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The implications of climate change on Mesoamerican agriculture and small-farmers coffee livelihoods

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Introduction

According to the fourth IPCC report, Mesoamerica is one of the regions that will suffer severe impacts from a progressively changing climate. Coffee production is the mainstay of thousands of families and the major contributor to the agricultural GDP of these countries. Besides cash crops such as coffee, small farmers depend also on a variety of crops that are not well studied. In this paper we first quantify the impact of climate change on coffee suitability using data of thousands of geo-referenced coffee farms all over Mesoamerica. We then appraise the suitability of 30 major and minor crops that are important to small-farmers livelihoods. Combining the two analyses we quantify the extent at which climate change could impact Mesoamerican agriculture in general and especially on coffee farmers livelihoods.

Methods and Materials

For Coffee we extracted 20,426 geographical coordinates of current coffee growing areas to a 30-arc-second spatial resolution (approximately 1km) from evidence data of more than 120.000 farms in Mesoamerica. To avoid the introduction of noise due to *Coffea robusta* species or farms whose altitudes were not representative, we only used sites in the range above 500 masl. Further we selected an additional 30 crops from the FAOSTAT database as alternative crops for analysis in the region of Mesoamerica, based on area harvested..

Historical climate data were obtained from the WorldClim database (Hijmans et al., 2005, www.worldclim.org). WorldClim data were generated at a 30 arc-second spatial resolution (1 km) through an interpolation algorithm using long-term average monthly climate data from weather stations. Variables included are monthly total precipitation, and mean monthly minimum and maximum temperatures. Hijmans et al. (2005) used data from stations for which there were long-standing records, calculating means of the 1960-1990 period, and included only weather stations with more than 10 years' data. The database consists of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

Projected climate conditions for the period 2040 to 2069 ("2050s") were initially derived from the 18 most reputable Global Circulation Models (GCM) used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007; http://www.ipcc-data.org). As explained below, some models were excluded after initial runs showed that their predictions

diverged strongly from those of the other models and the analysis were repeated based on the remaining models.
Maximum entropy (MAXENT) is a general-purpose method for making predictions or inferences from incomplete information (Phillips et al., 2006). The model estimates a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent (one's) incomplete information about the target distribution. ECOCROP (FAO, 2005) is a crop database, with a description of the growing environment for various crops. There is also a crop prediction model with the same name (Hijmans et al., 2005), which uses parameters in the FAO database to predict areas suitable for specific crops. ECOCROP is a very useful model for situations where there are no evidence data available for specific crops and one is forced to use environmental ranges instead. The results, however, are more general in nature and they can only be used to describe trends over significantly big areas.
Future suitability predictions were assessed through each of the GCM models via the software MAXENT for coffee and because of lacking evidence data with geographical coordinates, via ECOCROP for the other 30 crops. As stated before, the initial analysis using 18 GCMs revealed that the predictions of some of the GCM patterns differed strongly from those of the other GCMs. If predictions were significantly different from those of the other models according to Tukey's (1977) outlier test, they were removed from the final analysis. Two measurements of uncertainty were computed: (1) the agreement among GCMs calculated as percentage of GCMs predicting changes in the same direction as the average of all GCMs at a given location and (2) the coefficient of variation (CV) among GCMs.

Results and Discussion

Due to space constraints, results for Nicaragua are presented and discussed in more detail than results for Mesoamerica.

Predicted climate change in the coffee zones

The most representative GCMs (16 in Nicaragua) of the 4AR for the SRES-A2a (business as usual) emission scenario drew a trend of changing precipitation patterns and increasing temperature for coffee-producing regions in Mesoamerica. Total annual precipitation is predicted to decrease from 1740 mm to 1610 mm in Nicaragua, while the maximum number of dry months stay constant at 5 months. The mean annual temperature increases by 2.2°C, while the mean daily temperature range rises from 10.4 °C to 10.6°C in Nicaragua**.**

Impact of climate change on coffee suitability

According to the MAXENT model there is a general pattern of decrease in the area suitable for coffee and a decrease in overall suitability within these areas predicted (Figure 1) across Mesoamerica. Coffee potential will move upwards in the altitudinal gradient if climates changes as forecasted by this set of GCMs, with lower-altitude (< 1,500 m.a.s.l) areas being the most affected across Mesoamerica. The areas that will suffer the greatest loss of suitability (loss of 40-60%) in Nicaragua are located in the departments of Nueva Segovia, Jinotega, Matagalpa, Boaco, and on the border of Carazo, Masaya, and Managua. The areas that lose least suitability (loss of 20-40%) are located in Estelí and Madriz. Some small areas that up to 2050 will likely have an increase in suitability between 20-30% are located in Atlantico Norte, Estelí, Jinotega, and Madriz. The coefficient of variation (CV) is a measure of the agreement between the bioclimatic variables produced by the different GCMs. CVs less than 20% are considered low. The mean CV of all bioclimatic variables for the 2050 predictions varies between 10 and 20 % depending on the geographic location (data not shown here).

Further, with progressive climate change areas at higher altitudes become more suitable for producing coffee (right-bottom graph, figure 1). We did not consider altitude as such in the suitability modeling so that we can consider it independently to forecast where coffee might migrate with climate change. Altitude and temperature have a strong relation due to the lapse rate (average 0.6° per 100 m in the study region). The optimum coffee-producing zone in Nicaragua is currently at an altitude of elevation between 800 and 1400 masl; by 2050 the optimum elevation will increase to 1200 and 1600 masl, which is consistent with the predicted temperature increase and the lapse rate. Between today and 2050 areas at altitudes around between 500 m.a.s.l and 1500 m.a.s.l will suffer the greatest decrease in suitability and the areas above 1500 m.a.s.l the greatest increase in suitability.

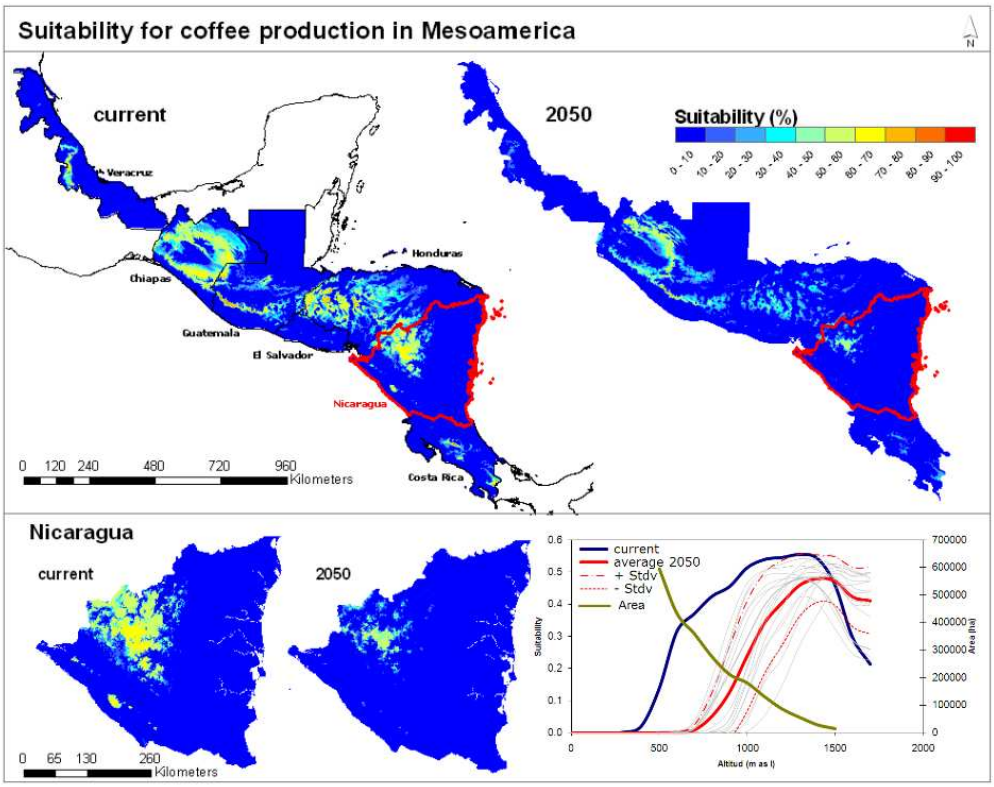

Figure 1: Predicted (according to MAXENT) suitability for coffee (*Coffea arabica*) production in the Nicaraguan and Mesoamerican coffee-producing area today and in 2050 and the relation between current and future (2050) coffee suitability and altitude of coffee in Nicaragua.

Impact of climate change on coffee and 30 most important smallholder crops

The changes in suitability of a particular area to grow coffee are site-specific because each site or area has its own very specific environmental conditions. There will be sites and areas (i) that will become unsuitable to grow coffee, where farmers will need to identify alternative crops; (ii) areas that will remain suitable for coffee, but only when the agronomic management is adapted to the changed conditions of the particular site or area; and (iii) areas where coffee is not grown today but in future will become suitable. The same is predicted for each of the thirty most important potential alternative crops. The situation turns critical in areas where coffee and

many of the diversification crops are predicted to decrease their suitability, which is the case in large areas across Mesoamerica. Less severe is the situation in the majority of the area, where coffee suitability decreases and alternative crop suitability increases. In small and isolated areas across the whole region coffee and alternative crops even gain in suitability (Figure 2).

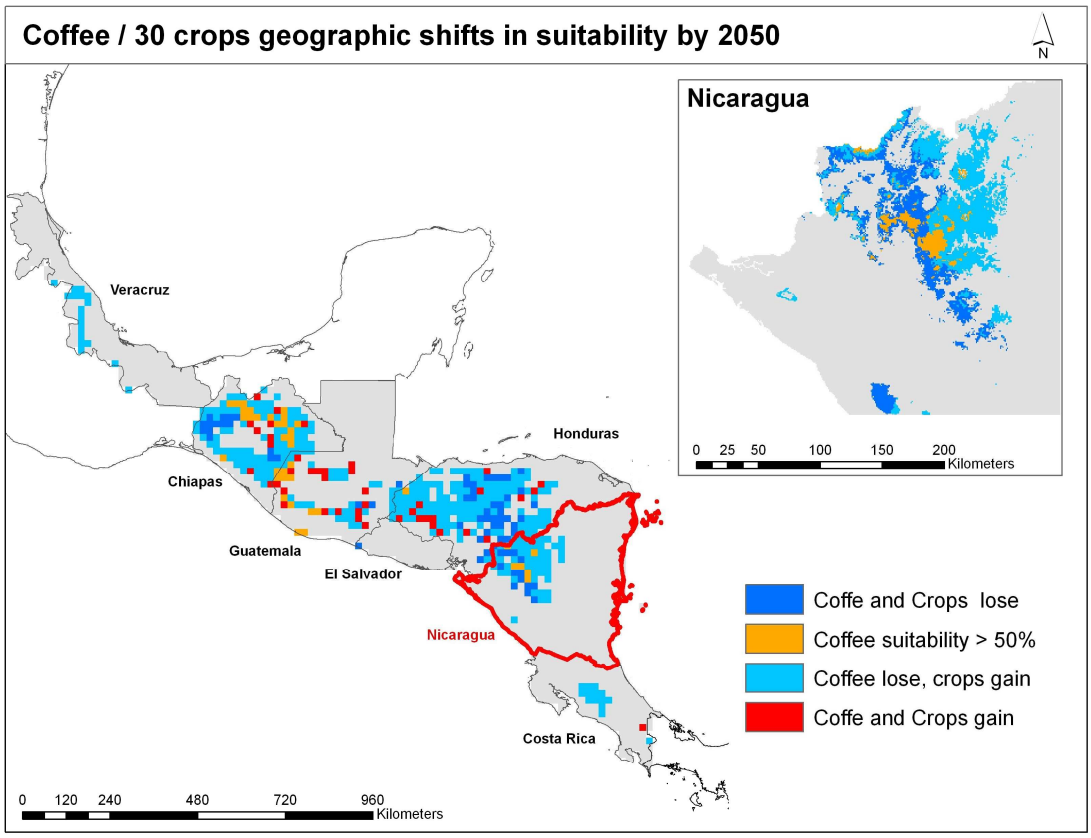

Figure 2: Predicted (combination of Maxent and Ecocrop) suitability change for coffee and the 30 most important crops for coffee smallholder farmers in Nicaraguan and Mesoamerica by 2050.

Conclusions

The analysis shows that Mesoamerican agriculture will suffer severe impacts as a result of climate change, but they also show that a great deal of opportunities are likely to appear if farmers have the access and information to change varieties and, if necessary, their crops. When crops are grown for cash, this is easy. However, when the crops are of large cultural importance and highly traditional, which occurs with most staple crops, adaptation measures could be significantly more difficult. In the case of coffee, whilst not being a staple it creates a unique rural economy which should be managed carefully in case of a crop transition. Incentives for alternatives should be sought which provide similar economic contexts to a region, including high labour requirements, post-processing and rural agribusiness opportunities for example. This analysis identifies hotspots of both opportunities and significant challenges where fundamental shifts in the agricultural system may be required. Regionally-oriented results are required in order to enhance and maintain smallholders' production and livelihoods towards the 21st century.

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