CROP SELECTION: ADAPTING TO CLIMATE CHANGE IN AFRICA

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PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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EXECUTIVE SUMMARY

This paper examines whether the choice of crops is affected by climate in Africa. Using a multinomial logit model, the paper regresses crop choice on climate, soils, and other factors. The model is estimated using a sample of over 7000 farmers across 11 countries in Africa.

The study finds that crop choice is very climate sensitive. For example, farmers select sorghum and maize-millet in the cooler regions of Africa, maize-beans, maize-groundnut, and maize in moderately warm regions, and cowpea, cowpea-sorghum, and millet-groundnut in hot regions. Further, farmers choose sorghum, and millet-groundnut when conditions are dry, cowpea, cowpea-sorghum, maize-millet, and maize when medium wet, and maize-beans and maize-groundnut when wet. As temperatures warm, farmers will shift towards more heat tolerant crops. Depending upon whether precipitation increases or decreases, farmers will also shift towards drought tolerant or water loving crops, respectively.

There are several policy relevant conclusions to draw from this study. First, farmers will adapt to climate change by switching crops. This will inherently reduce the damages from climate change as farmers move away from crops that cannot perform well in the new climate towards crops that can. Governments and farmers should anticipate that new crops will be grown in places that experience climate change.

Second, global warming impact studies cannot assume crop choice is exogenous. For example, agronomic studies or studies that use weather as a proxy for climate, implicitly assume that crop choice will not change as climate changes. Unless these studies treat crop choice as endogenous, they will seriously overestimate the damages from warming.

Third, this study only examines choices across current crops. Future farmers may well have more choices. There is an important role for agronomic research in developing new varieties more suited for higher temperatures. Future farmers may have even better adaptation alternatives with an expanded set of crop choices specifically targeted at higher temperatures.

1. Introduction

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?

In this paper, we estimate the climate sensitivity of specific crop choices made by farmers in Africa. Research has shown that major grains will be extremely vulnerable to climate change in Africa (Deressa et al. 2005; Gbetibouo & Hassan 2005; Rosenzweig & Parry 1994). 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.

The next section outlines the modeling framework in the paper. Crop selection is analyzed within the framework of a multinomial logit model (MNL). Section 3 outlines the available data. Section 4 presents the results of the empirical modeling on crop choice. The paper concludes in Section 5 with a discussion of the crop model results and the implications of climate change for the agriculture sector in Africa.

2. Theory

We assume that each farmer makes his crop decisions to maximize profit. We examine 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 is mutually exclusive: the farmer must pick one choice from the full set. The probability that a crop or crop combination is chosen depends on how profitable that choice is likely to be. We assume that farmer i's profit in choosing crop set *j (j=1,2,…,J)* is

$$\pi_{ij} = V(K_j, S_j) + \varepsilon(K_j, S_j) \tag{1}$$

where *K* is a vector of exogenous characteristics of the farm and *S* is a vector of characteristics of farmer *i*. For example, *K* could include climate, soils, and access variables and S could include the age of the farmer and family size. The profit function is composed of two components: the observable component *V* and an error term, ε. The error term is unknown to the researcher, but may be known to the farmer. The farmer will choose the crop that gives him the highest profit. Defining $Z = (K, S)$, the farmer will choose crop *j* over all other crops *k* if:

$$\pi^*(Z_{ji}) > \pi^*(Z_{ki}) \text{ for } \forall \text{ k} \neq \text{j.[or if } \varepsilon(Z_{ki}) - \varepsilon(Z_{ji}) < V(Z_{ji}) - V(Z_{ki}) \text{ for k} \neq \text{j]} \tag{2}$$

More succinctly, farmer $i's$ problem is:

$$\arg\max[\pi^*(Z_{1i}), \pi^*(Z_{2i}), ..., \pi^*(Z_{Ji})] \tag{3}$$

The probability P_{ji} of the jth crop being chosen is then

$$P_{ji} = \Pr[\varepsilon(Z_{ki}) - \varepsilon(Z_{ji}) < V_j - V_k] \ \forall \mathrm{k} \neq \mathrm{j} \ \text{where} \ \mathrm{V_j} = \mathrm{V(Z_{ji})} \tag{4}$$

Assuming ε is independently Weibull distributed[2] and $V_k = Z_{ki}\gamma_k + \alpha_k$,

$$P_{ji} = \frac{e^{Z_{ji}\gamma_j}}{\sum_{k=1}^{J} e^{Z_{ki}\gamma_k}} \tag{5}$$

which gives the probability that farmer i will choose crop j among J choices (Chow 1983; McFadden 1981).

The parameters can be estimated by Maximum Likelihood Method using an iterative non-linear optimization technique such as the Newton-Raphson method. These estimates are CAN (Consistent and Asymptotically Normal) under standard regularity conditions (McFadden 1999).

Greene (2003) shows that by differentiating the above with respect to the covariates, the marginal effect of individual characteristics is:

$$\delta_j = \frac{\partial P_j}{\partial X_i} = \left[\beta_j - \sum_{k=0}^{K} P_k \beta_k \right] = P_k(\beta_k - \overline{\beta}) \tag{6}$$

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[2] Two common assumptions about the error term are either the Normal or the Weibull distribution. Normal random variables have the property that any linear combination of normal varieties is normal. The difference between two Weibull random variables has a logistic distribution, which is similar to the normal, but with larger tails. Thus, the choice is somewhat arbitrary with large samples (Greene 2003).

Using the estimated relationship between climate and farm specific variables and crop choice across current households, we measure 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 model crop selection as a quadratic function of climate. Moreover, as climate is not uni-dimensional, we distinguish between seasonal temperature and precipitation. Following Greene (2003), climate sensitivities are estimated by the change in expected probability from the marginal change in climate variables. The estimated model is then used to predict marginal impacts of future climate change scenarios on African agriculture. We examine the marginal impact of climate on crop choice.

3. Data

The data for this study was collected in 11 countries – Burkina Faso, Cameroon, Egypt, Ethiopia, Kenya, Ghana, Niger, Senegal, South Africa, Zambia and Zimbabwe – by national teams. In each country, districts were chosen to get a wide representation of farms across climate conditions in that country. The districts are not representative of the distribution of farms in each country as there are more farms in more productive locations. In each chosen district, a survey was conducted of randomly selected farms. The sampling is clustered.

The number of surveys in each country varied, but a total of 9597 surveys were administered. Some farmers did not grow crops. Some surveys contained incorrect information about the size of the farm or area of cropland. Impossible values were judged to be missing. It is not clear what the sources of these errors were. They may reflect field errors due to a misunderstanding of the question, the units of measurement, or they may be intentional incorrect answers. Other surveys did not contain clear information on crop type and are therefore excluded. The final number of useable surveys for this analysis is 7296.[3] The distribution of surveys by country is shown in Table 1.

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[3] Kurukulasuriya and Mendelsohn (2006) was based on an analysis of 9063 surveys (complete dataset used in the Africa-wide Ricardian analysis). However, only a fraction of the farmers chose to grow crops.

Most of the surveys of farm production and input data are for the 2002–2003 agricultural year[4]. In this paper, the analysis is undertaken at the farm level. Plot specific data on crops grown is 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 examine crop alternatives where there are at least 100 observations. We are restricted to analyzing this subset of the data given that the district specific climate and soil variables place a limit on the number of covariates that can be accommodated in the analytical framework.[5] We therefore do not analyze very rare crop selections. Our primary purpose is to investigate how climate change is likely to affect the crop choice that the majority of farmers make and subsequently how that crop selection affects farm earnings.[6] Using this restricted dataset, the mean and median district-level yield price of each crop is also estimated (see Table 3).

Data on climate are from two sources. Long term temperature data comes from US Department of Defense satellites. The Defense Department satellites pass over every location on earth between 6am and 6pm every day. They are equipped with sensors that detect microwaves that can pass through clouds and detect surface temperature (Weng & Grody 1998). Precipitation data comes 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. The mean annual temperature and precipitation for each country in the sample is shown in Figure 1.

Although monthly climate measures were available, individual months are highly correlated with neighboring months. Previous research indicates it is useful to aggregate monthly data into seasons (Mendelsohn et al. 2004). However, it is not self-evident how to cluster monthly temperatures into a limited set of seasonal measurements. We explored several ways of defining three-month average seasons, starting with November, December and January for winter. Comparing the results, 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

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[4] Data from Cameroon, Ethiopia, Kenya and Zimbabwe were collected in 2003–2004.

[5] There are in total 394 districts in the sample. This places a restriction on the number of observations that can be in the model, given the district specific variables that we use to analyze the climate sensitivity of crops.

[6] The results of this research are under way.

assumption in turn implies that the next three months would be spring, the three months after that would be summer, and August, September and October would be fall (in the north). The choice of these particular seasonal definitions is motivated by the fact that they provided the best fit with the data and that they reflected the mid-point for key rainy seasons in the sample. 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 FAO (2003). The FAO data provides information about the major and minor soils in each location. Data concerning the hydrology was obtained 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.

4. Results

Table 2 summarizes the crop choice categories in the African analysis. The most popular crop choice in the sample is maize. 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 is maize-groundnut. We hyphenate crop combinations throughout the paper. Cowpea-sorghum, sorghum and millet-groundnut are also popular choices. While growing maize alone is the most popular choice in Zambia and Ghana, farmers in Cameroon prefer 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 are 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.

In Table 3, we examine the determinants of crop choice. In order to have sufficient observations of each choice, we analyze farmers who chose one of the nine most popular choices. These choices are 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 account for almost three-fourths of all farms in the data set.

The MNL regression includes a set of climate variables, a set of control variables, and a set of soil variables. The climate variables measure annual temperature and precipitation. Both a linear and a quadratic term are introduced to capture the expected non-linear effect of these variables. The control variables include water flow, farmland, a dummy for electricity, household size, and elevation. The soil variables include slope, texture and soil type. Soiltype1 reflects soils that have a fine texture and are in hilly to steep slopes. Soiltype2 incorporates soil types such as eutric gleysols or solodic planosols. Soiltype3 reflects lithosols or soils with medium texture in steep areas. Soiltype 5 includes 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 texture 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 texture 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.

From the perspective of this study, the most important coefficients in Table 3 concern annual climate. 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 2 we present the probability a farmer will choose each crop combination at each temperature. Figure 2a 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 2b 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. Finally, Figure 2c 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. Temperature effects which crops African farmers choose.

Figure 3 shows the relationship between precipitation and the probability crops are chosen. Crops chosen in drier regions are shown in Figure 3a: maize, maize-millet, cowpea, cowpea-sorghum and millet-groundnut. Note that all crops require some precipitation, so these relationships are hill-shaped. Figure 3b 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.

We also include an analysis that measures seasonal (not annual) climate. Table 4 is identical to Table 3 except that four seasonal climate variables have replaced each annual climate variable. The seasonal variables capture winter, spring, summer and fall. This second model tests whether seasonal factors matter or whether it is just annual temperature that is important. Note that the inclusion of seasonal climate variables has affected the significance of some of the soils and control variables. They generally have the same sign but some are now more significant and others less so. One exception is the sign reversal on elevation for millet-groundnut which was negative in Table 3 but positive in Table 4.

The most conspicuous difference between Table 3 and 4, however, 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. Note that the comparison in Figures 4 and 5 holds the relative contribution of each seasonal climate variable fixed as annual temperature changes. Figures 2 and 3 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. This shift in seasonal temperatures is part of the change in annual temperature in Figure 2 but not in Figure 4.

Many of the probability response functions of Figure 2 and Figure 4 to temperature are similar. However, a few crops behave quite differently. Cowpea is chosen in hot temperatures in Figure 2 but in cool temperatures in Figure 4. Maize-millet is chosen in cool temperatures in Figure 2 but in hot temperatures in Figure 4. ‘Other crops’ shifts from a wet region in Figure 3 to a dry region in Figure 5. 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. Whether Figures 2 and 3 are more or less accurate than Figures 4 and 5 would depend on future climate scenarios.

5. 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. This study has shown that African farmers adapt crop choice to climate. There is every reason to believe that they will continue to adapt 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. As a result, farmers will match future crops to future climates. 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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Table 1: Surveys by country

Country	Useable surveys	Percent total
Burkina Faso	716	9.81
Cameroon	518	7.10
Egypt	478	6.55
Ethiopia	644	8.83
Ghana	664	9.10
Kenya	692	9.48
Niger	871	11.94
Senegal	906	12.42
South Africa	243	3.33
Zambia	920	12.61
Zimbabwe	644	8.83
	7296	100.00

Table 2: 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**

Table 3: Multinomial logit crop choice model: Annual climate

Multinomial logistic regression		Number of obs	= 5277
		LR chi2(104)	= 6926.36
		Prob > chi2	= 0.0000
Log likelihood	= -7796.4556	Pseudo R2	= 0.3076

	COWPEA	SORGHUM	MINOR CROPS	MAIZE-BEANS
Mean annual temperature	-3.29***	-2.8***	-2.44***	-1.49***
	(.36)	(.25)	(.27)	(.41)
Mean annual temperature	0.09***	0.07***	0.05***	0.03***
squared	(.01)	(.01)	(.01)	(.01)
Mean annual precipitation	0.06***	-0.06***	-0.05***	-0.02
	(.02)	(.01)	(.01)	(.01)
Mean annual precipitation	-0.0002***	0.0002***	0.0002***	0.0001***
squared	(0.00)	(0.00)	(0.00)	(0.00)
Mean flow (mm)	0.07**	0.02	-0.1***	-0.08**
	(.04)	(.02)	(.02)	(.04)
Log (Area of farmland)	0.13	0.04	-0.06	-0.12**
	(.07)	(.05)	(.04)	(.05)
Elevation (m)	0.001***	0.0004***	0.00	0.0006***
	(0.00)	(0.00)	(0.00)	(0.00)
Log (Household size)	0.39**	0.67***	0.46***	0.46***
	(.16)	(.12)	(.12)	(.13)
Dummy household with	-0.88***	-1.74***	0.15	-0.23
electricity	(.22)	(.19)	(.14)	(.16)
Soil type 1	-1.96***	2.20***	-3.91***	-2.99***
	(.53)	(.46)	(.49)	(.46)
Soil type 2	-1.05***	-0.94***	-1.30***	-1.43***
	(.28)	(.21)	(.27)	(.33)
Soil type 3	2.37***	-1.89***	3.32***	3.34***
	(.49)	(.48)	(.38)	(.38)
Soil type 5	0.35	-1.30***	-0.06	-0.50
	(.43)	(.38)	(.31)	(.35)
Constant	23.39***	29.9***	27.64***	15.83***
	(4.24)	(2.76)	(2.86)	(4.15)

Table 3: (continued)

	COWPEA-SORGHUM	MAIZE-GROUNDNUT	MAIZE-MILLET	MILLET-GROUNDNUT
Mean annual temperature	-1.19***	0.20	-3.19***	-0.67
	(.4)	(.32)	(.28)	(.53)
Mean annual temperature	0.05***	0.00	0.08***	0.03***
squared	(.01)	(.01)	(.01)	(.01)
Mean annual precipitation	0.04***	0.00	0.00	-0.09***
	(.01)	(.01)	(.01)	(.01)
Mean annual precipitation	0.00	0.0001***	0.00	0.0003***
squared	(0.00)	(0.00)	(0.00)	(0.00)
Mean flow (mm)	-0.14***	-0.12***	-0.17***	-0.36***
	(.05)	(.03)	(.05)	(.07)
Log (Area of farmland)	0.28***	0.05	0.10	0.26***
	(.08)	(.04)	(.06)	(.1)
Elevation (m)	0.002***	0.0003***	0.0007***	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
Log (Household size)	1.11***	0.63***	0.91***	0.71***
	(.16)	(.1)	(.15)	(.17)
Dummy household with	-1.99***	-0.76***	-1.35***	-1.01***
electricity	(.25)	(.13)	(.22)	(.24)
Soil type 1	-1.13**	0.68	-0.01	1.86***
	(.49)	(.48)	(.49)	(.49)
Soil type 2	-0.32	-0.5***	-1.08***	-2.30***
	(.25)	(.16)	(.27)	(.36)
Soil type 3	0.56	-0.24	0.88	-0.72
	(.49)	(.47)	(.48)	(.54)
Soil type 5	-1.12	-0.36	-1.14***	4.22***
	(1.03)	(.2)	(.43)	(1.16)
Constant	-6.04	-4.62	28.48***	2.12
	(5.02)	(3.59)	(3.24)	(6.53)

Notes: Base category crop: MAIZE

*** significant at 1% ** significant at 5%

Measures of fit for previous model

Log-Lik Intercept Only:	-11259.634	Log-Lik Full Model:	-7796.456
D(5165):	15592.911	LR(104):	6926.358
		Prob > LR:	0.000
McFadden's R2:	0.308	McFadden's Adj R2:	0.298
ML (Cox-Snell) R2:	0.731	Cragg-Uhler(Nagelkerke) R2:	0.741
Count R2	: 0.464	Adj Count R2:	0.332
AIC:	2.997	AIC*n:	15816.911
BIC:	-28676.888	BIC':	-6034.962
BIC used by Stata:	16552.876	AIC used by Stata:	15816.911

Table 4: Multinomial logit crop choice model: Seasonal climate

Multinomial logistic regression		Number of obs	= 5277
		LR chi2(200)	= 9453.16
		Prob > chi2	= 0.0000
Log likelihood	= -6533.0545	Pseudo R2	= 0.4198

	COWPEA	SORGHUM	MINOR CROPS	MAIZE-BEANS
Temperature winter	0.03	2.78***	-1.05***	-0.20
	(.9)	(.44)	(.39)	(.5)
Temperature winter	-0.02	-0.08***	0.03***	0.00
squared	(.02)	(.01)	(.01)	(.01)
Temperature spring	-0.22	-4.76***	-0.36	-0.87
	(1.19)	(.51)	(.51)	(.65)
Temperature spring	0.03	0.11***	0.00	0.02
	(.02)	(.01)	(.01)	(.02)
Temperature summer	-5.63***	1.10**	-1.68***	-1.63
	(1.1)	(.55)	(.59)	(.86)
Temperature summer	0.10***	-0.02	0.03**	0.02
squared	(.02)	(.01)	(.01)	(.02)
Temperature fall	4.87***	-1.48**	1.68**	2.76***
	(1.19)	(.63)	(.73)	(.97)
Temperature Fall	-0.09***	0.03**	-0.02	-0.04
Squared	(.02)	(.01)	(.02)	(.02)
Precipitation winter	-0.07***	-0.09***	0.06***	0.01
	(.02)	(.02)	(.01)	(.01)
Precipitation winter	0.0007***	0.0005***	-0.0002**	0.00
Squared	(.)	(.)	(.)	(.)
Precipitation spring	0.01	0.05***	-0.06***	0.00
	(.02)	(.01)	(.01)	(.01)
Precipitation spring	0.00	-0.0003***	0.0001***	0.00
	(.)	(.)	(.)	(.)
Precipitation summer	0.19***	-0.05***	0.01	0.05***
	(.02)	(.01)	(.01)	(.01)
Precipitation summer	-0.0007***	0.0002***	0.00	-0.0002***
squared	(.)	(-0.00004)	(.)	(.)
Precipitation fall	-0.14***	0.03***	0.01	-0.03***
	(.02)	(.01)	(.01)	(.01)
Precipitation fall	0.0005***	-0.0001***	0.00	0.0001***
squared	(.)	(.)	(.)	(.)

Table 4: (continued)

	COWPEA	SORGHUM	MINOR CROPS	MAIZE-BEANS
Mean flow (mm)	0.10**	-0.04**	-0.08***	-0.04
	(.04)	(.02)	(.02)	(.03)
Log (Area of farmland)	0.08	0.10	-0.14***	-0.20***
	(.08)	(.06)	(.05)	(.05)
Elevation (m)	0.0008***	0.0006***	0.0007***	0.001***
	(.)	(0.0001)	(.)	(.)
Log (Household size)	0.73***	0.70***	0.36***	0.40***
	(.19)	(.13)	(.13)	(.14)
Dummy household with electricity	-0.79***	-1.71***	0.20	-0.21
	(.24)	(.22)	(.16)	(.18)
Soil type 1	0.51	2.40***	-2.62***	-0.96
	(.75)	(.71)	(.69)	(.7)
Soil type 2	-1.58***	-0.46	-1.05***	-1.04***
	(.37)	(.26)	(.32)	(.38)
Soil type 3	-0.90	-2.4***	2.07***	1.49***
	(.73)	(.71)	(.59)	(.59)
Soil type 5	1.10**	-0.92***	-0.66	-0.84
	(.55)	(.41)	(.39)	(.42)
Constant	0.17	27.00***	11.19***	-3.92
	(7.87)	(3.67)	(4.11)	(5.73)

Table 4: (continued)

	COWPEA-SORGHUM	MAIZE-GROUNDNUT	MAIZE-MILLET	MILLET-GROUNDNUT
Temperature winter	2.96***	0.64	2.06***	-2.29
	(1.02)	(.48)	(.61)	(1.41)
Temperature winter	-0.07***	-0.04***	-0.05***	0.05
squared	(.02)	(.01)	(.02)	(.03)
Temperature spring	-2.48**	-1.67***	-4.18***	2.80
	(1.27)	(.64)	(.65)	(1.95)
Temperature spring	0.06**	0.05***	0.1***	-0.03
	(.03)	(.01)	(.02)	(.04)
Temperature summer	-2.36**	-2.2***	0.02	4.99***
	(1.05)	(.68)	(.65)	(1.51)
Temperature summer	0.05***	0.045***	0.01	-0.09***
squared	(.02)	(.01)	(.01)	(.03)
Temperature fall	1.51	6.4***	0.52	-4.04***
	(1.04)	(1.03)	(.77)	(1.55)
Temperature fall	-0.04	-0.16***	-0.02	0.08***
squared	(.02)	(.03)	(.02)	(.03)
Precipitation winter	-0.13***	0.00	0.14***	0.10**
	(.03)	(.01)	(.02)	(.04)
Precipitation winter	0.001***	0.0003***	-0.0006***	-0.0005**
squared	(.)	(0.00006)	(.)	(.)
Precipitation spring	-0.03	-0.01	-0.13***	***29681
	(.02)	(.01)	(.02)	(.03)
Precipitation spring	0.00	0.00	0.0005***	0.00
	(.)	(.)	(.)	(.)
Precipitation summer	0.15***	0.06***	-0.03***	-0.09***
	(.02)	(.01)	(.01)	(.01)
Precipitation summer	-0.0005***	-0.0002***	0.0001***	0.0002***
squared	(0.00009)	(.)	(.)	(.)
Precipitation fall	-0.11***	-0.02***	0.04***	0.17***
	(.02)	(.01)	(.01)	(.02)
Precipitation fall	0.0004***	0.0001***	-0.0001***	-0.0006***
squared	(.)	(0.00003)	(.)	(.)

Table 4: (continued)

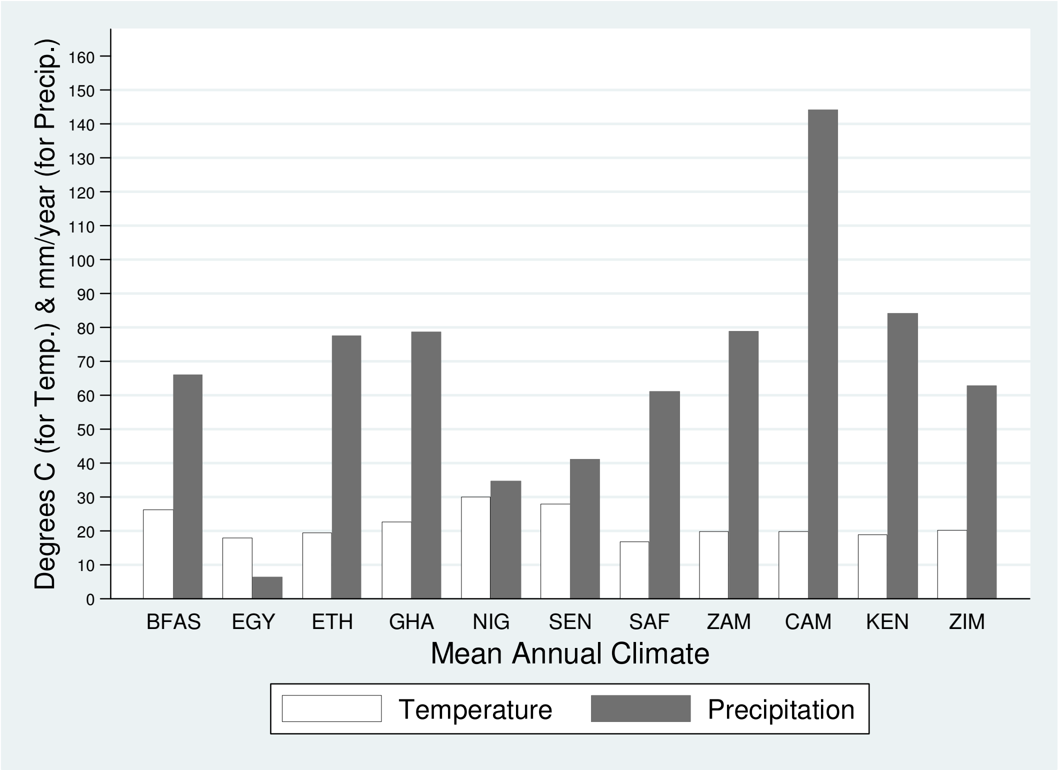
	COWPEA-SORGHUM	MAIZE-GROUNDNUT	MAIZE-MILLET	MILLET-GROUNDNUT
Mean flow (mm)	-0.09	-0.09***	-0.30***	-0.18**
	(.06)	(.03)	(.07)	(.08)
Log (Area of farmland)	0.18**	-0.02	0.08	0.08
	(.09)	(.04)	(.07)	(.12)
Elevation (m)	0.002***	0.0008***	0.002***	0.004***
	(.)	(.)	(.)	(.)
Log (Household size)	1.49***	0.76***	0.75***	0.58***
	(.18)	(.11)	(.17)	0.20
Dummy household with electricity	-1.80***	-0.51***	-0.96***	-0.64**
	(.27)	(.15)	(.24)	(.28)
Soil type 1	-0.30	0.45	-0.84	1.60**
	(.73)	(.7)	(.95)	(.74)
Soil type 2	-0.83***	-0.82***	-1.2***	-1.01**
	(.33)	(.22)	(.31)	(.42)
Soil type 3	-1.69**	-1.23	0.80	-1.70**
	(.72)	(.69)	(.94)	(.77)
Soil type 5	0.45	-1.44***	-2.21***	-1.95
	(1.1)	(.24)	(.48)	(1.22)
Constant	-2.61	-34.90	14.8***	-52.87***
	(7.92)	(6.72)	(4.79)	(15.99)

Notes: Base category crop: MAIZE

*** significant at 1% ** significant at 5%

Measures of fit for mlogit of cropcode

Log-Lik Intercept Only:	-11259.634	Log-Lik Full Model:	-6533.054
D(5069):	13066.109	LR(200):	9453.160
		Prob > LR:	0.000
McFadden's R2:	0.420	McFadden's Adj R2:	0.401
ML (Cox-Snell) R2:	0.833	Cragg-Uhler(Nagelkerke) R2:	0.845
Count R2:	0.537	Adj Count R2:	0.422
AIC:	2.555	AIC*n:	13482.109
BIC:	-30380.863	BIC':	-7738.937
BIC used by Stata:	14848.900	AIC used by Stata:	13482.109



Note: BFAS: Burkina Faso, CAM: Cameroon, EGY: Egypt, ETH: Ethiopia, GHA: Ghana, KEN: Kenya, NG: Niger, SEN: Senegal, SAF: South Africa, ZAM: Zambia, ZIM: Zimbabwe.

Figure 1: Mean annual temperature and precipitation

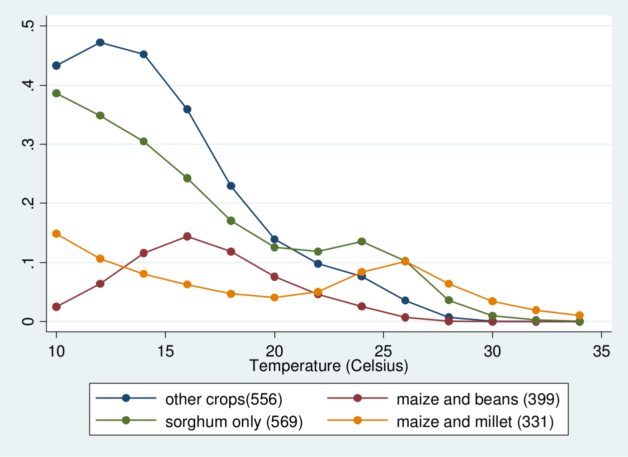


Fig 2a: Probability of selecting low temperature crops

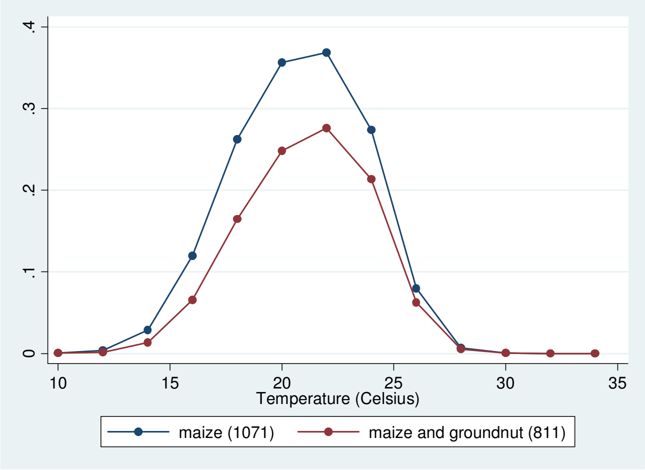


Fig 2b: Probability of selecting medium temperature crops

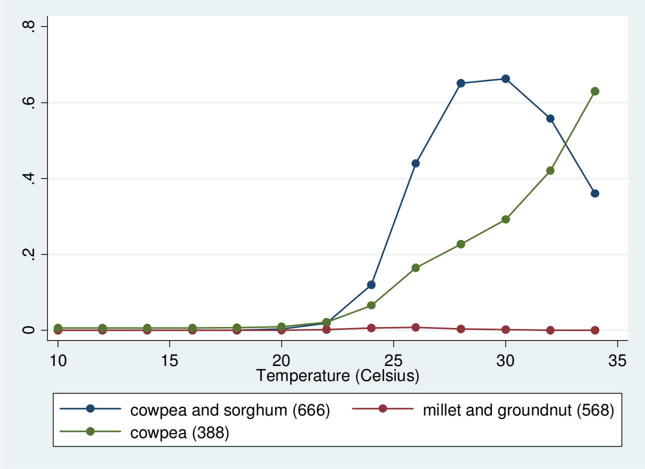


Fig 2c: Probability of selecting high temperature crops

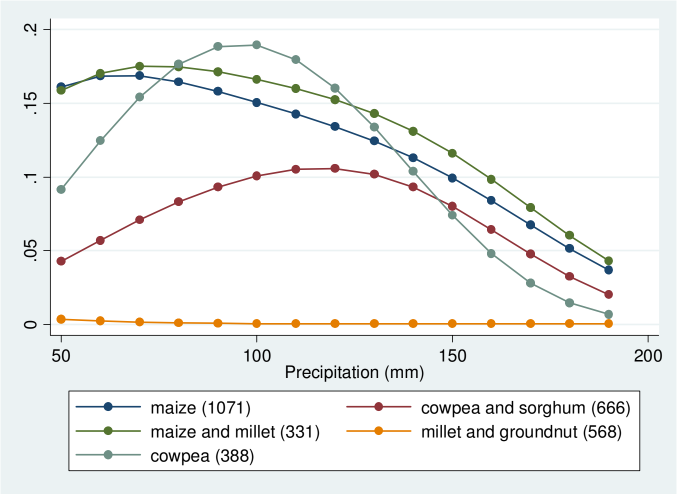


Fig 3a: Probability of selecting dry to moderate precipitation crops

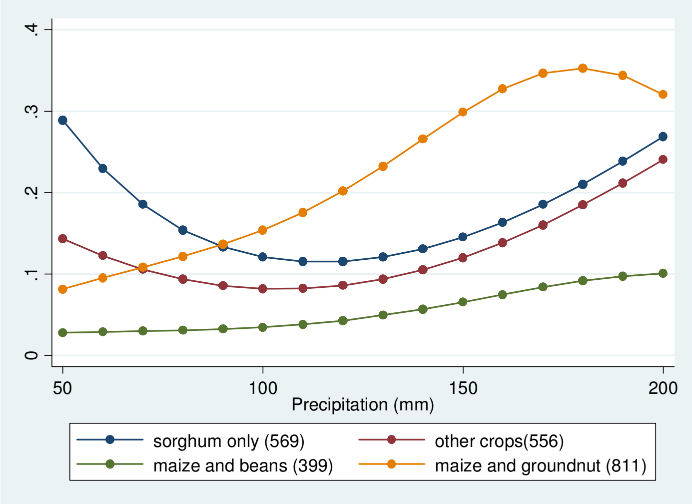


Fig 3b: Probability of selecting high precipitation crops

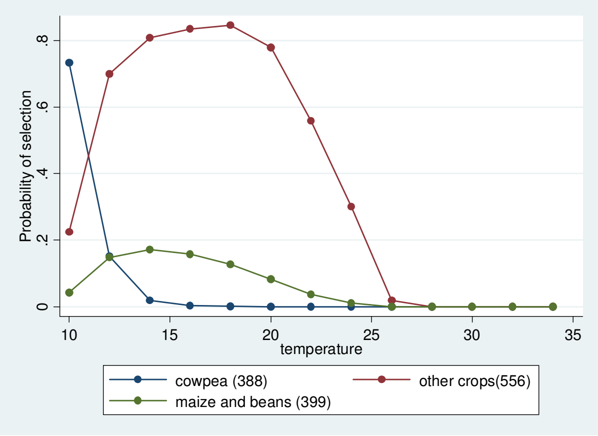
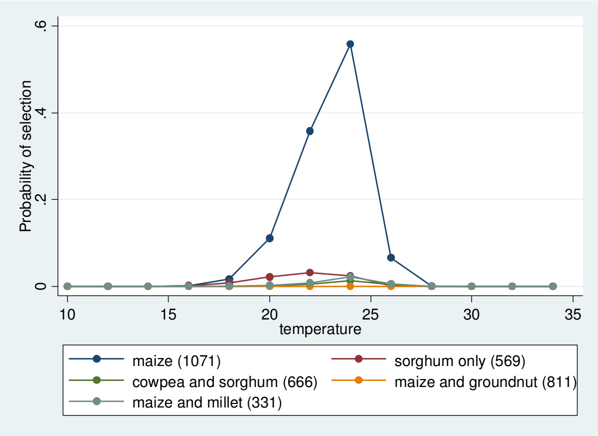


Fig 4a: Probability of selecting low temperature crops

(i) with maize



(ii) without maize

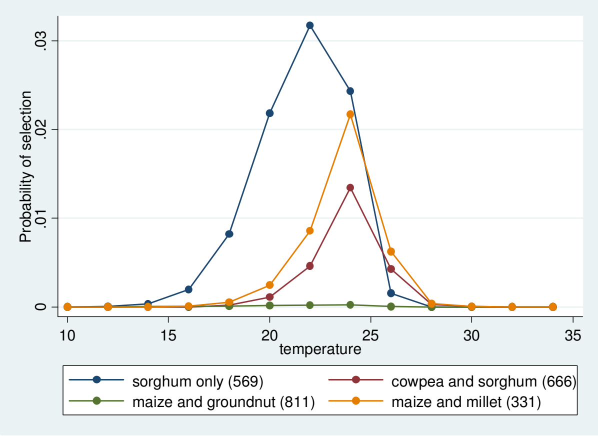
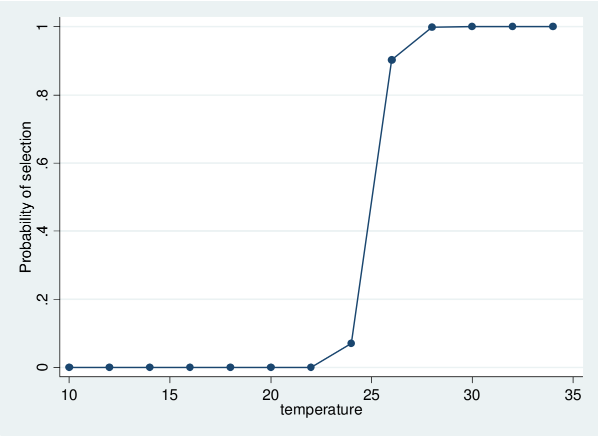


Fig 4b: Probability of selecting medium temperature crops



Note: Crop depicted above is millet-groundnut.

4c: Probability of selecting high temperature crops

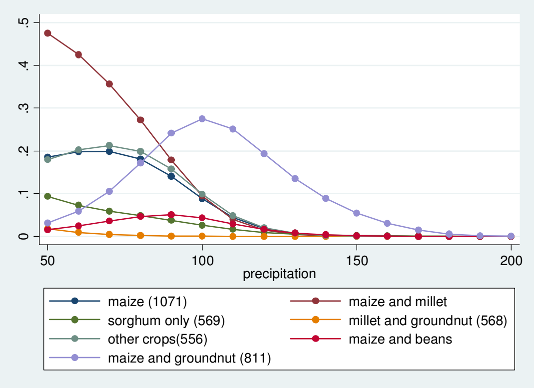


Fig 5a: Probability of selecting low to medium precipitation crops

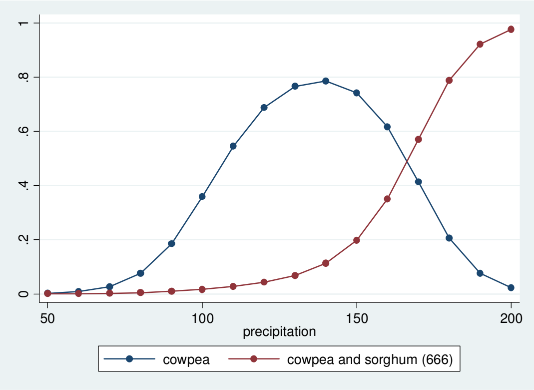


Fig 5b: Probability of selecting high precipitation crops