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Historical climate trends, deforestation, and maize and bean yields in Nicaragua

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ABSTRACT

Nicaragua has already experienced substantial climate change, in part due to a loss of one half of its forest cover in the last half-century. In this study, we assess the extent to which historical climate trends have contributed to stagnating yields for maize (*Zea mays*) and bean (*Phaseolus vulgaris*), the two main staple crops in the country. We first analyze 40 years of historical weather data throughout Nicaragua to estimate trends, and assess the extent to which these trends correlate with spatial deforestation patterns. Then, we create a regression model linking department-level maize and bean yields with seasonal weather conditions, and use the model to estimate the impact of historical climate trends on yields. Regressions are run for yields on both harvested and sown area, with the latter accounting for the effect of complete crop losses. Results confirm strong warming trends throughout the country, with daytime temperatures in deforested areas warming at more than double the rate of global averages in the tropics. Decreases in rainfall frequency are also seen almost everywhere, along with an earlier end to the rainy season. Regression model results show, as expected, that red bean is a highly temperature-sensitive crop, and that maize is more water-limited than bean due to its longer seasonal duration. Warming temperatures and less frequent rainfall have led to drought-related losses for both crops in the main commercial production areas, while heavier rains at planting and harvest have also negatively affected yields, especially for bean. Moreover, reduced precipitation in December and January has negatively impacted production for bean in the commercially important apante, or dry season, on the humid Atlantic side of the country. In these areas, however, substantial model uncertainty remains for maize, with an alternative model formulation showing substantial benefits from drier and sunnier conditions. At an annual, national scale, beans have been more affected by climate trends since 1970 than maize, with −5% yield declines per decade on harvested area for bean and −4% for maize, and −12% and −7% yield declines respectively on sown area (with the alternative model showing gains for maize). Climate adaptation responses include government efforts to limit bean exports to control consumer prices, a switch from red to black bean for commercial sales and export, and area expansion and migration for bean in order to maintain production levels.

1. Introduction

Despite technological advances around the world, agricultural production still remains highly dependent on the weather. In addition to the risk of crop losses from year-to-year weather variability and extreme events, a non-stationary climate with slowly shifting weather patterns (i.e. climate change) requires proactive planning, given that the long-term suitability of growing crops in certain locations will likely change. However, future projections of climate change impacts on agriculture have multiple layers of uncertainty which complicate efforts for proactive planning (Challinor et al., 2009; Hoffmann and Rath, 2013; Koehler et al., 2013; Vermeulen et al., 2013). One approach that may help to better understand the mechanisms of climate change impacts on agriculture is to look backwards in time for a certain region and set of crops, in order to understand how climate trends have already impacted yields to date, and how farmers have started to confront these impacts.

This study focuses on agricultural production in Nicaragua, a tropical country in Central America that relies mainly on rain-fed

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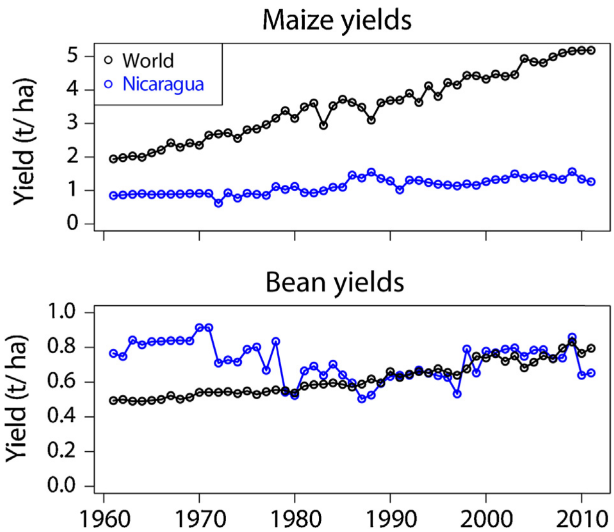

Fig. 1. Maize and bean yields in Nicaragua from 1960 to the present, as compared to world averages.
Source: FAOSTAT.

production on small farms to grow two key staple crops: maize (*Zea mays*) and bean (*Phaseolus vulgaris*). Maize and bean are grown both for home consumption and commercial sales, with roughly a fifth of national bean production exported to countries like El Salvador, Venezuela and the United States (Food and Agriculture Organization, 2012).

Nicaraguan maize and bean yields are low compared to world averages, and yield growth has also been relatively stagnant in the last half-century, especially for bean (Fig. 1). Maize yields have nearly doubled since 1960, although they were still less than a third of world averages in the 2000s. In contrast, bean yields, while closer to world averages in recent years, have actually fallen since the 1960s! Yield stagnation in Nicaragua has a number of causes which include political instability in the last half-century (wars and trade embargoes), natural disasters (both earthquakes and extreme climate events like hurricanes and droughts) (Kinzer, 2007; LeoGrande, 1996; Pielke et al., 2003), declining soil fertility (Stoorvogel and Smaling, 1998), and limited access to improved seed and inputs (Food and Agriculture Organization, 2012). Today, between a third and a half of Nicaraguan farmers use chemical fertilizers (CENAGRO, 2010), especially for maize production. However, input use still remains low, mechanization is almost non-existent, and less than 3% of farms in the country are currently equipped for irrigation (Food and Agriculture Organization, 2012). To cope with stagnating yields, aggressive expansion of the agricultural frontier toward the Atlantic Coast has helped to increase production, with a loss of more than a third of Nicaraguan forest cover since 1980 (Redo et al., 2012, Fig. 2).

Observational studies have demonstrated ongoing climate change in Central America in the last half century, principally warming, more intense and less frequent precipitation (Aguilar et al., 2005) and changes in the timing of the rainy season (Ray, 2013), related to both global greenhouse-gas induced warming and regional deforestation. In rain-fed farming systems, farmers have always faced production risk due to inter-annual variability in precipitation, in total volume as well as in timing, frequency and intensity. However, increasingly erratic and unpredictable rains at the start of the season are affecting the ability of farmers to determine appropriate planting dates and manage risk (Eakin, 1999; Simelton et al., 2013). Moreover, as warming progresses and rain events become less frequent, evaporative losses are increasing and soil moisture is declining, which is consistent with anecdotal reports of increasing drought by many Nicaraguan farmers.

The yields of both maize and bean are temperature-sensitive (Hatfield et al., 2011) through heat effects on crop duration, transpiration, and flowering and grain formation. High night temperatures are thought to be especially harmful for bean (Konsens et al., 1991), through negative effects on pod production. Also, compared to maize, bean has a lower temperature optimum (Hatfield et al., 2011; Prasad et al., 2002), and is therefore already grown at high altitudes and cooler temperatures within Nicaragua (Table 1). In particular, further warming is expected to substantially shrink suitability for bean cultivation within Central America without aggressive adaptation and crop breeding efforts to improve heat and drought-tolerance in the germplasm (Schmidt et al., 2012). In contrast, maize, with a higher temperature optimum, is grown on almost all arable land in Nicaragua. However, some studies have also suggested large projected impacts of climate change on maize, principally under rain-fed conditions (Jones and Thornton, 2003; Lobell et al., 2011a) and especially with low soil fertility (Schmidt et al., 2012), as is typical in Nicaragua.

In order to better understand yield stagnation and help guide future climate adaptation efforts for maize and bean production in Nicaragua, this study looks retrospectively to ask the question: to what extent have long-term climatic trends in recent decades retarded yield growth for maize and bean in Nicaragua? While acknowledging that yields are affected by many other non-climatic factors, this study helps to assess the extent to which climatic trends are stressing efforts to intensify production and increase yields. This study is complementary to the forward-looking Tortillas on the Roaster study (Schmidt et al., 2012) which analyzed future climate change impacts on maize and bean production in four Central American countries. However, this retrospective analysis represents the first attempt in the literature (that we are aware of) to identify the historical impact of climate trends on staple crop production in Central America, using similar methods as other studies that have focused on the United States, China and the globe (Lobell et al., 2011a; Maltais-Landry and Lobell, 2012; Tao et al., 2012).

The ultimate objective of this study is to assess the historical impact of climate trends on maize and bean yields in Nicaragua. Therefore, we perform three sequential analyses to arrive at this result. We first analyze a historical meteorological dataset from weather stations throughout the country to assess trends since 1970 in various seasonal weather variables. Second, we create a statistical model linking department-level maize and bean yields in the 2000s with reconstructed weather data in the principal growing areas for each crop. After interpreting estimated model coefficients, we finally use the model to back-cast the impact of historical climate trends on yields, allowing us to identify departments and growing seasons where farmers have likely experienced the most climatic stress on production. This work sets the stage for future work aimed at evaluating ongoing or future adaptation measures that could be adopted by farmers in these regions.

2. Methods and data sources

2.1. Maize and bean cultivation areas and growing seasons

Nicaragua can be divided into three principal climatic zones: the hot, dry Pacific coast, the cooler dry cultivation areas in the Central highlands, and the hot, humid, rainy and mostly forested Atlantic side (Figs. 2 and 3). The growing seasons in the Pacific and central zones typically follow the seasonal rains in May–July (referred to as the *primera*) and September–November (or the *postrera*), while in the rainier eastern half of the country, a 3rd crop is also grown in the dry season from December to March (the *apante*; Fig. 3).