CLIMATE CHANGE AND AFRICAN AGRICULTURE
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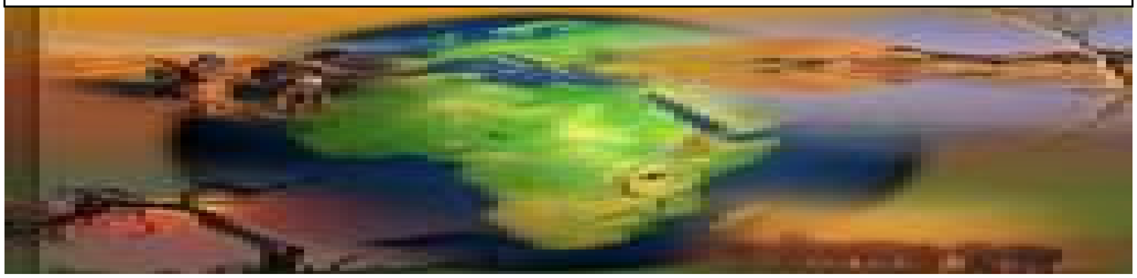

Climate sensitivity of crop choices in Africa[1]

Crop choice is frequently mentioned in the adaptation literature as a potential adaptation strategy to climate change. Farmers make crop selections based on several criteria, including available inputs such as labor (both hired and household), experience, availability of seed, prices, government policy and a host of environmental factors such as climatic and soil conditions and available surface flow. However, there are few studies that examine this question quantitatively. How important are these different factors to crop choice? What role does climate play in choosing crops? As climate changes, how will crop choice change?

Adaptation strategies will be necessary to overcome the expected adverse impacts from higher temperature and changing precipitation patterns. However, quantitative assessments on how farmers will switch crops if climate changes are scarce. This research addresses this gap in the literature. The modeling follows earlier research on the impact of irrigation as an adaptation strategy for African agriculture (Kurukulasuriya & Mendelsohn 2006) and animal selection for African livestock (Seo & Mendelsohn 2006). By examining the crop choices that farmers make across different agro-ecological zones, the analysis centers on how farmers in different climate zones have adapted to current climate. The results can then be used to predict how farmers in different regions will adjust their portfolio of crops in the long run to climate change.

Modeling crop selection

This study examined choices of individual crops as well as combinations of crops in each season. For example, farmers might combine two different crops as a choice. The full set of choices was mutually exclusive: the farmer had to pick one choice from the full set. The probability that a crop or crop combination was chosen depended on how profitable that choice was likely to be.

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[1] This Policy Note is prepared by R Hassan based on Kurukulasuriya & Mendelsohn (2006), Crop selection: Adapting to climate change in Africa, *CEEPA Discussion Paper No. 26, CEEPA, University of Pretoria.*

Using the estimated relationship between climate and farm specific variables and crop choice across current households, we measured the climate sensitivity of crop choice. As the agronomy literature indicates a non-linear relationship between climate (temperature and precipitation) and crop growth and, by extension, crop revenues and climate, we modeled crop selection as a quadratic function of climate. Moreover, as climate is not uni-dimensional, we distinguished between seasonal temperature and precipitation.

Following Greene (2003), climate sensitivities were estimated by the change in expected probability from the marginal change in climate variables. Crop selection was analyzed within the framework of a multinomial logit model (MNL). The estimated model was then used to predict marginal impacts of future climate change scenarios on African agriculture. We examined the marginal impact of climate on crop choice.

The data and empirical model

The data for this study was collected in 11 countries – Burkina Faso, Cameroon, Egypt, Ethiopia, Kenya, Ghana, Niger, Senegal, South Africa, Zambia and Zimbabwe. In each country, districts were chosen to obtain a wide representation of farms across climate conditions in that country. In each chosen district, a survey was conducted of randomly selected farms using cluster sampling. Out of a total of 9597 surveys administered 7296 were usable.

Most of the surveys of farm production and input data were for the 2002–2003 agricultural year. In this study, the analysis was undertaken at the farm level. Plot specific data on crops grown was summarized to obtain the suite of crops grown throughout the year. The full dataset revealed 130 distinct combinations of crops. However, some of the combinations were rare, with only a handful of observations. We only examined crop alternatives where there were at least 100 observations. We were restricted to analyzing this subset of the data given that the district specific climate and soil variables placed a limit on the number of covariates that could be accommodated in the analytical framework. We therefore did not analyze very rare crop selections. Our primary purpose was to investigate how climate change was likely to affect the crop choice that the majority of farmers make.

Data on climate were from two sources. Long term temperature data came from the US Department of Defense satellites and precipitation data from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003). This dataset, created by the National Oceanic and Atmospheric Association's Climate Prediction Center, is based on ground station measurements of precipitation.

Although monthly climate measures were available, individual months were highly correlated with neighboring months. However, it is not self-evident how to cluster monthly temperatures into a limited set of seasonal measurements. After exploring several ways of defining three-month average seasons, we found that defining winter in the northern hemisphere as the average of November, December and January provided the most robust results for Africa. This assumption implies that February, March and April would be spring, May, June and July would be summer, and August, September and October would be fall (in the north). We adjusted for the fact that seasons in the southern hemisphere occur at exactly opposite months of the year from northern hemisphere seasons.

Soil data was obtained from the FAO (2003) and hydrology data from the University of Colorado (IWMI & University of Colorado 2003). Using a hydrological model for Africa, the hydrology team calculated flow and runoff for each district in the surveyed countries.

Table 1: Crop choices by country

CROP	Burkina Faso	Cameroon	Egypt	Ethiopia	Ghana	Kenya	Niger	Senegal	South Africa	Zambia	Zimbabwe	Total
cowpea	11	8	0	3	25	41	271	0	1	16	12	388
groundnut	0	22	0	5	17	0	1	14	0	53	0	112
maize	0	62	6	122	364	47	2	3	44	312	109	1,071
millet	40	2	0	29	15	1	25	109	1	11	0	233
potato	0	25	12	24	3	18	0	0	5	17	0	104
sorghum	100	2	61	223	9	28	11	27	3	50	55	569
sugarcane	0	9	35	7	8	26	0	0	32	0	0	117
other crops	0	90	45	23	47	176	3	10	88	45	29	556
maize-beans	0	79	4	16	6	189	0	1	27	37	40	399
cowpea-sorghum	189	0	0	5	0	28	432	0	0	5	7	666
maize- cotton	15	0	50	3	0	1	0	3	0	21	51	144
maize-groundnut	14	200	0	5	58	25	0	24	9	249	227	811
maize-millet	14	4	0	32	15	55	22	100	1	35	53	331
maize-wheat	0	2	149	35	0	13	0	0	22	0	9	230
millet-groundnut	25	0	0	4	33	0	59	440	0	7	0	568
millet-sorghum	57	4	0	21	6	0	30	22	0	7	0	147
rice-maize	19	3	52	0	38	9	0	3	0	11	3	138
wheat-other	0	0	64	50	0	9	0	0	10	0	1	134
groundnut-sorghum-millet	51	2	0	3	6	0	13	67	0	0	0	142
maize-millet-sorghum	42	2	0	30	3	6	0	19	0	21	3	126
maize-sorghum-groundnut	13	0	0	1	10	17	2	15	0	23	35	116
millet-groundnut-maize-sorghum	126	2	0	3	1	3	0	49	0	0	10	194
Total	**716**	**518**	**478**	**644**	**664**	**692**	**871**	**906**	**243**	**920**	**644**	**7,296**

The most popular crop choice in the sample was maize (Table 1). This crop is capable of growing across a range of climates because there are a number of varieties of maize grown in Africa. The second most popular crop portfolio was maize-groundnut. While growing maize alone was the most popular choice in Zambia and Ghana, farmers in Cameroon preferred to grow maize-groundnut. Drought tolerant crops were the revealed preference of farmers in Burkina Faso, Niger and Senegal (sorghum, cowpea, or cowpea-sorghum). In Egypt and South Africa, as expected, the popular choices were maize and wheat. South African farmers also selected a variety of other crops (which did not belong to any of the other revealed categories). Farmers in Zambia and Zimbabwe indicated a preference for maize and maize-groundnut.

To have sufficient observations of each choice, we analyzed farmers who chose one of the nine most popular choices. These choices were maize (1071 observations), maize-groundnut (811), cowpea-sorghum (666), sorghum (569), millet-groundnut (568), ‘other crops’ (556), maize-beans (399), cowpea (388), and maize-millet (331). The farms that made these choices accounted for almost three-fourths of all farms in the dataset.

The MNL regression included a set of climate variables, a set of control variables, and a set of soil variables. The climate variables measured annual temperature and precipitation. Both a linear and a quadratic term were introduced to capture the expected non-linear effect of these variables. The control variables included water flow, farmland, a dummy for electricity, household size, and elevation. The soil variables included slope, texture and soil type. Soiltype1 reflected soils that had a fine texture and were in hilly to steep slopes. Soiltype2 incorporated soil types such as eutric gleysols or solodic planosols. Soiltype3 reflected lithosols or soils with medium texture in steep areas. Soiltype 5 included orthic ferralsols and chromic luvisols.

The control and soil variables affect crop choice. Higher elevation encourages cowpea, sorghum, cowpea-sorghum, maize-groundnut and maize-millet and discourages only millet-groundnut. Lower flow is associated with farmers choosing maize-beans, cowpea-sorghum, maize-groundnut, maize-millet, millet-groundnut and ‘other crops’. Lower flow probably implies that farmers cannot irrigate. Choosing crop combinations is one way for farmers to adapt to dryland farming in Africa. Farms that have electricity are more likely to choose maize and maize-beans but less likely to choose every other crop. Electricity may help in the production of maize or it may simply signal access to urban markets, which often accompanies access to electricity. Farmers whose farms have steep slopes and fine-textured soils are more likely to pick millet-groundnut but less likely to pick cowpea, sorghum, cowpea-sorghum, maize-beans, and ‘other crops’. Those whose farms have eutric gleysols and solodic planosols are less likely to pick every crop except cowpea-sorghum and maize. Those whose farms have lithosols or medium textured soils in steep areas are more likely to pick cowpea, maize-beans, and ‘other crops’, but less likely to pick sorghum. Finally, those whose farms have orthic ferrasols and chromic luvisols are more likely to pick millet-groundnut but less likely to pick sorghum and maize-millet.

Judging by the significance of the coefficients on both the linear and squared terms, annual temperature and precipitation are both quite important to crop choice. In order to show how temperature affects farmers’ choices, in

Figure 1 we present the probability a farmer will choose each crop combination at each temperature. Figure 1a reflects crops that prefer relatively cool temperatures in Africa: sorghum, maize-beans, maize-millet and ‘other crops’. The probability of these crops is high in the cool regions of Africa but much lower in warmer regions.

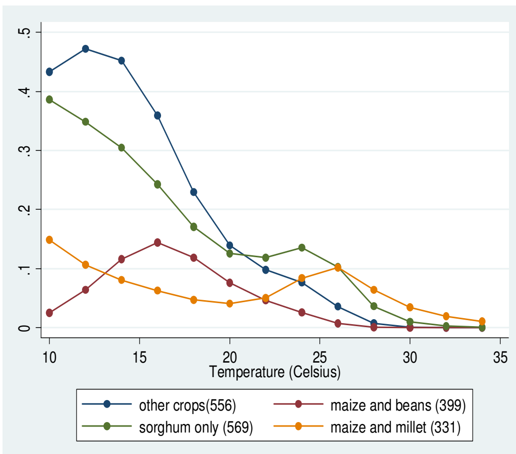

Figure 1a: Probability of selecting low temperature crops

Figure 1b reflects crops chosen near the mean temperatures of Africa: maize, maize-groundnut, and millet groundnut. The relationship of especially the first two crops is hill-shaped with respect to temperature.

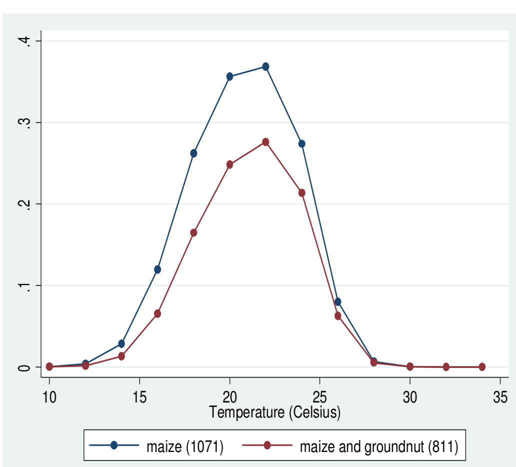

Figure 1b: Probability of selecting medium temperature crops

Finally, Figure 1c shows crops that are more likely to be grown in the warmest regions that support crops: cowpea and cowpea-sorghum. It is interesting to note that although growing sorghum alone occurs in the cooler regions, the combination of sorghum and cowpea is chosen in the warmest regions.

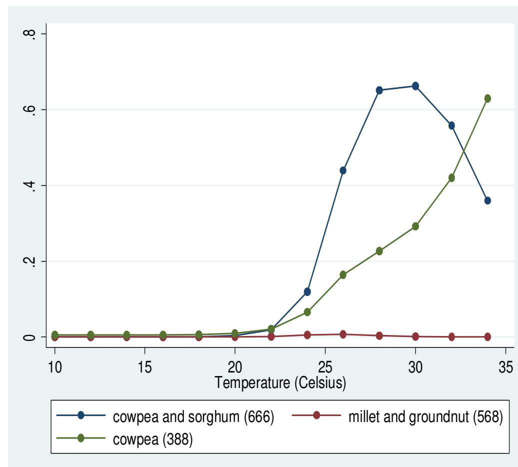

Figure 1c: Probability of selecting high temperature crops

Figure 2 shows the relationship between precipitation and the probability crops are chosen. Crops chosen in drier regions are shown in Figure 2a: maize, maize-millet, cowpea, cowpea-sorghum and millet-groundnut. Note that all crops require some precipitation, so these relationships are hill-shaped. Figure 2b shows crops that are more likely to be chosen in wet locations: sorghum, maize-beans, maize-groundnut, and ‘other crops’. Annual precipitation also clearly plays a large role in crop choice.

The study tested whether seasonal factors matter or whether it is just annual temperature that is important.

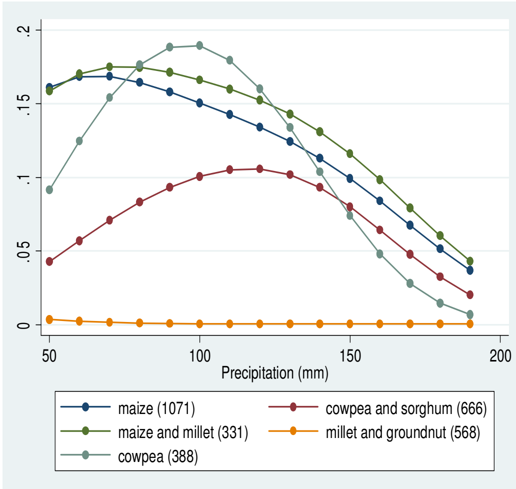

Figure 2a: Probability of selecting dry to moderate precipitation crops

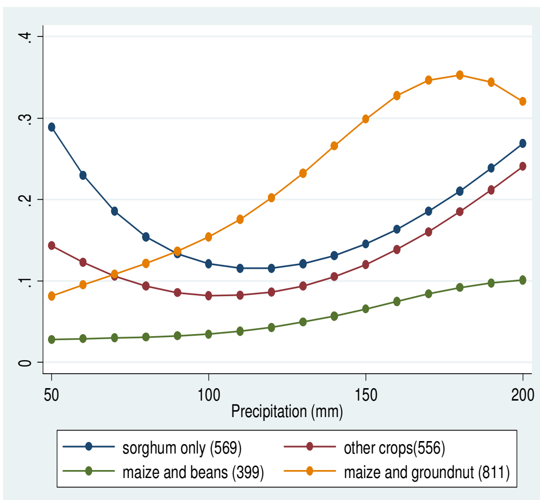

Figure 2b: Probability of selecting high precipitation crops

The most conspicuous difference observed is the complex role that seasonal climate plays in crop selection. The choice of different crops is sensitive to seasonal climate variables. The effect of seasonal climate variables varies by crop. For example, in comparison to maize, cowpea reacts to summer and fall temperatures and winter and summer and fall precipitation, whereas sorghum reacts to winter, spring and fall temperatures and precipitation in every season. Millet-maize in comparison reacts to winter and spring temperature and precipitation in all seasons.

Summing the effects across seasons, one can see what happens if all the seasonal temperature or precipitation measures increase together (i.e. holding the relative contribution of each seasonal climate variable fixed as annual temperature changes). Note that Figures 1 and 2 allow the seasonal mixture to change as annual temperature changes across the landscape. The results suggest that this is an important distinction. For example, as one moves from South Africa to the equator, all seasonal temperatures converge as annual temperature warms. While many of the probability response functions to temperature are similar, a few crops behave quite differently. The probability of selecting cowpea, maize-millet and 'other crops' changes as a result of allowing seasonal variations. Presumably all three of these crops are highly sensitive to the seasonal mix and not just to the average annual climate.

The results imply that one must be careful when using cross-sectional evidence as a proxy for future climate change. For example, if greenhouse gases cause temperatures to rise without making the temperature differences between seasons smaller, one would want to use the seasonal model for forecasting. However, if future warming decreases seasonal temperature differences, making the differences small, as they are near the equator, then one would want to use the annual model for forecasting.

Conclusion and policy implications

This paper examines the choices that farmers in Africa make across a wide spectrum of climate conditions. The study finds that crop choice is highly sensitive to both temperature and precipitation. Farmers adapt their crop choices to suit the local conditions that they face. For example, farmers in cooler regions of Africa choose maize-beans and sorghum, whereas farmers in hot regions choose cowpea and millet. Farmers in dry regions choose millet and sorghum, whereas farmers in wet regions choose maize-beans, cowpea-sorghum, and maize-groundnut. Other crops, such as maize, are grown throughout Africa.

The study found that sometimes farmers choose only a single crop to grow, such as sorghum, cowpea or maize. However, farmers often select a crop combination that will survive the harsh conditions in Africa, such as maize-beans, cowpea-sorghum, and millet-groundnut. These combinations provide the farmer with more flexibility across climates than growing a single crop on its own.

The results have significant policy implications for climate change. Since African farmers currently adapt their crop choice to climate, there is every reason to believe they will continue do so in the future. Governments and farmers must anticipate the need to change crops rather than try to hold on to old crops that repeatedly fail.

The study strongly suggests that agricultural analyses of climate change impacts must take into account crop selection. Studies that treat crop choice as exogenous will seriously overestimate the damages from global warming. For example, agronomic studies or empirical studies that use weather as a proxy must be careful not to assume crop choices are exogenous. Farmers will probably change crops in response to a new climate rather than repeatedly grow crops that historically were successful but now fail. Although this may still entail losses in agricultural income in Africa, the predicted losses will be much smaller than if one assumes crop choice is exogenous.

Finally, the paper examines crop choice only across the currently available selection of crops. Future research into new crops that are more suitable for higher temperatures could dramatically improve farmers' welfare, especially in hot locations such as Africa. Although a great deal of progress has been achieved in making existing crops more productive, future research efforts need to move towards making them more resilient to higher temperatures.

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The agricultural sector in sub-Saharan Africa is predicted to be especially vulnerable to climate change because this region already endures high heat and low precipitation, provides the livelihoods of large segments of the population, and relies on relatively basic technologies, which limit its capacity to adapt. This series of Policy Notes reports on the methods and results of the first continent-wide study of this kind assessing how the economic well-being of African farming communities is currently affected by climate, predicts how future climate change effects may unfold under various possible global warming scenarios, and evaluates the roles adaptation to climate change could play. The study is based on collaborative research efforts conducted in 11 countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia and Zimbabwe. The sampled districts used as the unit of analysis cover all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in Africa on such a scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting an analysis that uses economic impact assessment methods, river-basin hydrological modeling and crop growth simulation techniques.

All the reports produced under this GEF/WB/CEEPA funded project, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*, are found on CEEPA e-Library at its website link (www.ceepa.co.za/discussionp2006.html) and can also be accessed directly through the project link (www.ceepa.co.za/Climange_Change/project.html)

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