PART III

DEVELOPMENT AND GOVERNANCE

14 Do changes in farmers' seed traits align with climate change? A case study of maize in Chiapas, Mexico

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1 INTRODUCTION

Climate change is a growing problem for agricultural production, and farmers are faced with decisions on whether and how to adapt (Smit and Skinner 2002; Maddison 2007; Bryan et al. 2009; Moyo et al. 2012; Tambo and Abdoulaye 2012). The concept of bounded rationality posits that decision-makers must operate under constraints related to availability of information, individuals' ability to process that information, and the time available to make a decision (Simon 1982). Climate uncertainty imposes all three of these constraints on decision-makers, as information on possible climate change alternatives and consequences, farmers' ability to mentally model these scenarios, and the time in which farmers must make their farm management decisions are all limited. Low-income farmers do not have years of data and climate modeling tools against which their perceptions or 'best guesses' can be calibrated. Yet these same individuals experience climate fluctuations first-hand, often over several years, and at a smaller scale than most climate models can predict. Hence we ask whether farmers demonstrate evidence of smart decision-making given bounded rationality, where climate uncertainty means they cannot determine an optimal set of farm management decisions. We consider whether farmers assume no particular trends in climate variation and continue with the status quo, whether they perceive trends but their subjective probabilities are biased relative to statistical probabilities as a result of certain experienced events like a drought, or whether field-based farm-management decisions are aligned with the predictions of complex empirically driven climate models.

A growing literature examines how perceptions of climate change affect farmers' agricultural decisions. A 2012 study of sub-Saharan farmers' climate change adaptation behaviors in 16 agroecological zones finds that farmers have adapted their agricultural systems in line with changes in temperature and precipitation variation (Seo 2012). The author uses spatial logit analysis to show that increases in the variation in precipitation leads to an increase in integrated agriculture systems with both crops and livestock, and a decrease in specialized crops-only or livestock-only systems. Climate change adaptation measures vary depending on the type and degree of climate change perceived, but include crop diversification, changing planting dates, soil conservation, increasing rainwater capture, water conservation, planting trees, using shading and sheltering techniques, accessing government programs and insurance, and moving to non-farming activities (Smit and Skinner 2002; Maddison 2007; Gebrehiwot and van der Veen 2013).

Smithers and Smit (1997) argue that farmer adaptation responses depend on the degree and nature of the perceived climate stress, the scale and magnitude of particular climate shocks, and the properties of the agricultural system as a whole. Smit and Skinner (2002) observe that most adaptations are modifications to on-going farm practices rather than major changes, but Sutherland et al. (2012) note that 'trigger events' such as climate shocks or land availability can lead to major changes, such as discontinuing production of specific commodities or diversifying away from farm activities.

Maddison (2007) states that climate change adaptation involves a two-stage process, as farmers must first perceive that climate change has occurred, and then must decide whether to adopt a particular measure in response. Several studies find that farmers' adaptation decisions are primarily informed by their own perceptions of climate change and risks rather than by external information provision, and that farmers' perceptions do not always align with historical climatic data or with climate forecasts (Smithers and Smit 1997; Smit and Skinner 2002; Bryan et al. 2009; Moyo et al. 2012). Some studies argue for making climate information more accurate, accessible, and useful for farmers, pointing to the potential for extension services to influence farmers' climate adaptation decisions (Bryan et al. 2009; Maddison 2007; Mase and Prokopy 2014)

Not all farmers that perceive climate change decide to adapt their farm practices in response (Maddison 2007; Bryan et al. 2009). Several factors are found to influence farmers' adaptation decisions, including education, farming experience, social norms, extension services, proximity to markets, wealth and socioeconomic position, and access to land, credit, and climate information (Maddison 2007; Bryan et al. 2009; Tambo and Abdoulaye 2012; Gebrehiwot and van der Veen 2013; Mase and Prokopy 2014). While some studies find that access to technology is not a barrier to adaptation (Bryan et al. 2009; Maddison 2007), this may not be true in all contexts. A 2012 study of adoption of drought tolerant maize in rural Nigeria finds that the key determinants of adoption by farm households were access to the technology, complementary inputs, extension services, and climate change information (Tambo and Abdoulaye 2012). Barriers to adoption included household wealth and the cost of the technology and complementary inputs.

Another factor affecting climate change adaptation decisions is farmers' risk perceptions (Byerlee and Anderson 1982; Burton 1997; Hansen et al. 2004). A 2012 study of farmers in Zimbabwe finds that non-climatic factors influence farmers' perceptions of climate variability, and point to the fact that the majority of respondents 'were highly risk-averse, perceiving that most of seasons in any ten given years could be poor' (Moyo et al. 2012, p. 1). They suggest that this risk aversion means that farmers are less likely to modify practices to take advantage of good seasons. This finding is supported by a 2014 review of 47 articles on farmers' use and perceptions of weather and climate information in the United States, Australia, and Canada which reports that farmers may employ strategies to ensure some yield during most years and under most conditions rather than adjusting practices seasonally to maximize short-term gain (Mase and Prokopy 2014).

This study adds to the evidence base on farmers' climate change adaptation decisions using panel data from farmers in Chiapas, Mexico. We evaluate whether changes in farmers' selection of seed traits are aligned with climate forecast models, and assess the associations between adaptation decisions and farmer characteristics and perceptions of climate variations. We find that farmers in different villages made statistically significant changes in their ratings of seed tolerance or resistance to four environmental stressors, mostly notably tolerance for drought and excess rain. These changes in seed trait ratings are generally aligned with climate change predictions, though the degree of alignment varies by village and climate change model. Our results suggest that farmers' selection of seed agronomic characteristics, whether knowingly or not, accounts for long-term climatic fluctuations due to climate change, and thus provide some evidence that farmers exhibit smart decision-making given bounded rationality. Further, we find that baseline attitudes towards different stressors and farmers' education may also play a role in selection of seed traits.

2 BACKGROUND

Maize is one of the most important crops grown globally and is, by far, the most important crop cultivated in Mexico (Bellon et al. 2011; Mercer et al. 2012; Ureta et al. 2012). From 2000 through 2012, Mexico produced on average 20.8 million tons of maize, making the nation one of the top producers globally (FAO 2014). Moreover, roughly 3 million Mexican smallholders grow maize, mainly for subsistence (Borja-Vega and de la Fuente 2013). The global and national significance of maize, like rice, wheat, and other crops, raises important questions about how farmers are responding, or can respond, to climate change. For smallholders, one potential adaptation is via seed selection, both through selecting and saving seed that performs well, and through purchasing seed with improved traits tailored to local climate conditions. Yet despite the importance of maize and the threat of climate change, the global community has gained only a marginal understanding in the past decade as to whether small-scale maize farmers are adapting to climate change via seed selection.

The maize crop in Mexico is heavily dependent on climatic conditions (Conde et al. 1997) and significant bodies of literature have, for some time, suggested that the maize crop in Mexico will be susceptible to the effects of climate change (for example, Conde et al. 1997; Bellon et al. 2011). Nationally, nearly 80 percent of the country's crop is rain fed and most rain-fed land tends to be farmed by small-scale farmers (Fernández et al. 2012). Therefore, uncertain precipitation (and other factors, such as temperature and wind) constitute a main risk factor for these farmers and their planning environments (Bellon et al. 2011).

Smallholder maize farmers in Mexico also operate in tightly woven seed selection systems, where the farmer saves seed from the previous harvest and/or sources it from other local farmers, such as family or friends (Bellon et al. 2006, 2011). Smallholder farmers may also have access to improved varieties (such as hybrids) from outside these tightly woven systems as another way to adapt to real or perceived changes in climate. Though these improved varieties will not contain the environmentally adapted traits of native landraces, they may have been engineered to withstand local environmental stresses. A farmer's seed choice therefore depends on access and availability options, and perceived trade-offs between yield, resilience, and other desired seed and crop traits.

Several studies have addressed what forces drive maize seed selection and perception (Bellon and Brush 1994; Bellon et al. 2006; Bellon and Hellin 2011; Anderson et al. 2012). Bellon and Brush's seminal 1994 paper highlights how farmers maintain maize varieties through seed selection. They find that despite widespread adoption of more modern, higher-yielding varieties of seed, maize farmers in Chiapas, Mexico, continue to 'select maize varieties for specific soils and because of agronomic and use criteria' (Bellon and

Brush 1994, p. 196). Bellon and Hellin (2011) find that agricultural programs foster hybrid seed adoption, while cultural preferences drive landrace retention for commercially oriented small-scale farmers in the La Frailesca region of Chiapas, Mexico. Bellon et al. (2006) find that small-scale, subsistence-oriented farmers in Oaxaco and Chiapas, Mexico, have differing perceptions of the benefits of landraces versus hybrids, despite both groupings of farmers regularly planting creolized local varieties. Lastly, findings from Anderson et al. (2012) suggest that farmers' choices are related to feelings of control over risky outcomes. Farmers perceive hybrids as being able to protect against certain environmental stressors, and feel similarly for local seed varieties, or 'creoles' (Anderson et al, 2012). For example, for both creoles and hybrid seed technologies there is a statistically significant difference in the willingness to pay if the crop loss is owing to drought or pests. However, there is no difference in the willingness to pay if the crop loss is owing to wind lodging (Anderson et al. 2012).

Numerous studies have demonstrated the ability of maize to physiologically adapt to climate change (Pressoir and Berthaud 2004a, 2004b; Corral and Puga et al. 2008; Bellon et al. 2011; Ureta et al. 2012). Corral and Puga et al. (2008) suggest that some maize races have 'evolved adaptability' to certain changed environments (high rainfall, low rainfall, and hot and cold), while Ureta et al. (2012) suggest that some maize taxa may be suitable in future climate scenarios. Pressoir and Berthaud (2004a, 2004b) show that Mexican maize landraces contain high levels of genetic diversity and 'may evolve in response to altered conditions' (Mercer and Perales 2010). Less is known about whether farmers themselves are selecting seed in a manner consistent with climate adaptation, resulting in seed that will perform better under altered environments. Bellon et al., in their 2011 paper, note that 'small-scale maize farmers' adoption of . . . improved germplasm has been minimal to date' (Bellon et al. 2011, pp. 13434–5) in their Mexico study area and that, combined with tightly woven seed selection systems and a 'relatively low influx of outside seed', there is a 'strong selection' (Bellon et al. 2011, p. 13435) for local adaption. Moreover, contrary to their initial hypothesis, the authors note that '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' (Bellon et al. 2011, p. 13435). However, these studies, and others like them, do not test for specifically for seed adaption.

A 2011 study examining the agro-system of pearl millet in Niger, however, yields interesting results about farmers' selection of crop varieties associated with climate variations in the Sahel region of Africa (Vigouroux and Mariac 2011). This study finds a significant shift toward earlier flowering traits in a sample of pearl millet collected in 2003 relative to a sample collected in 1976. These adaptive traits are coincident with a reoccurring series of droughts that started abruptly in the early 1970s. Beyond this study, however, there is little empirical evidence to inform the debate over whether smallholders are adapting to climate change via seed selection.

Our work contributes to the small base of evidence on smallholder seed selection and its relevance to climate change, using data from a survey of 120 farmers in four villages in Chiapas, Mexico between 2005 and 2007. Assuming that a farmer's maize seed is not physiologically adapting over the two years of the survey study and that therefore changes in seed traits may be owing to selection of (purchased or saved) seed, we use the survey data to explore several research questions. First, we ask whether farmers change their rating of agronomic traits of the seeds they plant over a time period of two years between 2005 and 2007. We then compare the changes in seed trait ratings from our household survey to climate models to ascertain if changes in seed selection are aligned with predicted climate change. That is, despite the enormous uncertainties in the direction of climate change, we evaluate whether local farmers are 'getting it right' in their selection of seed with traits that are aligned with climate change models. Finally, though we do not have direct evidence that changing seed traits are a climate adaptation strategy, we note that local adaptation is often examined in terms of demographic and socio-economic constraints. To this discussion we add 'psychological' considerations, and in particular look at whether factors associated with changes in seeds' agronomic characteristics are associated with farmers' risk perceptions or sense of control.

3 METHODS AND DATA

The study of farmers in Chiapas was part of a joint project of the Food and Agriculture Organization (FAO) and the International Maize and Wheat Improvement Center (CIMMYT) on seed systems, farmer access to crop genetic resources, and farm diversity. The project included a household panel survey of 120 maize producers (30 from each of four villages) who source seed from companies and producer groups in the region. The first round of data was collected from small-scale farmers in 2005. The follow-up survey was administered in April 2007. The Frailesca region of Chiapas (see Figure 14.1) was selected because small-scale farmers in the region depend on both formal and informal seed sources and use hybrids and landraces ('creoles') to produce for the market and their own consumption, and nearly all operate rain-fed systems. Additionally, the region is experiencing increasing episodes of extreme heat and extreme cold (SMN 2014).

Enumerators collected data on traditional socio-economic and farm household production and labor measures (Table 14.1). The survey also asks respondents about their attitudes towards risk and their willingness to pay for improved varieties that reduce the frequency and amount of maize crop yield loss from particular stressors, including wind lodging, pests, and drought. The survey also provides data on farmers' sense of control

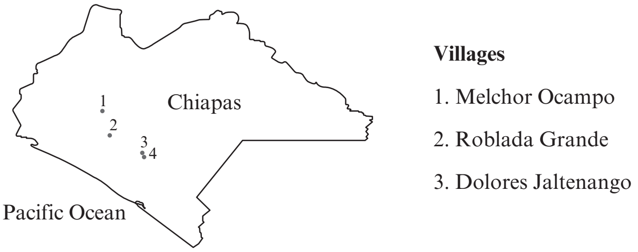

Figure 14.1 Map of the study communities included in La Frailesca region of Chiapas, Mexico

Table 14.1 Sample descriptive statistics (2005)

Variable	Overall	Dolores Jaltenango	Melchor Ocampo	Queretaro	Roblada Grande
Age	49.83	53.03	54.8	47.20	44.27
	(15.13)	(14.96)	(13.42)	(14.41)	(15.90)
Proportion with knowledge of	0.80	0.67	0.90	0.83	0.80
reading and writing	(0.40)	(0.48)	(0.31)	(0.38)	(0.41)
Years of education	3.90	3.39	4.79	3.59	3.79
	(2.91)	(2.89)	(3.22)	(2.58)	(2.86)
Proportion from the	0.82	0.87	0.90	0.93	0.60
community non-immigrants)	(0.38)	(0.35)	(0.31)	(0.26)	(0.50)
Household size	4.81	5.10	3.90	4.87	5.37
	(2.16)	(2.01)	(1.56)	(1.99)	(2.74)
Number of parcels seeded	2.26	2.13	2.13	1.83	2.93
with maize	(1.13)	(0.86)	(0.90)	(0.91)	(1.48)
Total area of parcels	5.15	3.04	4.86	2.96	9.75
(hectares)	(4.63)	(1.58)	(3.03)	(1.76)	(6.46)
Average area of parcels	2.35	1.50	2.30	1.76	3.84
(hectares)	(2.11)	(0.83)	(1.14)	(1.18)	(3.38)
Average land quality of parcels[a]	2.76	2.65	2.80	2.88	2.69
	(0.74)	(0.82)	(0.95)	(0.59)	(0.51)
Proportion of parcels that were	0.56	0.17	0.44	0.68	0.98
intercropped	(0.46)	(0.32)	(0.46)	(0.40)	(0.12)

Notes:
Standard deviations in parentheses.
[a] 0 = very poor, 1 = poor, 2 = regular, 3 = good, 4 = very good.

over losses from these stressors and how much crop they have lost in the past from each stressor.

The household survey asks farmers to rate the agronomic characteristics of the varieties of seeds planted according to whether they are wind-tolerant, drought-tolerant, rot-resistant, and excess rain-tolerant. Respondent choices included ‘very good’, ‘good’, ‘poor’, ‘very poor’, and ‘don’t know/no opinion.’ The study asked for farmers’ rating across multiple plots in their respective farms. We test for differences in seed trait ratings on farmers’ primary plots between 2005 and 2007 across the full sample of 120 maize producers and then broken out by village.

Our second research question is whether any changes in assessed seed traits align with historical and predicted climate variations in the region. To address this, we rely on publicly available weather and climate data for Chiapas, which provides us access to comprehensive historical baseline weather data, as well as climate change scenarios modeling future precipitation and temperatures. We were able to collect historical baseline weather data from a selection of small-scale farms in the Frailesca region, along with precipitation and temperature estimates for the location of farms under two different climate change scenarios.

Weather data to generate baseline averages on the Frailesca region of Chiapas and the four villages comes from two sources – the Digital Climate Atlas of México, developed by the Universidad Nacional Autónoma de México Centro de Ciencias de la Atmósfera, and the National Meteorological Service of Mexico. With the exact latitude and longitude of the four villages, we use Google Earth interfaces developed jointly by both sources to pinpoint the nearest operating weather station.[1] We selected a reasonable time series (many weather stations provide averages dating back to 1960, while the atlas provides averages from as far back as 1903) of actual and average precipitation and temperature, as these two indicators are most often associated with climate change scenario models. The two different sources of baseline data are represented in the results section as two black lines on the bar charts. Since the sources of data have different averages for the same village locations, we chose to use both to capture the variation across both precipitation and temperature.[2]

We reviewed several sources to select among climate change models. Conde et al. (2011) provide a particularly helpful overview of regional climate change scenarios for Mexico and report that the climate change scenarios for Mexico used in the Forth Communication were generated using data from the ECHAM5, HADGEM1, and GFDL CM2.0 models. Bellon and Hellin (2011) use the Hadley Centre Coupled Model Version 3 (HADCM3)[3] model in their paper, as do Jones and Thornton in their 2003 paper examining the potential impacts of climate change on maize production in Latin America and Africa. As our survey data is from Mexico, we follow Conde et al. (2011) and use the HADGEM1 and GFDL CM3.0 models available via Digital Climate Atlas of México (CM3.0 is the improved atmospheric model of 2.0).

Both models provide precipitation and temperature estimates for some future segment of years. The HADGEM1 model provides estimates of precipitation and temperature for both 2030 and 2050. We chose 2050 as the future scenario year, following Bellon and Hellin (2011). Additionally, in order to capture the uncertainty of global emission scenarios, we use data from the A2 and B2 scenarios for the HADGEM1 model. The A family of scenarios represent a future world with a greater emphasis on economic development. The B family considers a future world where there is a greater emphasis on sustainable development. In both the A2 and B2 scenarios, economic growth is sought through regional development as opposed to globalization, which is the driver of economic growth in the A1 and B1 families. The GFDL CM3.0 model captures a range of years. We use the model estimating precipitation and temperature for 2015–39. The GFDL CM3.0 model is referenced throughout the paper and in the summary analyses, but for the sake of brevity, graphic analyses for the GFDL CM3.0 model for both temperature and precipitation are located in Appendix 14.1 at the end of this chapter. The HADGEM1 model appears throughout the main body of text.

For each climate model, we consider temperature and precipitation predictions for specific months of the summer maize growing cycle in Chiapas for our analysis. Though most of Chiapas does have a long unimodal rainfall season during the spring and summer months (May through to November), there can be major variation in rainfall amounts that are often exacerbated due to topography, soil type, etc. (FAO 2006; Waddington 2014). Generally, for the main spring–summer rain-fed maize growing season, dry spells may be a problem for planting and establishment during the early months (May–June). In the later months (July–September), excess moisture and even local waterlogging during crop growth to tasseling is possible, increasing the likelihood of some water stress during silking, into the early grain fill months (September–October), though this is noted to be less of a concern relative to many other maize environments in México (Waddington 2014). As July marks the beginning of the growth cycle – a vulnerable time for plants, we use this month for both models. We also look at climate predictions for April rather than May, the more common beginning of planting, owing to the limits of the GFDL CM3.0 model in the Digital Climate Atlas interface.

In our analysis, we present historical baseline data layered on top of the expected precipitation and temperature levels to determine the differences farmers in each village can expect. We then evaluate whether differences in farmers' selection of seed traits align with predicted climate changes, focusing on drought and excess rain tolerance, as these potentially relate to changes in temperature and precipitation more than wind tolerance or rot resistance.

Finally, we evaluate whether risk attitudes are associated with changes in seed trait selection, looking at the absolute magnitude of changes in seed trait ratings for drought tolerance across all farmer plots. We use absolute values as farmers may be changing their selections of seed traits in response to different assumptions about which traits will be most useful. We conduct ANOVA and OLS analyses to evaluate the association between changes in selection of seed and several variables which may be expected to motivate seed selection. We consider farmers' attitudes, including willingness to take risks, measured on a scale from 1 to 5 with 1 indicating less willingness and 5 indicating more willingness, as farmers more willing to take risks may be more willing to change their seed selection. We also look at farmers' reports of how important these seed traits are in their decision to plant a variety of maize, and consider several variables relating to farmers' perception of and losses from drought, as these may also be expected to influence farmers' seed selection.[4] In addition, we include farmers' number of plots seeded with maize, age, knowledge of reading and writing, and village.

4 RESULTS

Research Question 1: Farmer Seed Trait Rating Changes

Results of paired *t*-tests for the full sample (all villages) suggest that there is no statistically significant change (though they are rated less highly) in the farmer ratings of wind tolerance, rot resistance, or excess rain tolerance for the seeds that they planted on their primary plot, but that drought tolerance is rated significantly more highly in 2007 than in 2005 (Table 14.2).

Results of the paired *t*-tests by village, however, indicate a high level of variation across traits and villages when comparing the supply of traits used in 2005 and 2007 (Table 14.3). For wind tolerance ratings, two villages show decreased ratings while two show increased ratings, but the only statistically significant change is the decrease for farmers in Dolores Jaltenango. Seed traits are rated on a scale from 1 (very poor) to 4 (very good), and farmers in this village decreased their rating for wind tolerance by a mean of 0.3793. For drought tolerance, results indicate increased ratings for seeds planted in all four villages, though the difference is only significant for farmers in Melchor Ocampo. We find mixed changes in the ratings for rot resistance and excess rain tolerance, with decreases

Table 14.2 Differences in farmers' in ratings of seed traits on primary plots, 2005–07 (full sample)

Trait	Mean	Standard deviation	*Pr*(|*T*| > |*t*|)
Wind tolerant	−0.0550	0.9412	0.5427
Drought tolerant***	0.1980	0.7214	0.0069
Rot resistant	−0.0275	0.8971	0.7494
Excess rain tolerant	−0.0816	0.9380	0.3911

Note: *** Significant at the .01 level.

Table 14.3 Differences in farmers' ratings of seed traits on primary plots, 2005–07 (by village)

Trait	Village	Mean	Standard deviation	*Pr*(|*T*| > |*t*|)
Wind tolerant	Dolores Jaltenango**	−0.3793	0.9029	0.0316
	Melchor Ocampo	−0.0400	0.8888	0.8237
	Roblada Grande	0.0370	0.8077	0.8135
	Querétaro	0.1786	1.0905	0.3938
Drought tolerant	Dolores Jaltenango	0.1538	0.7317	0.2939
	Melchor Ocampo**	0.3103	0.7608	0.0365
	Roblada Grande	0.1538	0.7317	0.2939
	Querétaro	0.1500	0.6708	0.3299
Does not rot	Dolores Jaltenango	0.0357	0.9615	0.8457
	Melchor Ocampo	−0.2500	0.7993	0.1095
	Roblada Grande***	−0.3462	0.6288	0.0096
	Querétaro**	0.4444	0.9740	0.0254
Excess rain tolerant	Dolores Jaltenango	0.1200	0.8813	0.5025
	Melchor Ocampo*	−0.3200	0.9000	0.0881
	Roblada Grande***	−0.5600	0.5831	0.0001
	Querétaro**	0.4783	1.0388	0.0380

Note: *** Significant at the .01 level; ** significant at the .05 level; * significant at the .10 level.

in Melchor Ocampo and Roblada Grande but increases in Dolores Jaltenango and Queretaro. These differences may be related to geographical differences between the villages, as Dolores Jaltenango and Queretaro are located in close proximity to one another (Figure 14.1). The decreased ratings in Melchor Ocampo are significant at the .10 level, while those in Roblada Grande are significant at the .01 level. The increased ratings for rot resistance and excess rain tolerance are relatively small in Dolores Jaltenango and are not significant, but are significant at the .05 level in Queretaro and indicate increases in the ratings for rot resistance and excess rain tolerance of nearly 0.5 on the scale from 1 to 4.

We also consider whether changes in farmers' ratings for particular seed traits on their main plots may differ from average ratings across all their plots, as farmers may be more willing to vary their selection of seed traits if they have more plots to experiment with. The changes in average seed trait ratings across all plots are generally similar to those presented for changes in seed traits on primary plots in Tables 14.2 and 14.3, with a couple of notable exceptions. The average change in ratings for excess rain tolerance across all plots for the full sample is significant at the .05 level, but the change was not significant when considering only farmers' primary plots. The other main difference is that the direction of the changes in trait ratings for rot resistance and excess rain tolerance in Dolores Jaltenango switches, putting their average changes in ratings in line with those of Melchor Ocampo and Roblada Grande rather than the changes in Queretaro, its neighboring village.

Research Question 2: Alignment of Seed Rating Changes with Climate Models

Our findings indicate that farmers in different villages are responding to different factors in their decisions of which seed traits to favor for planting maize. One potential driver of seed selection is adaptation to climate changes. Because of limitations on including environmental stressors in the climate change scenario modeling, we examine only whether farmers' seed trait changes align with climate change for two of the four traits – tolerance of excess rain and drought. However, the results from Table 14.3 imply linkages between trait characteristics. For example, the results from villages that had a statistically significant change in rating for excess rain tolerance mirror the ratings for seed that does not rot. It is logical that farmers, expecting more rain, would want seed that tolerates both excess rain and does not rot.

Review of the future climate data for both the HADGEM1 and GFDL CM3 models (and both scenarios A2 and B2 in the HADGEM1) suggests that average temperatures across almost all villages will likely increase in both April and July relative to the historical baselines, sometimes drastically so. For example, Melchor Ocampo is forecasted to experience nearly a 3-degree increase by April of 2050 in A scenario. The noteworthy exception is Queretaro in April, forecast to experience a temperature increase with the HADGEM1 model (Figure 14.2) but a decrease with the GFDL CM3 model (shown in Appendix 14.1).

Figure 14.2 shows expected village temperatures in April and July of 2050 under the two HADGEM1 scenarios,[5] with baseline averages from two sources (Digital Climate Atlas of México and National Meteorological Service of Mexico Weather Stations) indicated with black lines.[6] For example, the model indicates that we can expect a roughly 2.5 degree increase in temperature in April 2050 for Melchor Ocampo relative to the lower baseline average under continued economic development (A scenario). Under a more sustainable growth model (B scenario), we can expect a roughly 2-degree increase in temperature relative to the upper baseline average.

Model

While all villages may expect increases in average temperature, the models indicate significant variation across villages with respect to precipitation.[7] Models, scenarios, and months suggest that the villages of Queretaro and Dolores Jaltenango can expect to see consistently higher levels of precipitation in the future. The villages of Melchor Ocampo and Roblada Grande, however, have less certain precipitation futures. The GFDL CM3

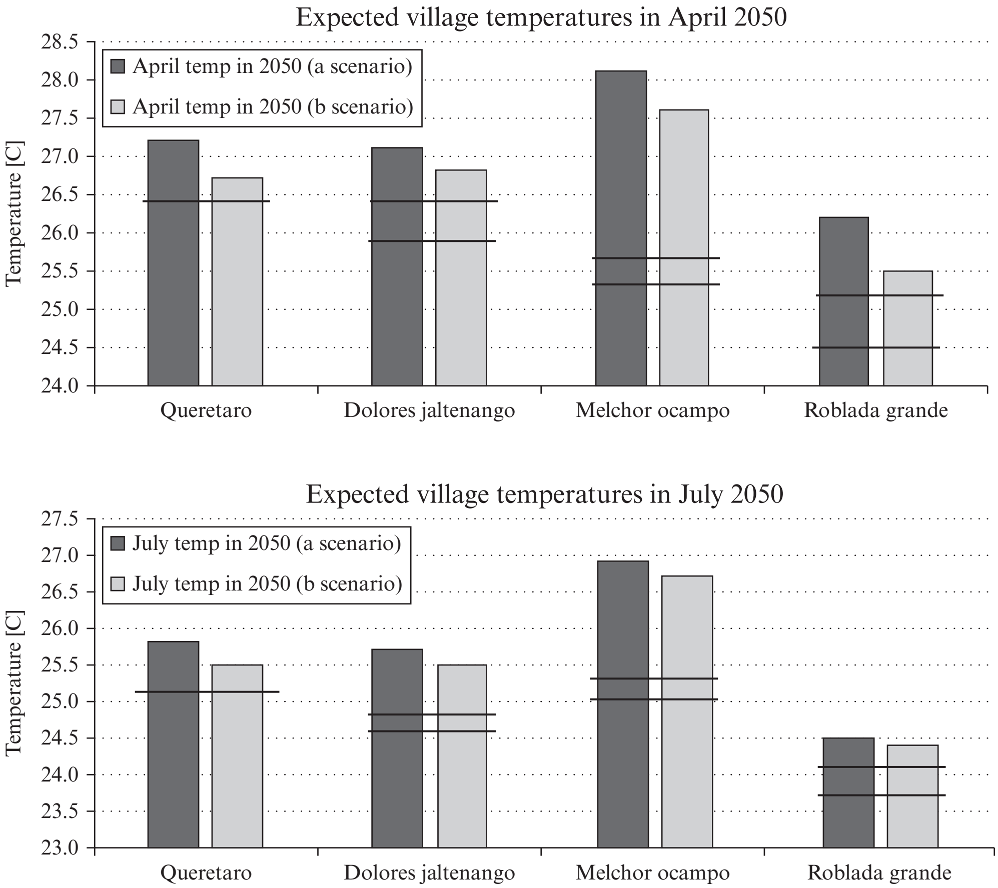

Figure 14.2 Expected village temperatures in 2050 under HADGEM1

model (shown in Appendix 14.1) forecasts decreased future precipitation for both months relative to historical baseline averages in Melchor Ocampo. For Roblada Grande, the model shows decreased future precipitation for April, but slightly elevated future precipitation in July. The HADGEM1 models (Figure 14.3) forecast slightly elevated precipitation levels for Melchor Ocampo in April and slightly decreased levels in July, when compared to historical baseline averages. Roblada Grande's precipitation is forecast to be slightly higher compared to historical baseline averages for both months. Also worth noting with the HADGEM1 model is that for all villages except for Roblada Grande, April is predicted to be wetter, while July is expected to be drier for Melchor Ocampo and there is no expected difference in precipitation in the other villages if we compare the model with the higher baseline average.

Table 14.4 summarizes forecast changes in temperature and precipitation by village. We find that three of the 16 cases do not align across models (as indicated by grey arrow in either direction). We do not find any consistent instances of monthly variation. For

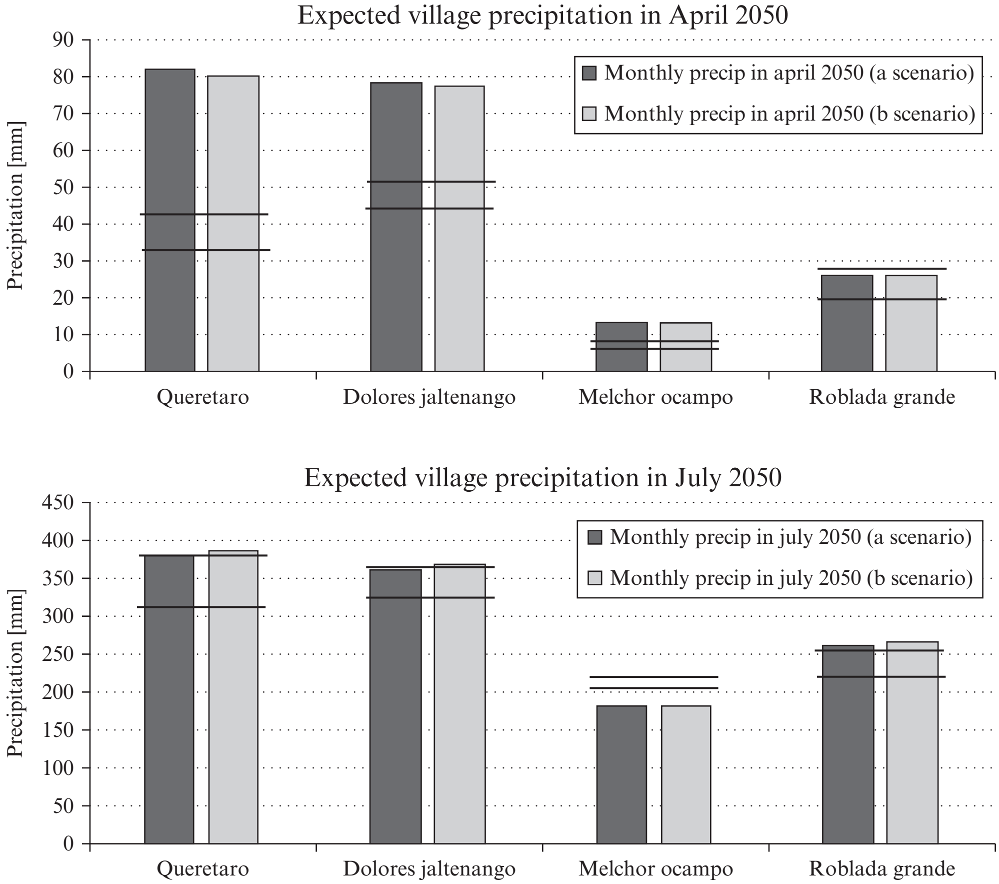

Figure 14.3 Expected village precipitation in 2050 under HADGEM1 scenario

example, under the GFDL CM3 model, Queretaro can expect a decrease in temperatures in April and an increase in July, but the HADGEM1 model indicates that temperatures in Queretaro will be higher in both months.

The GFDL CM3 model suggests that farmers in Melchor Ocampo and Queretaro are reporting changes in traits of planted seed that are aligned with climate change predictions. Farmers in Melchor Ocampo report a statistically significant increase for their rating for drought tolerance, which aligns with predictions of decreased precipitation for both months. Melchor Ocampo farmers' seed traits for rotting and excess rain tolerance are also in alignment, as their ratings for both rotting and excess rain decreased.[8] Farmers in Queretaro report significant increases in ratings for both excess rain and rotting tolerance, which aligns with forecast increases in precipitation for both months. Results for the GFDL CM3 climate change model for Roblada Grande are mixed. Farmers in Roblada Grande report decreases in ratings for excess rain tolerance and rot resistance, consistent with predictions of decreased precipitation for April but not with predicted increases for July. Farmers in Dolores Jaltenango did not significantly change their ratings of seed

Table 14.4 Summary of forecasted changes in temperature and precipitation by village

Under GFDL CM3 model				
Village	Temperature		Precipitation	
	April	July	April	July
Dolores Jaltenango	↑	↑	↑	↑
Melchor Ocampo	↑	↑	↓	↑
Roblada Grande	↑	↑	↓	↑
Queretaro	↓	↑	↑	↑
Under HADGEM1 model				
Village	Temperature		Precipitation	
	April	July	April	July
Dolores Jaltenango	↑	↑	↑	↑
Melchor Ocampo	↑	↑	↑	↑
Roblada Grande	↑	↑	↑	↑
Queretaro	↓	↑	↑	↑

Notes:
↑ denotes predicted increase in either temperature and/or precipitation compared to historical baseline averages.
↓ denotes predicted decrease in either temperature and/or precipitation compared to historical baseline averages.
Grey arrow indicates misalignment across climate models.
There are no significant differences between the A2 and B2 scenarios in the HADGEM 1 model, so those models are not disaggregated

traits relevant to temperature or precipitation, so we cannot evaluate whether changes align with climate change predictions.

The results with the HADGEM1 model are less straightforward. Increased rating in seed traits for drought tolerance and decreased ratings for excess rain and rot tolerance in Melchor Ocampo are inconsistent with April forecasts, as the model suggests slightly increased precipitation. The July model, however, suggests slightly decreased rainfall, consistent with the changes in ratings. Roblada Grande farmers' decreased ratings for excess rain and rot tolerance put them out of alignment for both stressors in both months, as precipitation is expected to increase. Ratings changes for farmers in Queretaro align with the HADGEM1 model in the same way as the GFDL CM3 model.

Table 14.5 summarizes which villages' farmers report a statistically significant change in their ratings for traits, and whether these changes are aligned with climate change predictions.[9]

The future climate data for both models suggest that average temperatures across almost all villages will likely increase in both April and July relative to the historical baselines, sometimes drastically so (the exception being Queretaro in April under the GFDL CM3 model). Higher temperatures increase evaporation and exacerbate water constraints. Because the majority of the maize in the farms surveyed are rain fed, it is logical to conclude that the maize is vulnerable to both temperature and precipitation stressors.

Table 14.5 Summary of farmers' rating of seed trait changes and alignment to model predictions of climate changes

Under GFDL CM3 model						
Village	Drought tolerant		Excess rain tolerant		Rot resistant	
Melchor Ocampo	April ✓	July ✓	April ✓	July ✓	April ✓	July ✓
Roblada Grande	N/A	N/A	April ✓	July ✗	April ✓	July ✗
Querétaro	N/A	N/A	April ✓	July ✓	April ✓	July ✓
Under HADGEM1 model						
Village	Drought tolerant		Excess rain tolerant		Rot resistant	
Melchor Ocampo	April ✗	July ✓	April ✗	July ✓	April ✗	July ✓
Roblada Grande	N/A	N/A	April ✗	July ✗	April ✗	July ✗
Querétaro	N/A	N/A	April ✓	July ✓	April ✓	July ✓

Notes:
✓ denotes farmers' rating of seeds are aligned with climate change predictions.
✗ denotes farmers' rating of seeds are not aligned with climate change predictions.
'N/A' indicates that there are no significant differences in farmers' ratings of the particular seed trait. None of the difference in ratings for Dolores Jaltenango are significant.
There are no significant differences between the A2 and B scenarios in the HADGEM 1 model, so those models are not disaggregated.

Moreover, plant-level productivity impacts are not only the result of single climate factors, but also of the interactions between those factors. Temperature, precipitation, CO_2 levels, radiation, and changes in weed or pest populations can all work singularly or in tandem to affect the environment and physiological state of the maize plant (Stokes-Prindle et al. 2010), and subsequently affect yields. As Lobell and Burke (2008, p. 1) note, 'understanding crop responses to temperature and the magnitude of regional temperature changes are two of the most important needs for climate change impact assessments and adaptation efforts for agriculture.' The overall increase in farmers' ratings for drought tolerance of their seed may therefore be motivated in part by expectations of climate change.

Research Question 3: Motivations for Changes in Traits of Farmers' Planted Seed

Our results suggest that seed traits are changing, and evolving in a manner that is largely consistent with climate predictions, depending on the climate model chosen. Farmers are no less able to predict the future with certainty than climate modelers, so it is not clear what is causing the changes in farmers' ratings of agronomic traits, and whether these seed trait changes are deliberate adaptations to climate change under Simon's concept of bounded rationality. We cannot test this directly, but we can exploit some additional survey data to evaluate other potential drivers of changes in seed ratings. In particular, we can analyze data on farmers' attitudes towards risk and different stressors to surmise whether the trait changes are related to farmer attitudes. Since farmers within these villages are experiencing similar climate and have similar access to seed, differences among households are potentially related to individual attitudes factoring into seed selection.

The degree to which farmers can be expected to take action to mitigate the effect of environmental stressors can be expected to vary with how they perceive future risks and the control they feel over the outcome. In turn, risk perceptions have been found to depend on base risk attitudes, and among other qualitative dimensions, our experience or familiarity with the risky outcome and whether it is perceived as catastrophic or not (Bubeck et al. 2012; Lujala et al. 2014). The 2005 household survey asked respondents to rate their perception of the relationship between taking risks and being successful on a scale from 1 ('one must be extremely careful when considering changes in life') to 5 ('it will not benefit one at all in life if one is not adventurous and takes great risk'), with a mean of 3.04. The survey also asked farmers to rate the importance of drought-tolerance in selecting seed, their perception of whether drought is a chronic or catastrophic stressor, their perceived control over losses from drought, their yield losses from drought over the past five years, and their willingness to pay to reduce the likelihood of catastrophic losses from drought.

We know that farmers indicate seed traits are changing. We do not know if this is because of their own seed selection decisions or some other reason (for example, a change in the available supply of seed), though we do know that farmers select and save seed in this region. Of interest, therefore, is whether there is any relationship between the variation among farmers reporting a change in agronomic rating and their baseline attitudes toward risk and perceptions of particular stressors.

As drought tolerance is the only agronomic trait that significantly changes across the overall sample and where all villages report increasing their use of seeds with that trait, we constrain our evaluation of drivers of seed trait changes to this trait. Drought is also reported to be responsible for the largest yield losses (Table 14.6). According to the North American Drought Monitor, from September through to December of 2004, parts of Chiapas, including at least two of the villages examined in this survey, experienced conditions ranging from abnormally dry to moderate drought levels (USNOAA 2004). Despite these conditions, actual precipitation levels in 2004 varied widely across villages. Year-to-year variation of loss due to other stressors (lodging and plague) is lower for 2000–2003 and therefore, aligns with the more chronic rating of these stressors.

Table 14.6 Mean yield loss (farmer reported) from environmental stressors across all years (kg)

Year	Loss due to drought	Loss due to lodging	Loss due to plague
2000	211.26 (722.40)	185.70 (595.31) 188.40	113.83 (372.19)
2001	140.97 (458.78)	132.65 (484.52) 131.75	160.13 (471.62)
2002	207.50 (642.19)	213.53 (608.23) 212.40	240.20 (620.69)
2003	1166.57 (437.11)	108.45 (399.58) 107.78	202.24 (531.19)
2004	769.36 (985.04)	75.03 (245.09) 75.75	187.33 (578.77)
Average	291.38 (297.48)	180.75 (323.93)	144.39 (297.18)

Table 14.7 Results of one-way ANOVA for absolute changes in ratings of seed drought-tolerance on primary plot and potential drivers of seed selection

Variable	SS	df	MS	F	Prob > F
Willingness to take risks	0.5061	3	0.1687	0.56	0.6396
Importance of drought-tolerant seed trait[a] **	2.4023	2	1.2012	4.39	0.0150
Perceived importance of drought stressor[b] *	0.9281	1	0.9281	3.24	0.0750
Average yield loss from drought over last 5 years	0.8156	4	0.2039	0.69	0.6014
Perceived control over losses from drought[c] ***	2.0202	1	2.0202	7.35	0.0079
WTP to reduce likelihood of catastrophic losses from drought	0.0124	3	0.0041	0.01	0.9978
Any WTP to reduce likelihood of catastrophic losses from drought[d]	0.0058	1	0.0058	0.02	0.8891

Notes:

[a] 1 = not important in selection of seed, 2 = important, 3 = very important.

[b] 0 = chronic stressor, 1 = catastrophic stressor.

[c] 0 = none, 1 = little, 2 = much.

[d] 0 = no WTP, 1 = WTP is greater than 0

*** Significant at the .01 level; ** significant at the .05 level; * significant at the .10 level.

As some farmers reduced their ratings of seeds' drought tolerance trait while others increased their ratings, we take the absolute value of ratings changes for drought tolerance to test for whether different factors are associated with any change in seed trait ratings. For comparison, Appendix 14.2 includes tables with our evaluations of drivers of seed trait changes for excess rain tolerance, as several villages had significant changes in their use of seeds with this trait.

To test whether the correlations are significant, we first conducted one-way analyses of variance (ANOVA) for the absolute change in ratings of seeds' drought tolerance and baseline measures of farmer attitudes (Table 14.7). The only non-categorical independent variables – average yield loss and willingness to pay (WTP) – were divided into quintiles using the egen command in Stata.

The results of the ANOVA tests (Table 14.7) indicate that there is not a statistically significant relationship between changes in farmers' selection of seed toward drought-resistant seed and baseline willingness to take risks, average yield loss from drought, or willingness to pay to reduce the likelihood of catastrophic losses from drought. Perceived control over losses from drought, however, is significant at the .01 level, and farmers' stated importance of drought-tolerance in seed selection and perceptions of drought as a catastrophic stressor are also significantly associated with changes toward from drought-tolerant seed, at the .05 and .10 level, respectively.

To further test these associations, we conducted simple ordinary least squares (OLS) regressions of the absolute change in ratings of seed drought-tolerance on farmers' primary plots against potential drivers of seed change, retaining baseline measures of willingness to take risks and the three variables that appear to have significant associations with changes in seed traits (Table 14.8). We also include some control variables that may be expected to influence seed selection, including age, literacy, and number of plots planted with maize. We hypothesize that farmers with a greater number of plots would be

Table 14.8 Results of OLS regression for absolute change in mean rating of seed drought-tolerance on primary plot

Variable	Coeff. (std. err.)	$P > \|t\|$
Willingness to take risks	−0.0263	0.667
	(0.0608)	
Importance of drought-tolerant seed trait[a]	0.2196	0.096*
	(0.1302)	
Perceived importance of drought stressor[b]	0.1662	0.341
	(0.1736)	
Perceived control over losses from drought[c]	0.7486	0.024**
	(0.3245)	
Age	−0.0045	0.276
	(0.0041)	
Knowledge of reading and writing	−0.2844	0.058*
	(0.1478)	
Number of plots planted with maize	0.0038	0.944
	(0.0538)	
Melchor Ocampo	0.1489	0.373
	(0.1663)	
Roblada Grande	−0.1643	0.339
	(0.1709)	
Queretaro	−0.0813	0.666
	(0.1874)	
Observations	90	
Adjusted-R^2	0.1155	

Notes:
[a] 1 = not important in selection of seed, 2 = important, 3 = very important.
[b] 0 = chronic stressor, 1 = catastrophic stressor.
[c] 0 = none, 1 = little, 2 = much.
** Significant at the .05 level; * significant at the .10 level.

more willing to change their selection of seed traits on a given plot, as they would still be able to use previously tested seeds on their other plots. In addition, we also include variables for farmer villages, as we have seen that farmers in certain villages have had more significant changes in their seed trait selection.

As with the ANOVA analysis, we find no statistically significant relationship between changes in farmers' rating of seed traits and willingness to take risks. We also find that the perception of drought as a catastrophic stressor is no longer statistically significant. Farmers' stated importance of drought tolerance in seed selection and perceived control over losses from drought, however, remain statistically significant and associated with larger changes in the drought tolerance of seeds on the primary plot. Perceived control over losses from drought appears to have the largest effect on selection of seed traits, with differences in control between 'none and a little', or 'a little and much', associated with three-quarters of a unit change in the four-point seed rating scale.

We find that farmers' age, village, and number of plots planted with maize are not significantly associated with changes in drought-tolerant traits of planted seed.

Unexpectedly, both Roblada Grande and Queretaro have negative coefficients, indicating smaller absolute changes in seed drought tolerance from 2005–07, even though farmers in both villages increased their ratings of their seed's drought tolerance, on average. This negative association may be because farmers in these villages had smaller absolute changes in drought tolerance ratings than farmers from Dolores Jaltenango, although these changes are not significant. Knowledge of reading and writing, however, is significantly but negatively associated with changes in drought tolerance ratings.

To test the robustness of our findings, we also conducted regression analyses looking at relative rather than absolute changes in drought tolerance ratings and looking at the average change in drought tolerance ratings across all farmer plots as opposed to just on their primary plot (not presented). The significance of different variables varies somewhat across these models. When considering relative changes in drought tolerance ratings of seeds on the primary plot, only the dummy variable for the village of Melchor Ocampo is significantly associated with a change in ratings of seeds on the primary plot. For relative changes in ratings for seeds across all plots, the Melchor Ocampo dummy variable along with the stated importance of drought-tolerant traits and perceived control over losses from drought are all significant. For absolute differences in seed trait ratings across all plots, only perceived control over losses from drought is significant.

We therefore observe that farmer's stated importance of drought-tolerant seed traits is significantly associated with changes in selection of drought-resistant seed in two of the four models, while farmers' perceived control over losses from drought is significant in three models. These findings suggest that farmers' seed selection decisions are associated with their perceptions of climate change and of their ability to respond to climate change, though the association is not always clear.

The survey does not ask farmers about their perceived importance of or control over excess rain as a stressor or about their willingness to pay to reduce losses from excess rain, but we conducted a similar analysis as for drought tolerance considering farmers' selection of seeds with excess rain tolerance, without these variables (Appendix 14.2). While farmers' stated importance of excess rain-tolerance in seeds is significant in the ANOVA analysis, none of the variables are significantly associated with absolute changes in excess rain tolerance ratings in the OLS regressions. In models using relative changes in excess rain tolerance ratings, the coefficient for Queretaro is significant when considering seed traits on all plots, while the coefficients for Roblada Grande and literacy are significant when considering seeds on the primary plot only. This finding suggests that village-level factors may play an important role in farmers' seed selection decisions.

5 CONCLUSION

Our research shows that farmers in four villages of Chiapas, Mexico, changed their seed ratings of tolerance or resistance to four environmental stressors, most notably drought tolerance, although average changes differed by village. Changes in ratings of drought and excess rain tolerance are generally aligned with climate change predictions for temperature and precipitation in these villages, though the degree of alignment varies by village and depending on the climate model we use. Not unexpectedly, farmers' changes in seed trait ratings do not perfectly correspond to climate change predictions, as climate variations are uncertain, and as current seed trait choices may be based on more short-term climate change expectations than those in our models.

While we cannot test whether changes in seed trait ratings are deliberate adaptions to climate change, we find that farmers' baseline attitudes may partially motivate changes in seed trait ratings. Although willingness to take risks does not appear to affect farmer seed selection, farmers' stated importance of drought tolerance in seed selection and their perception of control over losses from drought in 2005 are both associated with larger absolute changes in seed drought tolerance ratings between 2005 and 2007. On the other hand, literacy appears to decrease the likelihood of changes in ratings for this trait, though the possible reasons for this association are not clear.

The concept of bounded rationality suggests that individual rationality in decision-making is constrained by information availability, individuals' capacity to evaluate and process information, and time available to make decisions. Our results suggest that farmers' selection of seed agronomic characteristics, whether knowingly or not, are aligned with long-term climatic fluctuations owing to climate change as predicted by climate models, and that baseline attitudes towards different stressors and farmers' education may also play a role in selection of seed traits. Our findings are limited by the small sample size and by the relatively short timeframe of the study when compared with timelines for climate change, but are generally robust to several model specifications. This study lays a foundation for future investigation into what other variables may drive farmers' climate adaptation behaviors given rational behavior under enormous uncertainty.

NOTES

1. Digital Climate Atlas of Mexico: http://uniatmos.atmosfera.unam.mx/ACDM/servmapas and National Meteorological Service of Mexico Weather Stations: http://smn.cna.gob.mx/index.php?option=com_content&view=article&id=42&Itemid=75 (both accessed 11 January 2017).
2. Note that both sources had the same average for village of Queretaro in the HADGEM 1 temperature model (Figure 14.2).
3. The model at that time was the predecessor to the HADCEM 3 – the HADCM 2. Note that all HAD-rooted models stem from the Hadley Centre's larger Unified Model, but vary depending on the necessary application (seasonal, decadal and centennial climate predictions).
4. The survey does not include questions on perceptions of or losses from excess rain.
5. Figures showing expected temperatures for the GFDL CM3 model are included in Appendix 14.1.
6. The baseline average temperatures for Queretaro are the same for both sources, hence only one line.
7. The grey parallel lines on the bar graphs represent the baseline averages from two different sources.
8. Note that we are suggesting a relationship between excess rain and rotting, as excess rain can lead to rotting of the maize crop, and as changes in seed ratings for these two traits appear to be associated with one another.
9. Farmers in Dolores Jaltenango did not significantly change their ratings of seed traits with the exception of wind tolerance, so we cannot evaluate whether changes align with climate change predictions.

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APPENDIX 14.1 GFDL CM3 MODELS

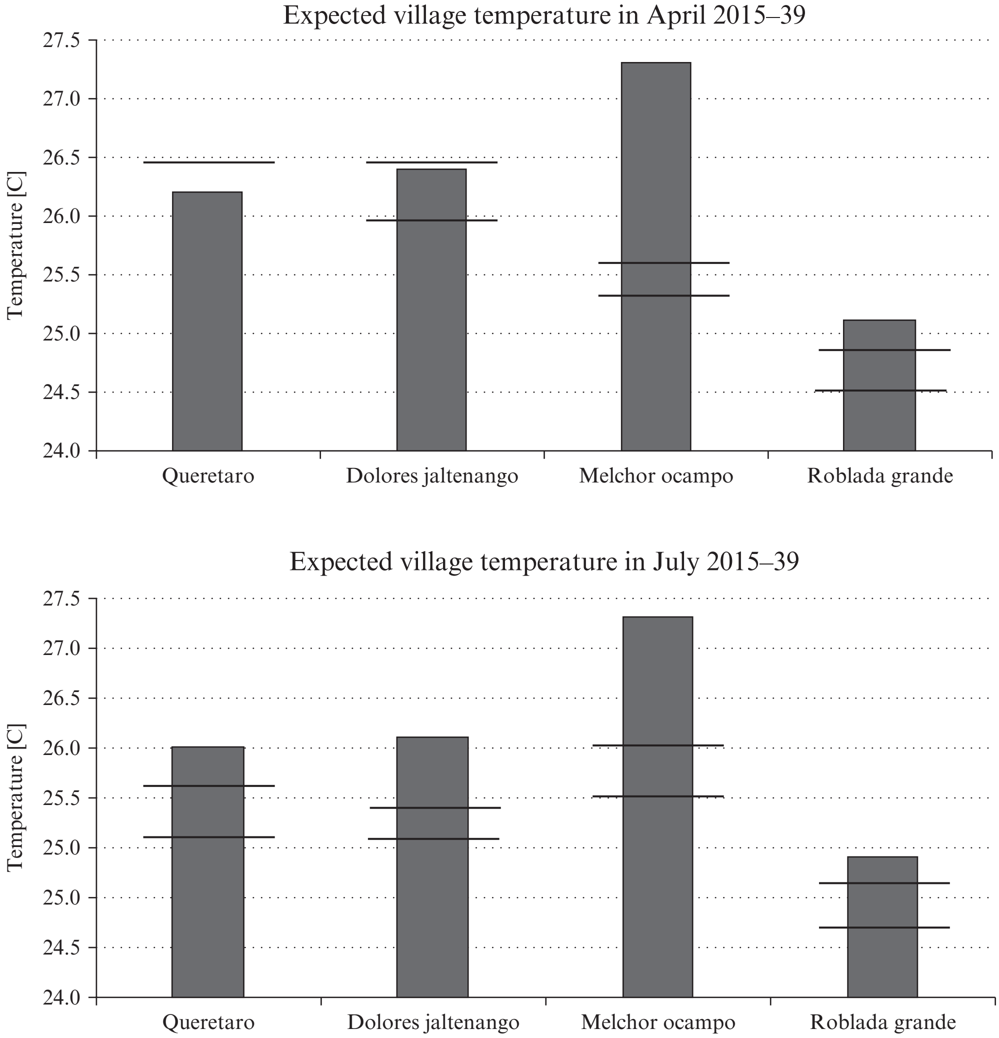
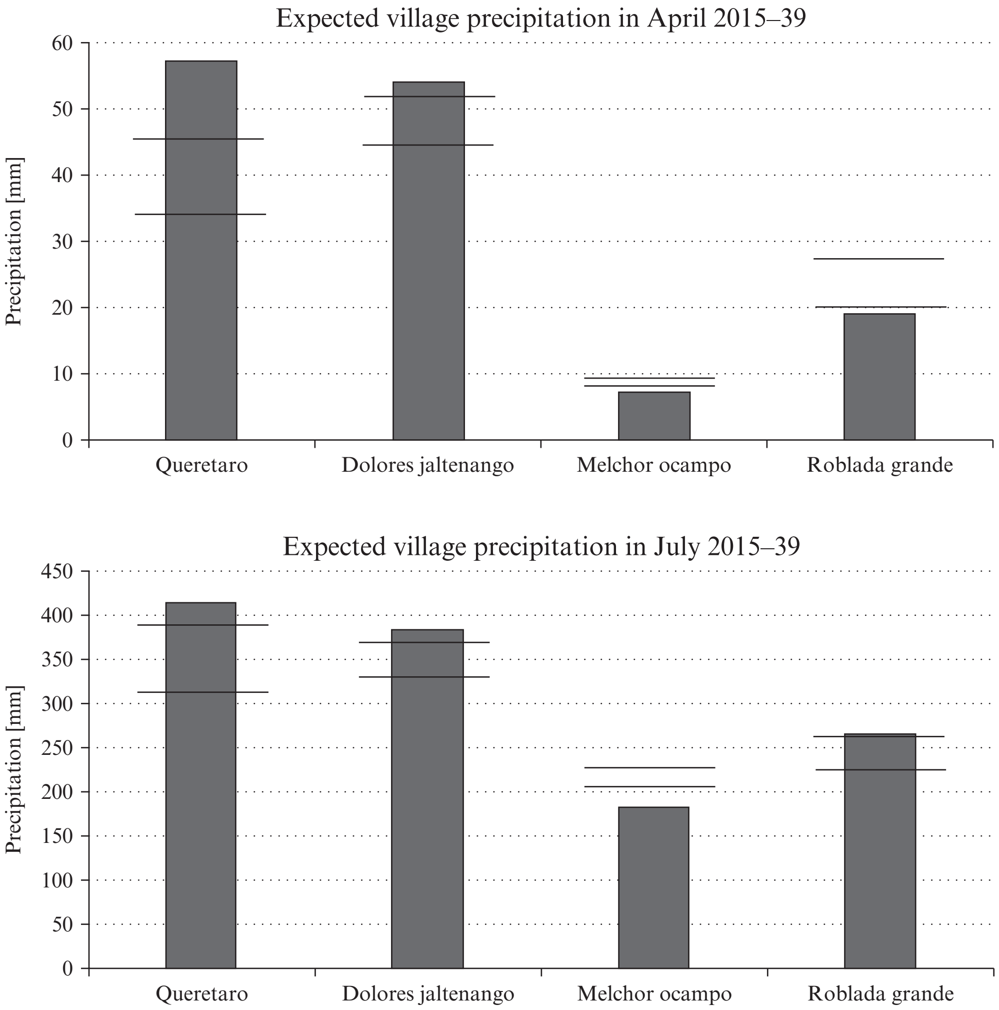


Figure 14A.1 Expected village temperatures under GFDL CM3 scenario



Expected village precipitation in April 2015–39

Expected village precipitation in July 2015–39

Figure 14A.2 Expected village precipitation under GFDL CM3 scenario

Table 14A.1 Results of one-way ANOVA for absolute changes in selection of excess rain-tolerant seed traits on primary plot

Variable	SS	df	MS	F	Prob > F
Willingness to take risks	1.0240	3	0.3413	0.68	0.5677
Importance of excess rain-tolerant seed trait[a] **	3.8637	2	1.9319	4.27	0.0168

Notes:
[a] 1 = not important in selection of seed, 2 = important, 3 = very important.
** Significant at the .05 level.

Table 14A.2 Results of OLS regression for absolute changes in rating of seed excess rain-tolerance on primary plot

Variable	Coeff. (std err.)	$P > \|t\|$
Willingness to take risks	0.0121 (0.0890)	0.892
Importance of excess rain-tolerant seed trait[a]	0.1783 (0.1111)	0.112
Age	−0.0086 (0.0055)	0.121
Knowledge of reading and writing	−0.2827 (0.2024)	0.166
Number of plots planted with maize	−0.0944 (0.0717)	0.192
Melchor Ocampo	0.1321 (0.2165)	0.543
Roblada Grande	−0.0246 (0.2241)	0.913
Queretaro	0.1047 (0.2266)	0.645

Note: [a] 1 = not important in selection of seed, 2 = important, 3 = very important.

Note

1. The survey does not ask farmers their perceptions of excess rain as a stressor. The three stressors that farmers are asked about are drought, pests, and root lodging.