, organized in 1982 to address the environmental and social crises affecting the Mixteca Alta (Blauert and Quintanar 2000). This group's current manifestation, the farmer-led Center for Integral Rural Development of the Mixteca Alta (CEDICAM), continues to garner international recognition for promoting sustainable agriculture, appropriate technology, and gender equality through a farmer-to-farmer training network (Boege and Carranza 2009). CEDICAM works to adapt the sustainable elements of traditional agriculture to modern conditions through "improved" indigenous technologies (Jesús León Santos, personal communication).

Researchers and CEDICAM collaborated in participatory research for a period of three years, from 2009 to 2011, conducting a total of eight day-long workshops with farmers in CEDICAM's farmer-to-farmer network. The first author of this article lived and worked alongside small farmers in the Mixteca Alta for a total of 20 months while conducting ethnographic studies, interviews, and agronomic field experiments. These experiences inform the research presented in this article.

Researchers and CEDICAM followed a co-investigation methodology similar to that described by Freire (1970). Meetings between researchers and CEDICAM identified objectives and reflected on outcomes of farmer workshops (Figure 3). While farmer workshops primarily aimed to empower small farmers to conduct their own analysis in the vein of Freire (1970), the workshops were also focus groups as described by Hennink (2007) and Wilkinson (1999), in that a series of qualitative research questions were embedded

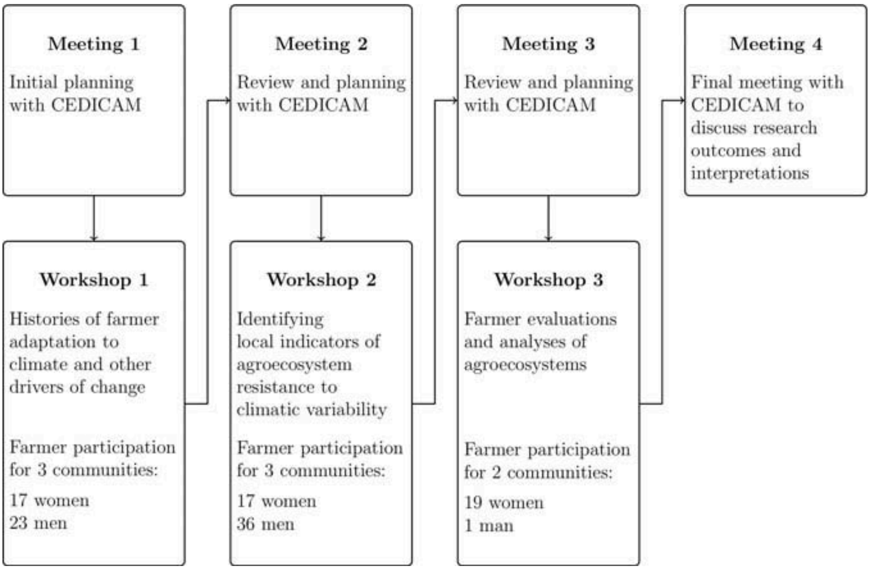


FIGURE 3 Diagram outlining the flow of co-investigation with the farmer-led Center for Integral Rural Development of the Mixteca Alta (CEDICAM) and researchers. The co-investigation process jointly defined objectives, refined methodologies, organized community members for workshops, and interpreted results. A constant emphasis was also placed on validating farmer perceptions throughout the research process. The number of communities and participating farmers during each phase of workshops is also displayed.

in the activities conducted by farmers. CEDICAM invited farmers in each community through their farmer-to-farmer training network. An average of 6 women and 7 men ranging from an estimated 18–70 years old attended each farmer workshop. However, participation varied greatly due to competing responsibilities in local governance positions and employment outside of their communities.

Climate Histories

In the first series of workshops, attended by 17 women and 23 men across the three communities, farmers discussed their adaptations to past climate challenges. Group discussions were an important strategy since participating communities maintain oral history traditions. From a focus group perspective, discussions between farmers obtained a more unified recollection of past experiences (Morgan and Krueger 1993). Farmers' climate narratives provided a basis for an investigation of the historical climate.

Researchers facilitated the workshops by recording farmers' narratives on a large sheet of paper. Key historical events in each community served as baseline references of a stratified timeline. The impacts and farmer adaptations to extreme climatic events—namely, severe droughts, storms, and frosts—were layered upon this baseline. Researchers relied on the farmers' interpretations of climatic extremes, since there are many possible interpretations of extreme events (Peralta-Hernandez et al. 2009). We also asked farmers how they experienced and responded to long-term climate changes, and how their production systems changed over time, as did Geilfus (1998) and Ortiz-Ávila et al. (2007).

Climate Record

For the regional climate record, we examined a $1^\circ \times 1^\circ$ region encompassing the communities (96.5–97.5°W, 17–18°N). We investigated monthly averaged data from a Mexican National Meteorological Service meteorological station in Nochixtlán and from high-resolution gridded datasets based on station data: temperature and rainfall from the Climatic Research Unit time series dataset (CRU-TS) version 3.21 (Harris et al. 2013); and rainfall from the Global Precipitation Climatology Center full data reanalysis (GPCC) version 6 (Schneider et al. 2013). The automatic station data were available from 2005 onward; we only used temperature since several months of rainfall appeared to be missing.

We investigated the 50-year climate record in the study region focusing on long-term secular changes to compare with farmer perceptions of climate. As the gridded products were at a much larger spatial scale compared to the farming communities and had lower temporal resolution compared to most extreme events, we did not expect individual local extreme events to be present in the data. Our workshop methodology may have primed respondents to associate climate changes with non-climate historical events in the communities. However, this was unlikely to have affected the farmers' perceptions of a long-term signal. Since the workshop participants were from a wide age range, we examined both 50-year (1961–2010) and 25-year (1986–2010) trends. Trends were calculated using the Kendall-Theil robust slope to reduce the influence of outliers, and we evaluated significance using a two-tailed Mann–Kendall test with a cutoff of α=0.05 (Helsel and Hirsch 2002). We characterized El Niño/Southern Oscillation (ENSO) Figure 2 events using the multivariate ENSO index (Wolter and Timlin 2011).

Local Indicators

A second series of workshops, attended by a total of 17 women and 36 men across the three communities, asked farmers to describe the biophysical attributes of their production systems that enabled or limited productivity given the climatic variability described in the previous workshop series. We referred to these biophysical attributes as indicators. The use of indicators in participatory research with farmers is well established in Latin America (Astier et al. 2011; Pulido and Bocco 2003).

The identification of local indicators followed a similar study of cacao agroforestry systems in Costa Rica and Nicaragua conducted by Altieri (2010). Field visits to three agroecosystems in each community stimulated a conversation between researchers and participating farmers about the most important indicators. It also became evident through these discussions that some of the indicators described conditions beyond the scale of one farmer's fields (landscape), while others were related to conditions directly influenced by farmers' actions on the field-scale (farmer management) or to conditions of soil quality at the field scale that for some indicators were indirectly related to farmers' intervention in the system (soil quality).

Farmers described conditions for each indicator within a three-tiered ordinal scale of marginal, acceptable, and optimal that were, respectively, linked to red, yellow, and green colors. Describing conditions of indicators with stop-light colors has been developed in Latin America as a simple methodology for farmers to evaluate their agroecosystems (Altieri 2010; Cammaert et al. 2007). However, farmers participating in this case study did not intuitively associate indicator conditions with colors since many had limited interaction with stop lights in their day-to-day lives. For the agroecosystem assessment phase described below, researchers paired colors with facial iconography: sad for marginal, normal for acceptable, and happy for optimal. While facial iconography was effective at improving communication between researchers and farmers during the workshops, for the purpose of this article we make reference to the scales of marginal, acceptable, and optimal.

TABLE 1 Forms used by farmers to evaluate four agroecosystems in each community of Zaragoza and El Rosario, based on the 14 locally derived indicators

Team:
Community:
Production system:

Category	Indicator	Marginal	Acceptable	Optimal
Landscape	– Territorial composition			
	– Windbreaks			
	– Field location			
	– Soil conservation			
Farmer management	– Crop rotation			
	– Crop varieties			
	– Polyculture			
	– Soil amendments			
	– Soil cultivation			
Soil quality	– Spontaneous plants			
	– Soil productivity			
	– Soil organic matter			
	– Soil depth			
	– Soil texture			

Researchers and CEDICAM subsequently refined the indicators described by farmers into a set of 14 indicators (Table 1). Repetitive indicators across communities were combined, as were those indicators that distinguished between dry and wet years. For example, while wheat was described as more resistant to drought than to excess soil moisture, most varieties of maize were sensitive to both drought and excess soil moisture. Therefore, we described wheat as more resistant to climatic variability than maize.

Agroecosystem Assessments

In the third series of workshops, three women farmers in Zaragoza and three groups of five predominantly women farmers in El Rosario independently evaluated four production systems in their communities using the set of 14 indicators. Researchers pooled the agroecosystem evaluations within each community by assigning numerical scores of 0 for marginal, 1 for acceptable, and 2 for optimal. Farmers analyzed outcomes by drawing bar plots of the pooled scores for their community. Farmers were prompted to analyze the results of their evaluations as a group by the following questions:

- How to obtain more happy faces (i.e. the optimal condition) in the landscape, farmer management, and soil quality categories?
- How to maintain the happy faces (i.e. optimal condition) that you already have in the landscape, farmer management, and soil quality categories?

These questions differ slightly from previous implementations of this methodology, where farmers are asked “how to move from marginal towards optimal?” (Altieri 2010; Cammaert et al. 2007). The modified questions aimed to direct farmers’ attention towards both improvements needed and characteristics to maintain in managing their agroecosystems.

RESULTS

Climate Histories

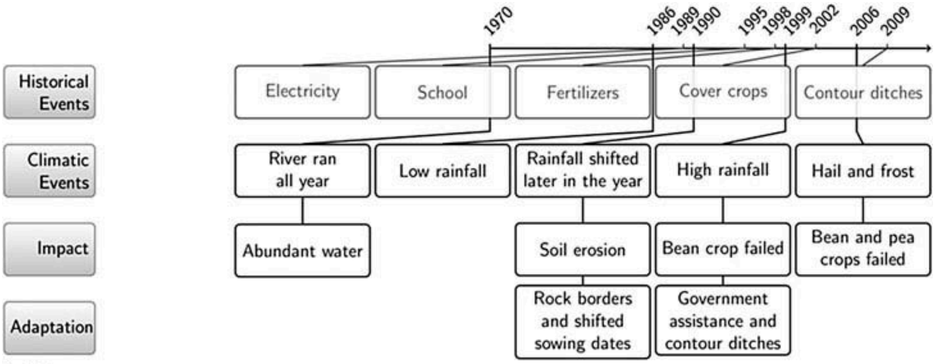
FARMER NARRATIVES AND THE REGIONAL CLIMATE

Climate histories dated back to the 1970s in Zaragoza, to 1969 in El Rosario, and to the 1930s for one individual in Coxcaltepec. Farmers reported that climate changes in recent decades—namely later rains and more drought—have made growing conditions less favorable for traditional forms of agriculture. Across the three communities, participants reported a shift towards a later onset of the rainy season. Zaragoza participants recalled the onset of rainfall before the 1990s between February and March while since approximately 1990 rainfall began from May to July (Figure 4a). In El Rosario, rainfall began from May to June during the 1970s, whereas they began between June and July starting in the 1990s (Figure 4b). Farmers in Coxcaltepec observed a progressive shift beginning in the 1970s in the onset of rainfall from May towards July (Figure 4c). These shifts were associated with historically important dates in the communities: the years electricity arrived in Zaragoza and Coxcaltepec and the year El Rosario’s main road was built.

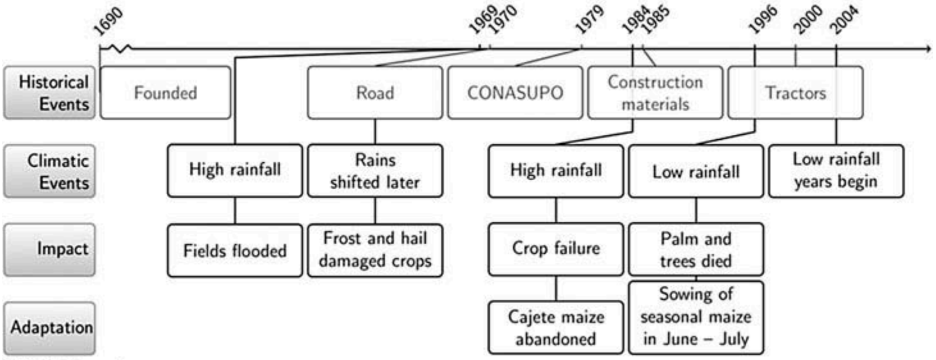
Increased storm intensities were particularly noted in the last decade by the three communities. Extreme climatic events described by farmers in the three communities were remembered for their impacts on agroecosystems. Zaragoza experienced a near complete crop failure in 2006 due to frost, as well as suppressed yields in 2009 due to high rainfall in June followed by an unusually dry mid-summer drought. El Rosario farmers recalled a catastrophic drought in 1996 that killed crops, trees, and palms alike.

FARMER ADAPTATION TO CLIMATE

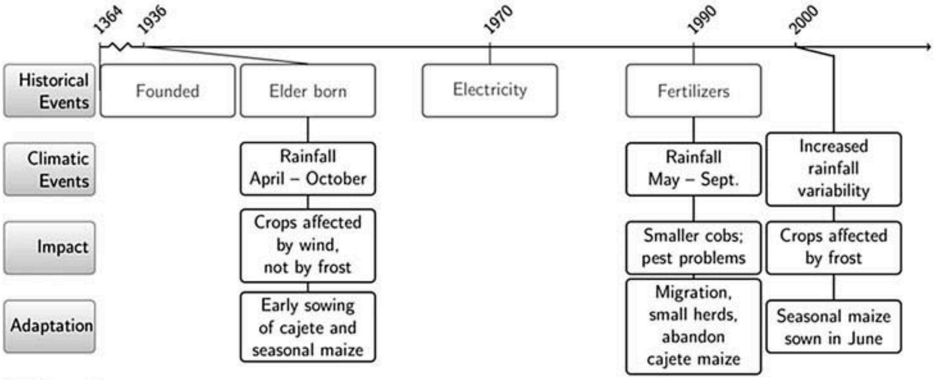
Farmers identified multiple instances of agroecosystem change that in some cases were associated with climate. Particular mention was made by farmers of detrimental climate changes during the beginning of the rainy season when many crops were sown (see “Climate” section of Figure 5). Sowing dates for seasonal maize had shifted from May to June in Zaragoza since the 1990s, and from between May to June 16 to between June and July 14 in El Rosario. Coxcaltepec and El Rosario participants noted that later sowing dates placed seasonal maize and beans at greater risk to frost damage in September and October.



(a) Zaragoza



(b) El Rosario



(c) Coxcaltepec

FIGURE 4 Stratified timeline summarizing farmer narratives of historical events in their communities, significant climatic events, impacts on agroecosystems caused by the climate, and adaptation strategies used by farmers to deal with the situation. Climate narratives are represented for the communities of a) Zaragoza, b) El Rosario, c) and Coxcaltepec.

Note: CONASUPO = National Company for Basic Commodities (Compañía Nacional de Subsistencias Populares).

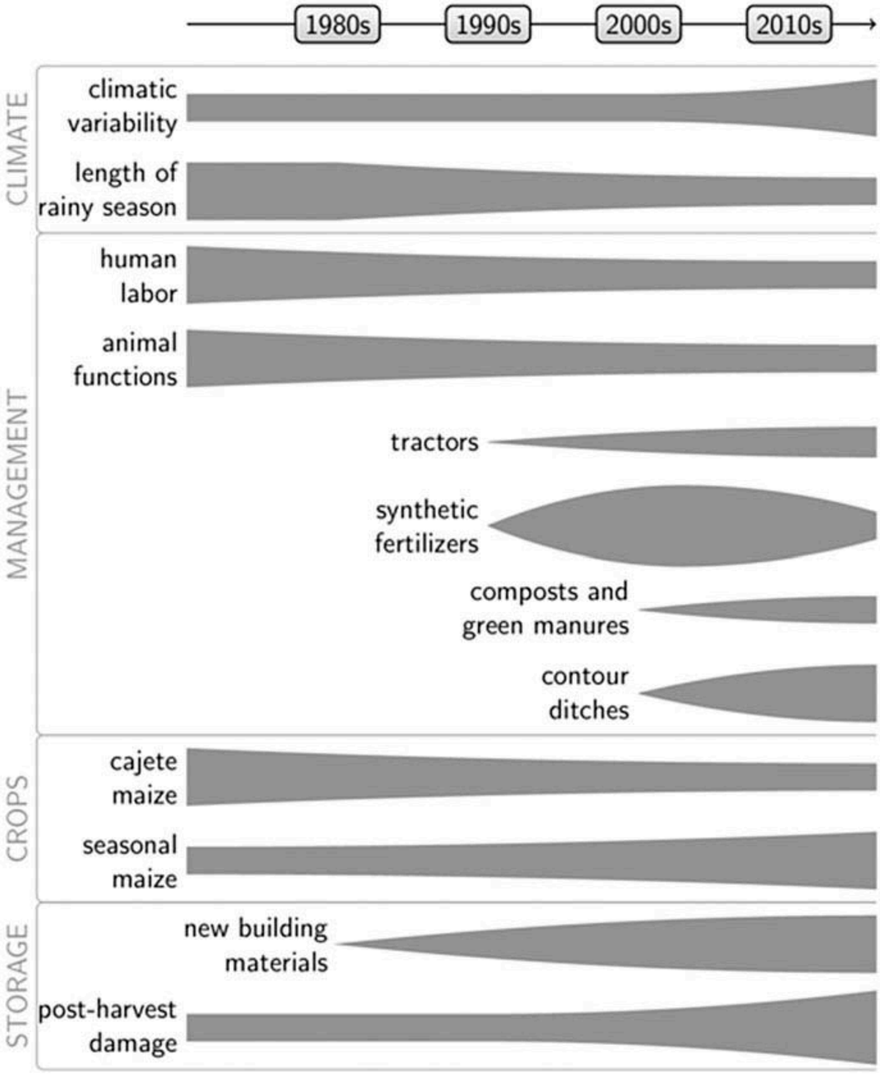


FIGURE 5 Changes in agroecosystems during approximately the past 50 years that were described by farmers in Zaragoza, Coxcaltepec, and El Rosario. The width of bands represents a qualitative presence of each element in the agroecosystems. The bands are grouped into themes to emphasize specific relationships between them.

In addition to shifting sowing dates, participants in El Rosario and Coxcaltepec largely abandoned cajete maize (see "Crops" section of Figure 5). While in the past, approximately half of arable lands were cultivated to cajete maize, in recent times, the practice is greatly reduced in the three communities. One reason cited by farmers was greater heat (*calor*), consisting of both extended dry seasons as well as more frequent droughts (*sequía*) during the rainy season. Similarly, Sánchez-Cortés and Lazos Chavero (2011) reported that changes in the agroecosystems of Zoque farmers in the Mexican State of Chiapas was provoked by less rain and increased temperature.

Farmer observations suggested that they had not necessarily responded to specific cases of climatic extremes, but rather their long-term management strategies buffered agroecosystems from climatic shocks. During a series of dry years from 2004 to 2009, cajete maize and wheat were most resistant while seasonal maize and beans failed. Farmers attributed this to cajete maize suffering less damage from excessive rainfall and frost at the end of the rainy season since it was harvested earlier than seasonal maize.

Farmers in the three communities described how contour ditches improved water infiltration, recharged aquifers, retained water in dry years, and facilitated drainage of fields in wet years. Vegetated borders and windbreaks, as told by farmers, protected maize from windthrow. Farmers noted that CEDICAM had contributed to training communities to conserve soils using appropriate technologies, such as the Apparatus A (León Santos 2007). Additionally, farmers recognized the importance of governmental support for conservation practices, like the funding Zaragoza's municipality received from government sources to build contour ditches in 2009.

NON-CLIMATE DRIVERS OF CHANGE

The impacts of climate were interwoven with other drivers of change. Beyond climate, crises of labor and soil fertility also contributed to the shift from cajete maize to seasonal maize. Participants in the three communities noted a decrease in rural labor and an increase in labor-saving agricultural technologies (see "Management" section of Figure 5). Farmers reported that the massive out-migration of youth from Coxcaltepec contributed to the abandonment of cajete maize in favor of labor-saving crops such as seasonal maize. Farmers associated reduced rural labor with declines in animal husbandry since the 1980s. The majority of oxen used for plowing fields were sold by Coxcaltepec farmers with the introduction of tractor technology in 2009. Consequently, farmers substituted traditional soil fertility management based on animal manures with purchased synthetic fertilizers in Zaragoza since 1998 and in Coxcaltepec since the 1990s.

Maize yields increased initially by the change in soil fertility management. However soils were negatively affected over time and productivity eventually declined. Zaragoza farmers began experimenting with green manures and composts in 2002 to reduce the costs of synthetic fertilizers and to improve soil quality. An initial reduction in yields was followed by increases in subsequent years. Research from Mixteca Alta (Edinger 1996; Garcia-Barrios and Garcia-Barrios 1990) and elsewhere in Mexico (H. Eakin 2000; H. C. Eakin 2006) support similar observations by farmers that their agroecosystem management was influenced by economic conditions and access to technology.

Farmers recognized that the adoption of new technologies were accompanied by unanticipated consequences. Farmers associated greater heat during the dry season with elevated postharvest losses in Zaragoza and El Rosario due to the increased prevalence of grain weevils and moths (see "Storage" section of Figure 5). Temperature is a well established factor in the degree of postharvest damage (McFarlane 1988). According to farmers, postharvest pest damage was exacerbated by state-subsidized construction materials of cement, cinder block, and corrugated metal introduced since the 1980s that elevate indoor temperatures compared to traditional building materials of adobe, palm, reeds, and oak.

Climate Record

TEMPERATURE

Figure 6 shows the annual mean CRU–TS temperature anomalies from 1961–1990 over the study region. The 25-year and 50-year trends both showed statistically significant warming (0.16 and 0.18°C per decade). This was consistent with our finding of regional-scale warming over south–central Mexico (15–20°N, 95–100°W) in the Climatic Research Unit variance-adjusted land surface temperature record (CRUTEM4) version 4.2.0.0 (Jones et al. 2012), which is not shown. The influence of ENSO was also apparent on

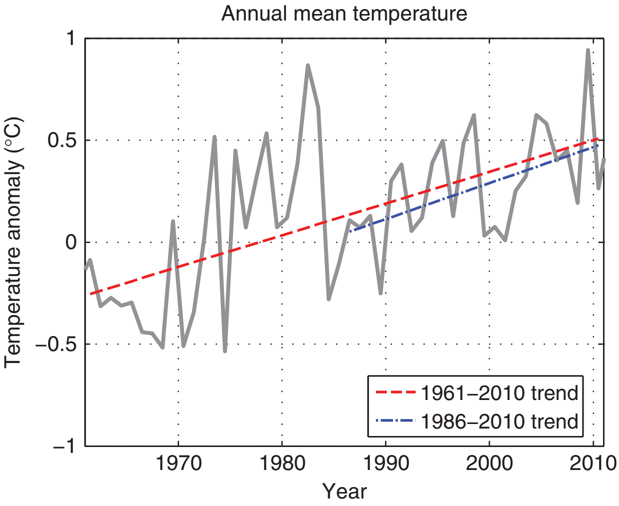


FIGURE 6 Annual mean temperature anomalies (°C; solid line) over 96.5–97.5°W, 17–18°N based on data from CRU–TS. The dashed lines show the 1961–2010 (evenly dashed) and 1986–2010 (unevenly dashed) trend lines. Anomalies are with respect to 1961–1990.

interannual timescales, with anomalously high temperatures associated with the strong El Niño events of 1982–1983 and 2009.

RAINFALL INTENSITY

For an estimate of rainfall intensity, we divided total annual rainfall by the count of days with rainfall from CRU–TS to obtain an average of the rainfall amount per rain day. Figure 7 shows this estimate of annual mean rainfall intensity. There are increasing trends over both 1961–2010 and 1986–2010, although neither is statistically significant. The increase has been larger in recent years; the 1986–2010 trend is over three times as large as the 1961–2010 trend (0.03 cm/ rain day and 0.10 cm/ rain day per decade), and three of the four most intense years were in the 2001–2010 decade. There is also an association with the ENSO activity: The very intense rain years of 1983 and 2010 were each in the second year of a strong El Niño. 2010 also transitioned quickly into a strong La Niña (Ruiz Barradas 2011).

RAINFALL SEASONALITY

It was difficult to directly assess the length and timing of the rainfall season both because we did not examine daily rainfall data, and there was not a strict threshold for the onset of the local rainy season. For a sense of changes in rainfall seasonality, we examined the time series of early season rainfall (April–June), late season rainfall (July–September), and the difference

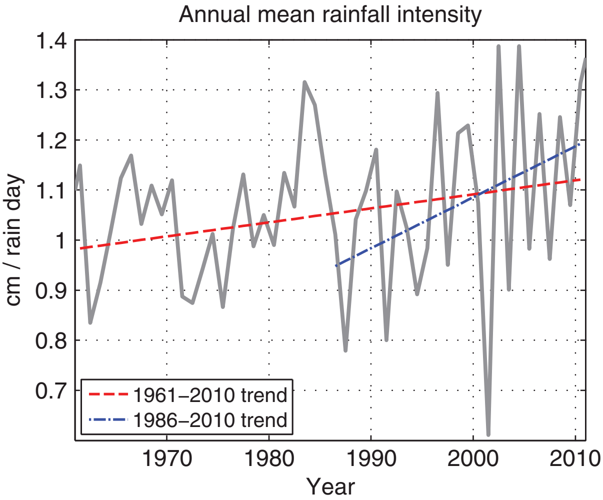


FIGURE 7 Annual mean rainfall intensity (cm per rain day; solid line) over 96.5–97.5°W, 17–18°N based on data from CRU–TS. The dashed lines show the 1961–2010 (evenly dashed) and 1986–2010 (unevenly dashed) trend lines.

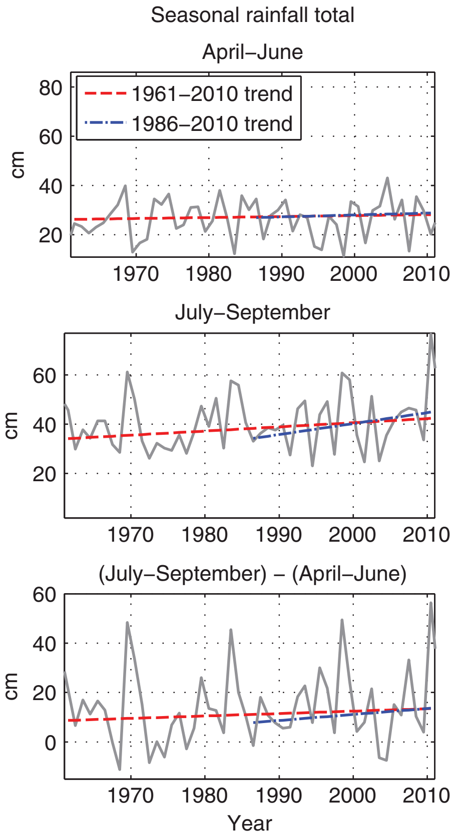


FIGURE 8 Seasonal rainfall totals (cm; solid line) over 96.5–97.5°W, 17–18°N for April–June (top), July–September (middle), and the seasonal difference (bottom) based on data from CRU–TS. The dashed lines show the 1961–2010 (evenly dashed) and 1986–2010 (unevenly dashed) trend lines.

between these two seasons (Figure 8). The early and late rainfall seasons had different associations with ENSO. July–September had dramatic spikes in rainfall in 1983, 1998, and 2010—each the second year of a strong El Niño (as mentioned above, 2010 also transitioned into a strong La Niña). These years had low April–June rainfall, resulting in a very large seasonal difference. 1969 had a similar rainfall pattern, but did not appear to have been a strong El Niño.

The 1961–2010 and 1986–2010 trends were slightly positive for both April–June (0.39 and 0.78 cm per decade) and July–September (1.68 and 4.43 cm per decade). Since the July–September trend was larger, the difference also had a positive trend over both 1961–2010 (0.98 cm per decade) and 1986–2010 (2.43 cm per decade). None of the trends were statistically significant. Similar results were found in the GPCC dataset (not shown).

Although the gridded data did not directly support a later spring rainfall onset, the increasing difference between the late and early season may have accounted for the farmers' perception of a shift to later rainfall, as found in a recent study of farmer climate perceptions in the Caribbean (Gamble et al. 2010).

LOCAL INDICATORS

The conditions of optimal, acceptable, and marginal for the 14 indicators are described per category of landscape (Table 2), farmer management (Table 3), and soil quality (Table 4). We highlight below several indicator conditions to demonstrate how they were grounded in farmers' local knowledge for dealing with climatic variability.

At the scale of the farmers' territory (landscape), Zaragoza farmers observed that vegetated borders and perennial vegetation with multiple uses mitigated exposure to extreme climatic events (see "Living barriers" indicator, Table 2). Similarly, Coxcaltepec farmers recognized that heterogeneous and forested landscapes provided ecosystem services, including protecting fields, bringing rain, retaining groundwater, accumulating soil organic matter, and controlling insect pests (see "Territorial composition" indicator, Table 2). Some tree species competed with crops for resources or negatively affected crops if their leaves produced heat (*calor*), such as juniper and pine, in contrast to the cool leaves of oak, manzanita, and madrone. El Rosario

TABLE 2 Description of landscape indicators

Indicator	Marginal	Acceptable	Optimal
Territorial composition	The majority of fields are producing the same crop and during the same cycle as the production system being evaluated	Surrounding the production system there are other production systems in fallow or with different crops, but no forests	Surrounding the production system there are forests and other production systems in fallow or producing different crops
Windbreaks	Without trees or windbreaks	Large trees that compete with crops, such as juniper, pine, and eucalyptus	Multiple purpose vegetation for firewood, wood, forage, and fruit
Field location	Steep slope or in risk of frequent floods	Flat to intermediate slope with some risk of flooding	Flat to intermediate slope, below native forests and without risk of flooding
Soil conservation	No border on the edges of the production system	Rock piles on the edge of the production system	Contour ditches with some slope for drainage. Distance between bunds based on slope

TABLE 3 Description of farmer management indicators

Indicator	Marginal	Acceptable	Optimal
Crop rotations	No rotation or fallow	Rotations without legumes	Yearly rotations that include legumes
Crop varieties	Less precocious varieties of seasonal maize; beans	Precocious varieties of seasonal maize; less precocious varieties of wheat (var. largo and rocomé); squash; fava	Precocious varieties of wheat (var. pelón); cajete maize, white sweet clover clover; Peas
Polyculture	Monoculture	Intermediate polyculture	Functional polyculture
Soil amendments	No application of fertilizers, composts, or manures	Synthetic fertilizer or poor quality manures	High quality composts, green manures, and animal manures
Soil cultivation	Tractor for cajete maize	Tractor for seasonal maize	Discing with tractors followed by hilling up with draft animals

TABLE 4 Description of soil quality indicators

Indicator	Marginal	Acceptable	Optimal
Spontaneous plants	Few spontaneous plants in the milpa	Intermediate number of spontaneous plants in the milpa	Excessive amount of spontaneous plants in the milpa
Soil productivity	Poor soil that is unproductive unless amended	Fragile soil with poor harvests	Good soil that does not require many amendments
Soil organic matter	Soil with little organic matter that is difficult to cultivate, does not retain humidity, or that floods	Intermediate organic matter	Soil with high organic matter that is easy to cultivate, retains moisture, and is porous
Soil depth	Rocky, shallow or thin soils that the plow does not enter and presence of gullies	Thin soil where the plow enters approximately a half forearm (codo), or approximately 10 cm, and presence of rills	Deep soil where the plow enters approximately one forearm (codo) or 25 cm and without signs of erosion
Soil texture	Clayey soil that is sticky or sandy soil that dries quickly	Gravelly soil that retains soil moisture	Loamy soils that do not flood

participants described that contour ditches capture soil and water, and that a slight slope to the contour ditches avoids flooding and breaching during heavy rainfall events (see “Soil conservation” indicator, Table 2).

Indicators of farmer management at the field-scale included the importance of crop genetic and species diversity for stabilizing overall yields given the variation in crop performance from year to year (see "Crop varieties" and "Polyculture" indicators, Table 3). While farmers described maize as generally more vulnerable to climatic extremes than wheat, cajete maize was described as more resistant than seasonal maize. The apparent contradiction between farmers' prior narratives of abandoning cajete maize and subsequent ranking of cajete maize as more resistant than seasonal maize is discussed later in this article. The indicator of "Soil amendments" (Table 3) were derived from farmer testimonies that synthetic fertilizer only improved crop yields with favorable rainfall; in drought years, synthetic fertilizer was ineffective and "even burned crops". Coxcaltepec participants recommended substituting synthetic fertilizers with various locally derived soil amendments, including animal manures, worm castings, forest humus, and human urine.

Soil quality was also described by farmers to affect the impact of climatic variability on agroecosystems. The three communities associated soil moisture retention with soil texture and depth. Although soil color was also mentioned as an indicator, it was difficult to use due to apparent contradictions of color classifications across communities. Generally, clayey soils were described as the most productive in drought years, but also difficult to cultivate in wet years (see "Soil texture" indicator, Table 4). In contrast, farmers described sandy soils as the easiest to cultivate in wet years but also the least productive. Farmers considered deep soils, measured by how far the Egyptian plow entered the soil, are considered by farmers to be the most productive soils in both wet and dry years (see "Soil depth" indicator, Table 4).

Agroecosystem Assessments

Overall, farmers in Zaragoza and El Rosario ranked their agroecosystems in decreasing order as optimal (175 counts), acceptable (119 counts), and marginal (42 counts) across both communities (Figure 9). However, the rankings differentiated most clearly between categories of indicators, as described below.

The assessments show that farmers consider their field-level management to be largely appropriate. In both communities, indicators in the category of farmer management gained the highest number of optimal rankings (46 counts in Zaragoza and 34 counts in El Rosario) and the lowest number of acceptable and marginal rankings combined (14 counts in Zaragoza and 26 counts in El Rosario). Soil quality received a close to equally divided ranking between optimal (29 counts in Zaragoza and 32 counts in El Rosario) and the combined rankings of acceptable and marginal (31 in Zaragoza and 28 in El Rosario). In contrast, landscape indicators received higher numbers of acceptable and marginal rankings (27 in Zaragoza and 35 in El Rosario, combined) compared to optimal rankings (21 in Zaragoza

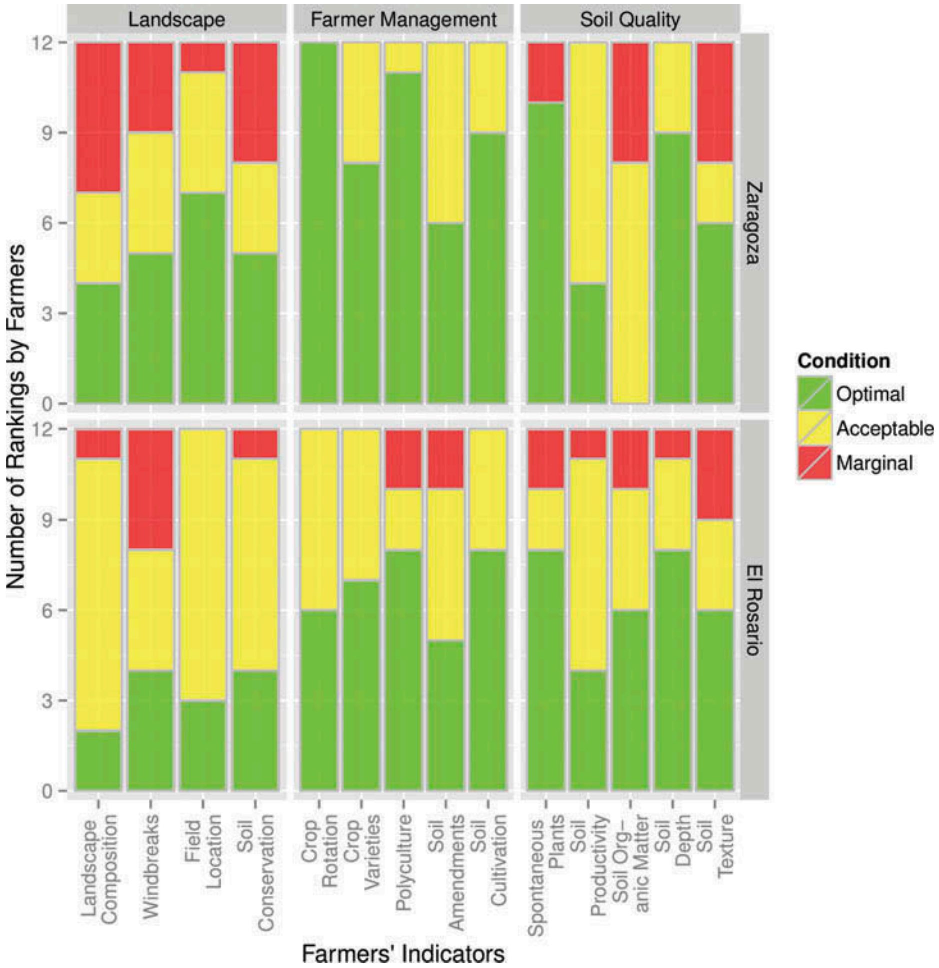


FIGURE 9 Mosaic plot of evaluations of four agroecosystems using 14 indicators that were conducted by farmers in each of the communities of Zaragoza and El Rosario. In Zaragoza, three farmers evaluated the agroecosystems. In contrast, El Rosario farmers formed three groups of five farmers to evaluate the agroecosystems. The y-axis represents the number of farmers' rankings for the agroecosystems in their community along an ordinal scale of marginal, acceptable, and optimal (depicted by the different shading of the bars). The three evaluations conducted over four agroecosystems produces a total count of 12 per indicator in each community. The 14 indicators are grouped into those operating at the landscape scale, those directly influenced by farmers' management, and those describing soil quality.

and 13 in El Rosario). Therefore, soil quality indicators had mixed rankings, while landscape-scale indicators were in the greatest need of improvement.

The lowest and highest scored indicators served as points of departure for discussing how farmers could sustain the optimal conditions of their agroecosystems while improving the marginal ones. Farmers ranked the most acceptable and marginal scores to soil organic matter in Zaragoza

(8 and 4 counts, respectively) and to windbreaks in El Rosario (4 and 4 counts, respectively). The indicators with the most optimal scores were crop rotation in Zaragoza (12 counts) and soil cultivation in El Rosario (8 counts).

Farmers' analysis of their evaluations identified multiple local strategies to better prepare for climatic variability. Strategies recommended by farmers for improving their agroecosystems given climatic variability involved establishing perennial vegetation and adopting more soil conservation strategies along field margins (e.g., agroforestry, terraces, contour ditches and stone borders; Table 5). In response to low scores for landscape indicators, Zaragoza farmers proposed planting fruit trees and acacia at the edges of fields to diversify the production of food, forage, and fodder, as well as to stabilize soils. Moreover, El Rosario farmers recommended making better use of stone borders (*camellones*) for stabilizing soils, given local soil conditions.

Farmers in Zaragoza and El Rosario discussed social constraints to establishing perennial vegetation that would need to be addressed were they to improve landscape-scale indicators. Farmers both discussed the important services that animal husbandry provided to their agroecosystems, including manure, farm labor, and income. However, they also recognized that poorly managed herds provoked overgrazing and challenged the establishment of perennial vegetation. Fallow fields and field margins were common pool resources traditionally used by all members of the community to graze animals. This limited the establishment of perennial vegetation, especially at fields further from homesteads where families exercised less oversight. Farmers recommended educating community members about responsible

TABLE 5 Farmer strategies for dealing with climatic variability

Category	Strategies for moving towards optimal
Landscape	– Education of community members – Plant trees for fruit, fodder, etc.; protect them from animals with fences – Improve livestock management – Construct contour ditches – Maintain windbreaks
Farmer management	– Apply animal manures and composts – Relax weeding – Cultivate soil with the oxen – Respect the seasons – Harvest water
Soil quality	– Plant fruit trees and acacia – Sow green manures – Apply animal manures and composts – Avoid synthetic fertilizers

animal husbandry and conservation that would allow for the establishment of perennial vegetation.

While farmer management and soil quality indicators generally ranked high, farmers discussed several field-scale strategies that primarily aimed to increase levels of soil organic matter (Table 5). El Rosario and Zaragoza farmers suggested that cutting weeds and allowing weeds to reseed would provide the benefits of a living mulch without compromising grain yields. Also, farmers recommended using traditional crop polycultures of maize and legumes as a green manure to improve soil fertility and reduce soil erosion.

DISCUSSION AND CONCLUSIONS

This research described farmers' interpretations of climate and identified local strategies for dealing with climatic variability. The workshops highlighted the depth of farmers' knowledge for dealing with climatic variability. The basis of small farmer agroecosystem management in traditional ecological knowledge is well documented in Mesoamerica (Wilken 1987; Pulido and Bocco 2003; Toledo and Barrera-Bassols 2008). Farmer-led evaluations leveraged local knowledge to identify best-bet agricultural practices for the region. The participatory methodology used with small farmers in this case study can easily be applied in other regions of the world to similarly identify site-specific farmer strategies for dealing with climatic variability.

It is noteworthy that farmers' analysis of their situation mirror general policy recommendations for climate change adaptation and mitigation. Farmers' criteria for evaluating landscape features, agricultural practices, and soil attributes overlap with many of the indicators of agricultural resilience proposed by Cabell and Oelofse (2012), including ecological self-regulation, connectedness, spatial and temporal heterogeneity, etc. Moreover, farmers' ideas for transforming their agroecosystems correspond to climate adaptation and mitigation strategies recommended by the Intergovernmental Panel on Climate Change, notably increasing reforestation, increasing soil carbon retention, composting, decreasing emissions from manure and petroleum-based fertilizers, and reducing fossil fuel dependency in agriculture (Smith et al. 2007).

Farmers in the Mixteca Alta described long-term modifications to their agroecosystems that represent important strategies for adjusting to changes in mean climatic conditions. Farming practices significantly changed over the past generation. Farmers responded to changes in rainfall patterns by shifting sowing dates, sowing different crops, and selecting crop varieties that succeeded given environmental disturbances. Farmers made decisions about timing of sowing and crop selection based on rainfall patterns in a given year, which has led to progressively later sowing of rainfed crops and the selection of more precocious crop varieties.

Farmers were more interested in stabilizing fluctuations in yields over time rather than maximizing yield potential. Such stabilizing practices identified from the workshops included soil management to increase soil organic matter, agricultural diversification, and landscape complexity. This perspective may offer space to broaden the lens of appropriate mitigation and adaptation strategies to a changing climate. It is particularly important to consider local strategies and multiple agroecosystem objectives for greater responsiveness to climate change and social need.

Dealing with challenges posed by climatic variability involves much more than a set of farming practices. The apparent contradiction of farmers abandoning cajete maize—one of the drought resistant crops identified by farmers—requires further investigation. Farmer narratives and climate records point to changes in agricultural environments of the Mixteca Alta that may favor seasonal maize over cajete maize despite cajete's resistance to drought events. Although maize cajete is more resistant to drought events, it requires cooler temperatures and moist soils during the dry season. We speculate that the warming and intensity trends have caused a drying of the mean state of soils, so that planting seasonal maize is more favorable. Just as important may be reductions in available rural labor for maintaining traditional practices associated with the production systems like cajete maize. Farmers expressed concerns that labor-saving technologies were negatively affecting their production systems, but considered that many labor-intensive traditional technologies are today impractical.

An unanticipated outcome of the workshops were calls by participating farmers in Zaragoza and El Rosario for greater community mobilization. Farmers recognized that improving landscape-scale indicators would require community-wide education and collective action. Before evaluating their agroecosystems, farmers expressed sentiments typified by one participant in El Rosario: "the rains come differently every year. When there is no rain, there is nothing we can do." After conducting their assessments, farmers recognized how their management strategies influence their ability to cope with climatic variability. Again in El Rosario, a farmer asked the group "we know what we need to do now, but how will we make it happen?" The farmers agreed to organize working groups to take action. We interpret this as a process of moving from inevitability, to empowerment, and finally action. In fact, this may reflect the mobilization toward food sovereignty occurring through farmer networks across Latin America that in its collective sense has been described in the literature as a growing agroecological revolution (Altieri and Toledo 2011).

The active participation of the CEDICAM network in all aspects of this research validated local ways of knowing and prioritized farmer interventions. We observed that the pre-Hispanic practices for regulating soil erosion described by Rivas Guevara (2008) inspire modern efforts by CEDICAM to reduce soil loss and crop damage from extreme climatic events. The methodology that we proposed and implemented in this research may be scaled up through farmer networks and applied in different regions to motivate local preparation, adaptation, and mitigation strategies.

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