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Differential Adaptation Strategies to Climate Change in African Cropland by Agro-Ecological Zones

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Abstract

This paper quantifies how African farmers have adapted their crop and irrigation decisions to their farm's current agro-ecological zone. The results indicate that farmers carefully consider the climate and other conditions of their farm when making these choices. These results are then used to forecast how farmers might change their irrigation and crop choice decisions if climate changes. The model predicts African farmers would adopt irrigation more often under a very hot and dry climate scenario but less often with a mild and wet scenario. However, farms in the deserts, lowland humid forest, or mid elevation humid forest would reduce irrigation even in the very hot and dry climate scenario. Area under fruits and vegetables would increase Africa-wide with the very hot and dry climate scenario, except in the lowland semi-arid agro-ecological zone. Millet would increase overall under the mild and wet scenario, but decline substantially in the lowland dry savannah and lowland semi-arid agro-ecological zones. Maize would be chosen less often across all the agro-ecological zones under both climate scenarios. Wheat would decrease across Africa. The authors recommend that care must be taken to match adaptations to local conditions because the optimal adaptation would depend on the agro-ecological zone and the climate scenario.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at Niggol.seo@yale.edu, Robert.mendelsohn@yale.edu, Adinar@worldbank.org, Rashid.hassan@up.ac.za, and Pradeep.kurukulasuriya@undp.org.

DIFFERENTIAL ADAPTATION STRATEGIES TO CLIMATE CHANGE IN AFRICAN CROPLAND BY AGRO-ECOLOGICAL ZONES[1]

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1. Introduction

Awareness of global warming has increased rapidly among scientists, policy makers, and the general public over the past decade (Nordhaus 1992, 2007, IPCC 1996, 2001, 2007). There is an increasing consensus that greenhouse gases should be curbed by international cooperation. However, the very high cost of completely eliminating greenhouse gas emissions suggests that mitigation policy should only slow climate change, not completely halt it at least in the near term (Nordhaus 1992, 2007). Consequently, even with an efficient international mitigation policy, global warming is likely to continue for several decades if not the rest of the century. Communities around the world should consequently be prepared to adapt to climate change. This is especially urgent for farmers who so clearly depend on the climate for their livelihood. Adaptation is especially urgent for low latitude developing country farmers who are expected to bear the brunt of climate change impacts (Mendelsohn et al., 2006). Agriculture in developing countries is one of the most vulnerable sectors of the global economy to climate change (Rosenzweig and Parry 1994, Kurukulasuriya et al 2006; Seo and Mendelsohn 2008c). Farmers will be especially hard hit if they do not adjust at all to new climates (Mendelsohn et al. 1994, Rosenzweig and Hillel 1998; Reilly et al. 1996).

Recent empirical studies indicate that farmers have already adapted to the existing climates that they face by choosing crops or livestock or irrigation (Kurukulasuriya and Mendelsohn 2007, 2008; Nhemachena and Hassan 2007; Seo and Mendelsohn 2008a, 2008b) ideal for their current climate. Farmers currently choose their crops or livestock or some mix of them to match their climate. It therefore follows that farmers are likely to select new crops and livestock as climate changes, at least in the long run. By studying adaptation, researchers can help farmers and policy makers identify efficient adaptations, adaptations that will maximize future income in new climate conditions.

Existing adaptation studies suggest that farmers should take different adaptation measures depending on their initial climate conditions. For example, a farmer in a wet location would choose vegetables more often than a farmer in a dry location would do. Farmers may also choose not to irrigate given that sufficient rainfall is available to support cultivation. However, these studies focused on the possibility of farmers to adapt to climate change but did not provide differential adaptation strategies specific to a certain zone. This information is crucial to the farmers and policy makers who are interested in making adjustments in anticipation of future climate changes because continental scale adaptation measures would be misleading due to a wide variety of agro-economic conditions across the continent. The purpose of this paper is to provide differential adaptation measures suitable for each location across the landscape. We make use of the Food and Agriculture Organization's (FAO) typology of Agro-Ecological Zones (AEZs) of Africa. Specifically, we focus on the choice of crops and irrigation in African cropland by 16 AEZs. The results of this analysis are then extrapolated from the sample of farms explored in this study to all of Africa using the AEZ classification of farms.

We begin by analyzing the choice of crops and irrigation as a function of climate and other control variables using a sample of over 9000 farmers from 11 countries in Africa who grow crops. We then use the FAO classification of African cropland into 16 AEZs to examine AEZ specific adaptation strategies. We use these zone specific adaptation strategies to see how adaptations would be applied across Africa.

The next section develops a simple theoretical model of crop and irrigation choice. We use a logit to explain irrigation choice and a multinomial logit to examine crop choice. In the following section, we describe the data used in this paper which is based on GEF/World Bank project in Africa and the FAO classification of Agro-Ecological Zones. In the rest of the paper, we present empirical results and simulation results of the impacts of climate change on these decisions based on two climate models. We conclude the paper with a summary of key results and a discussion of relevant policy insights.

2. Economic Theory

Farmers are observed to make many management decisions on their farms. We assume that they make these choices to maximize profit. Through generations of learning by doing, most farmers know what choices work best on their farms. With changing conditions, of course, farmers must determine how to adapt, how to change these choices. Farmers are commonly observed adjusting to changes in government policy, market prices, availability of new varieties, and changes in access as these changes occur. This paper does not address the short term problems farmers face keeping up with rapidly changing conditions. Rather, we focus on long-term adaptations that farmers make after they have had time to learn about the new conditions and adjust to them.

In this paper, we focus on two important decisions by crop farmers: whether to irrigate or not, and which crops to grow. Let the profit associated with irrigation in a specific AEZ (*w*) be written in the following form:

$$\pi_{jw} = V_j(Z_w) + \varepsilon_{jw} \quad \text{where j} = 0 \text{ or } 1, \text{ w} = 1,..., \text{W}. \tag{1}$$

where *Z* is a vector of exogenous characteristics of the farm and characteristics of the farmer. The subscript j=1 refers to irrigated farms and j=0 to rainfed farms. The subscript w refers to the AEZs. The farmer will choose to have irrigation if:

$$\pi_1^* > \pi_0^* \tag{2}$$

Assuming that the cumulative distribution of the error term is a logistic function, the choice of whether or not to establish irrigation system can be estimated with a standard logit model.

Modeling the choice of crops is slightly more involved technically since the choice set includes more than two alternatives. Additionally, some farmers can choose a combination of different crops whereas other farmers select only one crop. To include all combinations of crops as a discrete choice is not feasible since African farmers report more than 50 individual crops. In this study, we examine all the combination of crops that appear in significantly large numbers of farms in the sample (Seo and Mendelsohn 2008a, Kurukulasuriya and Mendelsohn 2007). The majority of farms have a single crop or a combination of two crops in our sample.

Let the profit from raising a specific crop or a combination of crops for a farm in AEZ *w* be written in the following form:

$$\pi_{njw} = V\ (Z_{njw}) + \varepsilon_{njw} \quad \text{where n} = 1,..., \text{N, j} = 1,..., \text{J and w} = 1,..., \text{W}. \tag{3}$$

where *Z* is a vector of all the independent variables that are appropriate for the explanation of farm profits. For example, Z could include climate, soils, water availability, access variables, electricity provision, household size, education of the farmer, and crop prices. The subscript n refers to the n-th farm in the sample, j refers to a crop or a combination of crops, and w refers to Agro-Ecological Zones at which the farm is located. Note that the farmer chooses crop j, but he does not choose AEZ w. The profit function in equation 3 is composed of two components: the observable component *V* and an error term ε. The error term is not known to the researcher but may be known to the farmers. The error term is known up to its cumulative distribution.

The decision of a farmer who is located in AEZ *w* is to choose one crop from the many alternative crops that is most profitable to him given the external conditions, which can be written succinctly as follows:

$$\arg\max_{j}\{\pi^{*}_{n1w}, \pi^{*}_{n2w}, ..., \pi^{*}_{nJw}\} \quad (4)$$

Suppressing subscript n and *w* for convenience of the discussion for the moment, the farmer will choose crop j over all other crops if:

$$\pi_j^{*} > \pi_k^{*} \text{ for } \forall \text{ k} \neq j. \quad [\text{or if } \varepsilon_k - \varepsilon_j < V\ (Z_j) - V\ (Z_k) \text{ for k} \neq j] \quad (5)$$

The probability P_j for crop j to be chosen is then

$$P_j = \Pr[\varepsilon_k - \varepsilon_j < V_j - V_k]\ \forall \text{ k} \neq j \text{ where } \mathrm{V_j} = \mathrm{V}\ (\mathrm{Z_j}) \quad (6)$$

The probability for the n-th farm is calculated by integrating the appropriate indicator function as follows:

$$P_{nj} = \int_{\varepsilon} I(\varepsilon_{nk} - \varepsilon_{nj} < V_{nj} - V_{nk},\ \forall \text{ k} \neq j) \cdot f(\varepsilon_n)\, \mathrm{d}\varepsilon_n, \quad (7)$$

where I is the indicator function and f is the probability density function of the error term. If the density f follows an identical and independent Type I Extreme Value distribution and the profit can be written linearly in the parameters, then the probability can be calculated by successive integration of the above density function as

$$P_j = \frac{e^{Z_j\gamma_j + Z_j^2\alpha_j}}{\sum_{k=1}^{J} e^{Z_k\gamma_k + Z_j^2\alpha_k}} \quad (8)$$

which gives the probability of crop j to be chosen among J crops (McFadden 1981). For each AEZ *w*, the marginal effect of climate change on the probability can be obtained by differentiating Equation (8):

$$\frac{\partial P_{jw}}{\partial z_l} = P_{jw}[\gamma_{jl} + 2Z_{jwl}\alpha_{jl}] - \sum_{k=1}^{J} P_{kw}[\gamma_{kl} + 2Z_{kwl}\alpha_{kl}] \text{ for w} = 1,2,...,\text{W}. \quad (9)$$

The coefficients of the choice model γ and α are not dependent on the AEZ. However, the marginal impact of climate on the probability of selecting a crop depends on the climate conditions in each AEZ and so will vary by AEZ.

3. Description of Data

A typology of AEZs was developed by the FAO as a mechanism to classify the growing potential of land using the length of the growing season (FAO 1978). The growing season is defined as the period where precipitation and stored soil moisture is greater than half of the evapotranspiration. The longer the growing season, the more crops can be planted (or in multiple seasons) and the higher are the yields (Fischer and van Velthuizen 1996; Vortman et al. 1999).

Figure 1 maps AEZs across Africa. AEZs are classified by climate, soils, and altitude. They are divided into five zones depending upon the length of the growing period: semi-arid, dry savannah, moist savannah, sub-humid, and humid forest. Each of these five zones is again divided into three zones depending upon elevation: lowland, mid-elevation, and high elevation. The remaining AEZ is desert. The Sahara desert occupies a vast amount of area in the north. There is also a desert in the south-western edge of the continent. South of the Sahara desert is semi-arid zones followed by dryland savannah, moist savannah, and humid forest. In central Africa around Cameroon, it is mostly humid forest in high elevation with high rainfall. This high-elevation humid forest turns into mid-elevation and then into dry savannah as it stretches east toward Kenya. South of the humid forest is moist savannah followed by dry savannah. The AEZs of South Africa are mostly moist savannah in the east, dry savannah in the center, and desert in the west.

The economic data for this study were collected by national teams as part of the GEF/World Bank project on climate change in Africa (Dinar et al 2008). The survey asked detailed questions on crops and livestock operations during the agricultural period of July 2002 to June 2003. The data were collected for each plot within a household and household level data were constructed from plot level data. In each country, districts were chosen to get a wide representation of farms across climate conditions in that country. In each chosen district, a survey was conducted of randomly selected farms. The sampling was clustered in villages to reduce sampling cost. A total of 9,597 surveys were administered across the 11 countries in the study.

Data on climate were gathered from two sources (Mendelsohn et al. 2007). We relied on temperature data from satellites operated by the Department of Defense of the United States (Basist et al. 2001). The precipitation data came 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.

Soil data were obtained from FAO (2003). The FAO data provide information about the major and minor soils in each location as well as slope and texture. Data concerning the hydrology were obtained from the results of an analysis of climate change impacts on African hydrology (Strzepek & McCluskey, 2006). Using a hydrological model for Africa, the authors calculated flow and runoff for each district in the surveyed countries. Data on elevation at the centroid of each district were obtained from the United States Geological Survey (USGS 2004). The USGS data is derived from a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately one kilometer).

4. Empirical Results

Tables 1, 2, and 3 summarize the data on irrigation and crop choice in Africa. About 25% of the farms in our sample irrigated their land. The irrigation clearly depends on where the farm is located. Farms in dry places such as dry savannah, semi-arid, and deserts are highly likely to irrigate their land whereas farms in sub-humid and humid forest, especially in the lowland, do not.

Table 2 summarizes eight crops or combinations of crops that are chosen most often by African farmers. For Africa as a whole, maize (32%), millet (5%), wheat (7%), and fruits and vegetables (10%) are chosen widely as a single crop to manage. Most farms choose a mix of some crops: fruit/vegetables and maize (17%), maize and ground nuts (14%), millet and ground nuts (11%), millet and sorghum (6%). The crop shares reflect the percent of farms that select this particular crop or crop combination.

The distribution of crops chosen differs widely across different AEZs, which is shown in Table 3. Maize is chosen very frequently in mid elevation dry or moist savannah, but by fewer farms in the deserts, high elevation dry savannah, or high elevation semi-arid farms choose maize. Fruits and vegetables with maize or without maize are chosen very often by the farms in the humid forests regardless of the elevation of the farms. Wheat is the choice for many farms in high elevation or dry places including deserts. Millet is the choice of crop when the farm is located in dry places such as high elevation dry savannah, lowland dry savannah, or mid elevation semi-arid AEZs. Ground nut and maize combination is chosen most often in mid elevation moist savannah. Ground nut and millet combination is chosen most often in lowland dry savannah.

Tables 1, 2, and 3 clearly suggest that both irrigation and crop choice vary with AEZs[7]. To test whether there is a statistical relationship between these choices and climate, we run in Table 4 a binary choice model of whether to choose irrigation or not over climate variables and controls. Control variables in Table 3 include a set of soils, water availability, and household characteristics. The choice of irrigation clearly depends on dominant soil types. When soil Arenasols is dominant in the district, farmers tend to choose rainfed agriculture. On the other hand, when the soil is Cambisols or Planasols, they irrigate more often. Large farms are more likely to irrigate, so are farms with electricity. Irrigation requires a substantial capital investment in many cases and electricity as well. Farms in high elevation tend to irrigate less often. The amount of water flowing into the districts does not affect the choice. The variables of most concern to us are climate variables. The model is specified as a quadratic function of summer and winter temperature and precipitation. All four seasons were not relevant for modeling irrigation choice. Many climate variables are significant, though weakly, indicating that irrigation decision depends on the climate where the farm is located[8]. The Likelihood Ratio test indicates the overall model is very significant.

To understand what might happen to irrigation adoption when the current climate is disturbed, we calculate marginal effects of climate change on the probability to choose irrigation at the mean climate of the corresponding AEZs in Table 5. As temperature increases, farmers tend to irrigate more frequently. Irrigation is clearly an adaptation strategy to warming. When precipitation increases, they tend to irrigate less often and resort to natural rainfall more often. However, these regional results do not apply to all AEZs. Farms in the deserts reduce irrigation when temperature increases. Similarly, when precipitation increases, farms close to the deserts

[7] Note that we do not use AEZs as independent variables in which case climate variables are correlated with.
[8] This implies climate change will shift the current AEZ and irrigation decisions.

increase irrigation.

The second analysis of cropland farm adaptations is crop switching. Table 6 shows seven sets of regressions, setting wheat as base case, from multinomial logit model of crop choice. The choice set includes fruits and vegetables, maize, millet, and wheat as a single crop, and a combination of fruits/vegetables and maize, a combination of maize and ground nuts, a combination of millet and ground nuts, and a combination of millet and sorghum. The choice of one crop from the eight available crops was run against climate variables, soils, water availability, household characteristics, and crop prices. Soils are significant factors to the decision of crops to plant. When soil is Nitosols, farmers tend to choose the seven crops more often in contrast to wheat. When soil is Gleysols, it reduces the chance of millet being chosen. Large farms tend to avoid millet. Farms in high elevation tend to choose millet for a single crop or in combination with sorghum or ground nuts. Family size does not matter in the choice of crops. Farms with electricity tend to choose fruits and vegetables or millet less often. The amount of water flowing in the district affects the crop choice significantly. When summer flow is high, it reduces the choice of the seven crops while when fall flow is high it increases the choice of these crops in contrast to wheat. Crop choices depend on crop prices of maize, millet, and wheat. The prices of ground nuts or sorghum are not significant. When maize or millet price is higher, farmers tend to reduce the planting of these seven crops while when wheat price is higher, they increase the planting of these crops[9].

The regressions confirm that the choices of all the crops are sensitive to climate. In contrast to irrigation choice, most of the seasonal climate parameters are significant. All four seasons are relevant in modeling crop choice in part because it involves many alternatives in the choice set than the binary choice of irrigation. Most of the quadratic terms are also significant indicating second order relationship of the choice of each crop to the corresponding climate variables.

However, due to its complex specification in Table 6, it is difficult to interpret these results in terms of climate vulnerability. In Table 7, we calculate marginal effects of an annual increase in temperature and an annual increase in precipitation evaluated at the mean climate for the sample of farms that choose each crop combination. If temperature increases slightly, farmers tend to

[9] The current model is only concerned with supply side. But it is likely that demand conditions such as preference changes affect the future crop choice.

move away from wheat, maize, millet-ground nuts, or millet-sorghum. Instead, they choose fruits-vegetables, fruits-vegetables-maize, millet, or ground nuts-maize. If precipitation increases, farmers move away from groundnut-millet and maize towards fruits-vegetables-maize, maize-groundnut, and millet.

These behavioral changes at the African level, however, do not hold for all Agro-Ecological Zones. Although the choice of fruits-vegetables is expected to increase when rainfall increases, it is reduced in dry zones such as deserts, lowland dry savannah, and lowland semi-arid zone. Similarly, millet will decrease even though temperature increases if the farm is located in lowland moist savannah or lowland sub-humid AEZs. Maize will decrease with higher temperature, but the exceptions are deserts and high elevation dry savannah.

5. Forecasting Climate Change Impacts on Irrigation and Crop Choices

As climate change unfolds over the coming century, farmers are likely to adapt to it by switching crops or irrigating their land. In this section, we use the results from the previous section to predict how farmers might adapt in the future. We explore how adaptations might be different depending on the climate scenario. We also explore how they might be different depending on the AEZ of each farm. In practice, future farm practices will also depend on economic development, technological changes, and price changes. We do not examine these other important influences but rather focus simply on the role of climate change. We are predicting how climate influences farm choice, not each farmer's actual future choices. We assume all other factors remain unchanged and examine the effects of climate change alone.

We examine a set of climate change scenarios that are consistent with the range of likely outcomes predicted in the most recent Intergovernmental Panel on Climate Change report (IPCC 2007). Specifically, we use the A1 scenarios from the following two models: CCC (Canadian Climate Centre) (Boer et al. 2000) and PCM (Parallel Climate Model) (Washington et al. 2000).

Table 8 presents the mean temperature and rainfall predicted by the two models for the years 2020 and 2100. In Africa in 2100, PCM predicts a 2°C increase and CCC a 6°C increase in temperature. Rainfall predictions vary. PCM predicts a 10% increase in rainfall in Africa and CCC a 10% decrease by 2100. Even though the mean rainfall in Africa is predicted to increase/decrease depending on the scenario, there is also substantial variation in rainfall across countries. Examining the path of climate change over time reveals that temperatures are predicted to increase over time for all two models. Precipitation predictions, however, vary across time for Africa: CCC predicts declining precipitation whereas PCM predicts a slight increase. However, it should be noted that predicted changes vary slightly for individual countries and regions.

5.1 Analysis for Africa

We first present the predicted changes in the probabilities to choose irrigation for Africa as a whole in Table 9. In 2020, under the relatively hot CCC scenarios, more farmers are expected to irrigate their land. On the other hand, if precipitation increases as in PCM, farmers tend to irrigate less often and rely on natural rainfall. By 2100, farmers increase irrigation by 15% under the CCC scenario, but reduce it by 2% under the PCM scenario.

Table 10a describes simulation results of crop choice by 2020 for Africa. Under CCC, farmers choose fruits/-maize, millet, or millet- sorghum more often while they choose the other crops less often. The results from PCM are quite different. They increase fruits/ vegetables, millet, or millet-sorghum while they reduce the other crops. By the end of this century, as shown in Table 10b, farmers increase fruits/vegetables with maize or without maize substantially as well as millet and sorghum. On the other hand they reduce maize substantially under CCC. Under PCM, they choose fruits/vegetables or millet at the sacrifice of maize.

5.2 Analysis by Agro-Ecological Zones

Which crops to grow or whether to irrigate is certainly dependent on the current AEZ of the farm. Farmers cannot simply follow the advice which is deemed appropriate for Africa as a whole. They must determine what is the most appropriate response to climate change in their AEZ.

As we can see in Table 9, African farmers are better off by adopting more irrigation under the CCC 2020 scenario. However, farms in the deserts, lowland humid forest, or mid elevation humid forest are better off by reducing irrigation in the same scenario. Under PCM 2100, farmers tend to irrigate less often due to higher precipitation, but the farms in the deserts are still better off by irrigating more often.

In Figure 2, we extrapolate our results to all of Africa using AEZ information. The figure maps changes in the probability to irrigate the land. Under the CCC scenario (Left), farmers will increase irrigation substantially due to higher temperature expected in this scenario. The expected increase is lower in the deserts while it is higher in West Africa, Central Africa, North of the Sahara desert, and East Africa. Under the PCM scenario (Right), on the other hand, farmers reduce irrigation overall except for the desert areas. The reduction is largest in the lowland and wet zones.

Crop choice would also vary widely across the AEZs. Table 10a describes which crops would likely be chosen in each AEZ. Although the combination of fruits/ vegetables and maize is expected to increase in Africa under CCC 2020, many AEZs would see the decline of this combination, especially in the high elevation semi-arid AEZ. Similarly, maize is likely to decline Africa wide under CCC 2020, but it will increase in some AEZs such as high elevation dry savannah.

By 2100, as shown in Table 10b, these differential responses continue to magnify. Fruits and vegetables increase Africa wide under the CCC scenario, but they are expected to decline substantially in the lowland semi-arid AEZ. Under the PCM scenario, millet increases overall, but it declines substantially in the lowland dry savannah and lowland semi-arid AEZs. Not all the crops exhibit differential responses across the AEZs. For example, maize is chosen less often across all AEZs under both climate scenarios.

In Figures 3 and 4, we extrapolate the results for two crops, maize and fruits/vegetables, to all of Africa using the AEZ information. Maize will be reduced across all of Africa due to higher temperature, but farms in the lowland wet zones are hit the hardest under CCC. Under PCM, however, farms in the high elevation are the most affected. In the case of fruits and vegetables, the variation across the AEZs is much larger. Under CCC, it will increase substantially in high elevations, lowland savannahs, and in Southern Africa. Farms in the deserts or lowland wet zones will lose this type of crop. The probability distribution under PCM will be similar to that under CCC with some areas seeing larger increases while other areas seeing larger losses.

6. Conclusion and Policy Implications

This paper quantifies differential farm adaptations taken by cropland farmers in Africa in 16 Agro-Ecological Zones. We rely on the economic data from the recently completed GEF/World Bank project and the FAO classification of the AEZs of Africa. We focus on two important farm adaptation decisions in cropland: irrigation and crop switching. Simple logit and multinomial logit models are used to examine the sensitivities of these decisions to climate.

We find that farmers make irrigation decisions to match the current AEZ in which the farm is located. Comparing choices across climates, at the African continental level, farmers tend to irrigate more frequently in warmer climates. In wetter climates, they tend to irrigate less often and resort to natural rainfall more often. However, these regional results do not apply to all AEZs. Farms in the deserts reduce irrigation when temperature increases. Similarly, when precipitation increases, farms close to the deserts and dry areas increase irrigation.

Crop choices also depend on the current AEZs. At the African continental level, in warmer places, farmers tend to choose wheat, maize, millet-ground nuts, or millet-sorghum less often and they instead choose fruits/vegetables, fruits/vegetables-maize, millet, or ground nuts-maize more often. In wetter places, farmers choose fruits/vegetables or millet more often at the expense of wheat or maize. However, the responses differ substantially across the AEZs. Although fruits/vegetables are expected to increase in wetter places, they decline in dry zones such as deserts, lowland dry savannah, and lowland semi-arid zone. Similarly, millet will decrease even though temperature increases if the farm is located in lowland moist savannah or lowland sub-humid AEZs. Maize will decrease with higher temperature, but not in deserts and high elevation dry savannah. However, farmers across Africa are less likely to choose wheat in warmer places. .

Based on the estimated parameters from the sample, we simulated how these farm choices might change as climate changes. The results indicate that by 2100, African farmers will adopt more irrigation under the very hot and dry CCC scenario but less irrigation under the mild and moist PCM scenario. However, farms in the deserts, lowland humid forest, or mid elevation humid forest reduce irrigation even under CCC. Similarly, farms in the deserts irrigate more even under PCM.

The distribution of crops across Africa in the future will be different depending upon which climate scenario occurs. Fruits and vegetables will increase Africa wide under CCC, but decline substantially in the lowland semi-arid AEZ. Under PCM, millet will increase overall, but it will decline substantially in the lowland dry savannah and lowland semi-arid AEZs. However, not all the crops exhibit differential responses across the AEZs. For example, maize is chosen less often across all AEZs under all the climate scenarios. Wheat will also decline across Africa as climate warms.

Policy makers should take note of the spatial variation of desired adaptations across the AEZs.

First, AEZ-specific policies could be designed for each AEZ. These polices could be the same across many African countries. Second, adaptations can be designed to match climate change over time as well. Policy makers can prepare the needed infrastructure, institutions, and budgets both across space and across time.

Although there is a need for an African-wide policy, it probably should not be a blanket policy that treats every location alike. Rather, the ideal policy would be a quilt like arrangement designed around AEZs. Because AEZs do not recognize political boundaries, they become trans-boundary in nature. As such, experience gained by one country in a 'shared' AEZ can be used by a neighboring country as well. This fact calls for cooperation among countries that share similar AEZs. Institutions can be developed that transfer technologies, experience, and data. All these may work to the benefit of farmers residing and working in Africa who share a common AEZ.

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Table 1: Percentage of Irrigated Farms by AEZs

AEZ	Description	Number	Percentage
Africa		2147	23.59
AEZ 1	Desert	821	85.61
AEZ 2	High elevation dry savanna	93	79.49
AEZ 3	High elevation humid forest	317	33.69
AEZ 4	High elevation moist savannah	240	63.66
AEZ 5	High elevation semi-arid	67	91.78
AEZ 6	High elevation sub-humid	491	61.38
AEZ 7	Lowland dry savannah	509	15.42
AEZ 8	Lowland humid forest	103	8.29
AEZ 9	Lowland moist Savannah	417	17.5
AEZ 10	Lowland semi-arid	288	41.2
AEZ 11	Lowland sub-humid	159	12.36
AEZ 12	Mid-elevation dry savannah	391	29.09
AEZ 13	Mid-elevation humid forest	226	22.97
AEZ 14	Mid-elevation moist savannah	636	24.32
AEZ 15	Mid-elevation semi-arid	97	72.39
AEZ 16	Mid-elevation sub-humid	498	47.93

Table 2: Percentage of Farms Adopting Each Crop Choice in Africa

Crops	Percentage	Crops	Percentage
Fruits/Vegetables and Maize	16.62	Maize and ground nut	13.55
Fruits/Vegetables	9.94	Millet	4.79
Ground nut and Millet	10.86	Millet and Sorghum	6.11
Maize	31.67	Wheat	6.45

Table 3: Percentage of Farms Adopting Each Crop Choice by AEZs

AEZ	Percentage	AEZ	Percentage
AEZ 1 Desert		AEZ 9 Lowland moist Savannah	
Fruits/Vegetables and Maize	10.13	Fruits/Vegetables and Maize	15.89
Fruits/Vegetables	26.58	Fruits/Vegetables	5.66
Ground nut and Millet		Ground nut and Millet	11.43
Maize	14.87	Maize	28.07
Maize and ground nut		Maize and ground nut	16.1
Millet		Millet	5.01
Millet and Sorghum	0.95	Millet and Sorghum	11.53
Wheat	47.47	Wheat	6.31
AEZ 2 High elevation dry savanna		AEZ 10 Lowland semi-arid	
Fruits/Vegetables and Maize		Fruits/Vegetables and Maize	12.24
Fruits/Vegetables	12.5	Fruits/Vegetables	27
Ground nut and Millet		Ground nut and Millet	3.8
Maize	2.08	Maize	11.39
Maize and ground nut		Maize and ground nut	0.42
Millet	14.58	Millet	5.91
Millet and Sorghum	22.92	Millet and Sorghum	5.06
Wheat	47.92	Wheat	34.18
AEZ 3 High elevation humid forest		AEZ 11 Lowland sub-humid	
Fruits/Vegetables and Maize	41.93	Fruits/Vegetables and Maize	24.5
Fruits/Vegetables	7.59	Fruits/Vegetables	14.18
Ground nut and Millet		Ground nut and Millet	4.44
Maize	29.91	Maize	35.53
Maize and ground nut	1.9	Maize and ground nut	17.05
Millet	0.16	Millet	1.72
Millet and Sorghum	5.85	Millet and Sorghum	2.15
Wheat	12.66	Wheat	0.43
AEZ 4 High elevation moist savannah		AEZ 12 Mid-elevation dry savannah	
Fruits/Vegetables and Maize	24.34	Fruits/Vegetables and Maize	6.46
Fruits/Vegetables	2.65	Fruits/Vegetables	3.17
Ground nut and Millet	1.33	Ground nut and Millet	0.35
Maize	26.11	Maize	46.01
Maize and ground nut	3.1	Maize and ground nut	22.3
Millet	5.75	Millet	1.29
Millet and Sorghum	12.39	Millet and Sorghum	9.51
Wheat	24.34	Wheat	10.92

AEZ 5 High elevation semi-arid		AEZ 13 Mid-elevation humid forest	
Fruits/Vegetables and Maize		Fruits/Vegetables and Maize	36.71
Fruits/Vegetables	38.89	Fruits/Vegetables	13.72
Ground nut and Millet		Ground nut and Millet	
Maize		Maize	32.25
Maize and ground nut		Maize and ground nut	6.86
Millet		Millet	0.17
Millet and Sorghum	55.56	Millet and Sorghum	2.06
Wheat	5.56	Wheat	8.23
AEZ 6 High elevation sub-humid		AEZ 14 Mid-elevation moist savannah	
Fruits/Vegetables and Maize	26.08	Fruits/Vegetables and Maize	14.82
Fruits/Vegetables	7.11	Fruits/Vegetables	3.33
Ground nut and Millet		Ground nut and Millet	0.52
Maize	29.53	Maize	44.8
Maize and ground nut	0.43	Maize and ground nut	22
Millet	1.08	Millet	1.49
Millet and Sorghum	16.16	Millet and Sorghum	7.58
Wheat	19.61	Wheat	5.46
AEZ 7 Lowland dry savannah		AEZ 15 Mid-elevation semi-arid	
Fruits/Vegetables and Maize	6.17	Fruits/Vegetables and Maize	3.33
Fruits/Vegetables	6.1	Fruits/Vegetables	23.33
Ground nut and Millet	25.88	Ground nut and Millet	
Maize	27.57	Maize	6.67
Maize and ground nut	11.25	Maize and ground nut	
Millet	10.64	Millet	23.33
Millet and Sorghum	6.91	Millet and Sorghum	36.67
Wheat	5.49	Wheat	6.67
AEZ 8 Lowland humid forest		AEZ 16 Mid-elevation sub-humid	
Fruits/Vegetables and Maize	35.08	Fruits/Vegetables and Maize	35.9
Fruits/Vegetables	23.43	Fruits/Vegetables	8.06
Ground nut and Millet		Ground nut and Millet	0.35
Maize	33.42	Maize	23.29
Maize and ground nut	8.07	Maize and ground nut	3.15
Millet		Millet	1.93
Millet and Sorghum		Millet and Sorghum	10.51
Wheat		Wheat	16.81

Table 4: Logit Model of Irrigation choice

Variable	Estimate	Chisq Statistic	P value
Intercept	0.9447	1.52	0.2169
Summer Temperature	-0.0847	2.73	0.0983
Summer Temperature^2	-0.00015	0.02	0.8866
Summer Precipitation	-0.00481	9.38	0.0022
Summer Precipitation^2	5.48E-06	0.95	0.3287
Winter Temperature	-0.0572	1.12	0.2907
Winter Temperature^2	0.00489	10.69	0.0011
Winter Precipitation	-0.00423	3.14	0.0762
Winter Precipitation^2	-3.77E-06	0.05	0.8175
Flow summer	-0.0373	0.25	0.6203
Flow winter	-0.4994	0.71	0.3978
Flow spring	0.5799	1.94	0.1634
Flow fall	0.0752	0.46	0.4991
Log farm land	0.1195	30.64	<.0001
Log elev	-0.0474	4.71	0.03
Log household size	0.5127	112.3	<.0001
Electricity	0.0317	44.3	<.0001
Soil Cambisols	1.1152	16.33	<.0001
Soil Lithosols	0.1568	0.58	0.4452
Soil Arenasols	-1.2377	108.38	<.0001
Soil Planasols	0.9985	5.98	0.0145

N=9102

LR=1231.5 (P<0.0001)

Table 5: Marginal Climate Effects on Probability of Irrigation (%)

	Africa	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Base	0.499	0.561	0.488	0.484	0.467	0.498
T (˚C)	0.011	-0.005	0.011	0.007	0.007	0.007
P (mm/mo)	-0.001	0.000	-0.001	-0.002	-0.001	-0.001

	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11
Base	0.475	0.476	0.517	0.513	0.500	0.558
T (˚C)	0.006	0.017	0.012	0.015	0.018	0.014
P (mm/mo)	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001

	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Base	0.428	0.466	0.419	0.488	0.489
T (˚C)	0.007	0.008	0.006	0.006	0.008
P (mm/mo)	-0.001	-0.002	-0.001	-0.001	-0.001

Table 6: Multinomial Logit Model of Crop Choice

	Fruits/Vegetables and Maize		Fruits/Vegetables	
	Coefficient	Chi-sq	Coefficient	Chi-sq
Intercept	-5.6471	0.38	-3.6519	0.15
Summer Temperature	-9.4634	33.88	-8.6524	28.7
Summer Temperature^2	0.1398	16.34	0.1258	13.54
Summer Precipitation	-0.0411	6.56	-0.0345	3.68
Summer Precipitation^2	0.000081	2.52	0.000021	0.12
Winter Temperature	-4.1439	24.31	-3.2764	16.38
Winter Temperature^2	0.1097	19.04	0.0823	11.27
Winter Precipitation	-0.3908	40.78	-0.3795	38.63
Winter Precipitation^2	0.00395	19.83	0.00392	19.56
Spring Temperature	5.1551	33.77	3.2715	15.5
Spring Temperature^2	-0.1183	27.52	-0.0735	11.65
Spring Precipitation	0.1082	33.05	0.0914	19.52
Spring Precipitation^2	-0.00011	0.00	-0.00005	0.88
Fall Temperature	8.7806	21.63	8.9192	22.08
Fall Temperature^2	-0.1217	8.04	-0.1262	8.65
Fall Precipitation	0.0439	13.03	0.0451	9.39
Fall Precipitation^2	-0.00005	0.00	-0.00002	0.3
Flow summer	-5.8743	12.88	-8.7044	23.7
Flow winter	-8.5132	2.03	-16.9561	7.86
Flow spring	-1.2433	0.07	4.4689	0.85
Flow fall	6.6689	14.79	9.4867	29.27
Log farm land	0.0048	0.00	0.0115	0.01
Log elev	0.3048	3.02	0.2013	1.48
Log household size	0.0317	0.01	-0.0978	0.13
Electricity	-0.4545	3.61	-0.7801	10.37
Soil Gleysols	0.6272	0.15	-0.1618	0.01
Soil Nitosols	6.454	34.63	4.6676	19.13
Maize price	-4.1686	3.76	-2.3409	1.3
Ground nuts price	0.421	0.13	-1.5366	1.6
Millet price	-11.2749	8.19	-11.277	7.93
Wheat price	12.1774	21.39	10.3714	14.2
Sorghum price	1.1661	0.28	3.3064	2.25

Note: N=4882, LR test= P<0.001

Table 6: Continued.

	Ground nuts and millet		Maize	
	Coefficient	Chi-sq	Coefficient	Chi-sq
Intercept	-66.4997	10.89	-5.9205	0.44
Summer Temperature	-5.9788	6.18	-9.126	33.31
Summer Temperature^2	0.1164	6.27	0.1418	17.86
Summer Precipitation	-0.3102	62.81	-0.00013	0
Summer Precipitation^2	0.000895	41.34	-0.0001	3.73
Winter Temperature	-11.8131	21.09	-2.7359	11.63
Winter Temperature^2	0.2822	19.58	0.0577	5.71
Winter Precipitation	-0.3872	21.13	-0.34	31.14
Winter Precipitation^2	0.00357	14.11	0.00367	17.13
Spring Temperature	15.911	17.04	4.0045	23.12
Spring Temperature^2	-0.3033	16.17	-0.0798	13.96
Spring Precipitation	0.0562	1.16	0.0693	13.16
Spring Precipitation^2	0.00018	0.22	0.000054	1.83
Fall Temperature	4.919	3.08	8.7403	22.41
Fall Temperature^2	-0.114	3.84	-0.1354	10.47
Fall Precipitation	0.3561	32.33	0.00945	0.61
Fall Precipitation^2	-0.00125	28.42	0.000066	0.00
Flow summer	-6.1847	7.41	-6.6475	16.8
Flow winter	7.7337	0.51	-10.0751	2.91
Flow spring	-15.7417	1.53	-0.7136	0.02
Flow fall	4.9392	5.03	7.5618	19.47
Log farm land	0.1058	0.29	0.0289	0.07
Log elev	0.8685	10.52	0.2768	2.59
Log household size	0.0824	0.06	-0.2302	0.77
Electricity	-0.1665	0.31	-0.4764	4.08
Soil Gleysols	0.1712	0.01	1.5694	1
Soil Nitosols	4.7433	15.88	5.6247	27.14
Maize price	-19.787	23.41	-6.6727	10.03
Ground nuts price	-0.2425	0.02	-0.2859	0.07
Millet price	-7.2536	2.54	-13.1645	11.32
Wheat price	19.3352	18.05	13.6417	28.65
Sorghum price	-1.534	0.37	1.7167	0.65

Table 6: Continued.

	Maize and Ground Nut		Millet		Millet and Sorghum	
	Coefficient	Chisq	Coefficient	Chi-sq	Coefficient	Chi-sq
Intercept	-23.0095	4.18	-43.5027	6.7	-15.515	2.41
Summer Temperature	-10.6886	39.09	-5.0479	4.78	-10.1016	35.93
Summer Temperature^2	0.1739	23.34	0.1184	7.06	0.1804	25.61
Summer Precipitation	-0.0151	0.61	-0.2817	55.14	-0.0426	3.69
Summer Precipitation^2	-8.98E-06	0.02	0.000836	42.87	0.0001	1.69
Winter Temperature	-2.9099	9.47	-5.1111	5.21	-1.4776	2
Winter Temperature^2	0.0401	2.09	0.1365	5.56	0.0196	0.42
Winter Precipitation	-0.3084	24.74	-0.3066	14.99	-0.4306	46.11
Winter Precipitation^2	0.00363	16.65	0.00282	8.8	0.00417	21.78
Spring Temperature	2.8425	7.96	7.6047	5.76	3.125	7.44
Spring Temperature^2	-0.0371	2.22	-0.1777	7.69	-0.0589	4.66
Spring Precipitation	0.058	7.15	0.0626	2.43	0.1449	33.94
Spring Precipitation^2	0.000088	2.34	0.000542	7.88	-0.00032	11.11
Fall Temperature	12.761	34.27	4.1057	2.89	9.8931	24.92
Fall Temperature^2	-0.2238	20.3	-0.0878	2.85	-0.1792	15.75
Fall Precipitation	0.0426	7.48	0.3982	49.43	0.043	3.63
Fall Precipitation^2	-0.00003	0.79	-0.00123	34.78	-0.00011	2.13
Flow summer	-6.0605	13.43	-4.5023	6.92	-7.4169	20.22
Flow winter	0.8522	0.02	2.6275	0.12	-17.6754	8.13
Flow spring	-10.7095	4.64	-18.7256	6.85	4.9707	1.06
Flow fall	6.0499	11.6	5.1426	7.43	9.0126	26.27
Log farm land	0.1071	0.89	-0.444	5.2	0.2179	2.93
Log elev	0.0945	0.24	1.4395	27.09	0.5663	6.61
Log household size	0.3825	1.89	-0.3592	1.13	0.2855	0.96
Electricity	-0.319	1.69	-0.0578	0.04	0.4211	2.15
Soil Gleysols	-0.1882	0.01	-6.4971	6.95	-0.22	0.02
Soil Nitosols	4.4139	16.29	5.2091	18.88	5.5647	24.2
Maize price	-7.1471	10.57	-24.3805	35.91	-4.8962	4.61
Ground nuts price	-0.9233	0.64	-0.8272	0.29	-0.0757	0
Millet price	-7.8208	3.77	-2.4492	0.3	-7.7912	3.68
Wheat price	16.2668	38.32	21.8431	30.63	11.3867	18.28
Sorghum price	-0.0693	0	-4.5841	2.57	-0.4599	0.04

Table 7: Marginal Climate Effects on Probability of Crop Choice by AEZs (%)

	Africa	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Fruits/Vegetables and Maize	0.1805	0.0729	0.0894	0.4491	0.2369	0.1505
T (˚C)	0.0172	0.0268	0.0219	0.0443	0.0255	0.0299
P (mm/mo)	0.0010	-0.0003	0.0005	0.0032	0.0019	0.0005
Fruits/Vegetables	0.0793	0.1366	0.0706	0.0812	0.0598	0.0802
T (˚C)	0.0115	0.0112	0.0223	0.0097	0.0098	0.0165
P (mm/mo)	0.0002	-0.0008	0.0003	0.0002	0.0002	0.0003
Ground nuts and millet	0.1136	0.0001	0.0241	0.0001	0.0149	0.0001
T (˚C)	-0.0066	0.0000	0.0174	0.0000	0.0043	0.0002
P (mm/mo)	-0.0020	0.0000	-0.0014	0.0000	-0.0007	0.0000
Maize	0.3376	0.1015	0.3145	0.3470	0.4046	0.4878
T (˚C)	-0.0280	0.0164	0.0098	-0.0391	-0.0176	-0.0078
P (mm/mo)	-0.0028	-0.0007	-0.0019	-0.0032	-0.0030	-0.0016
Maize and ground nuts	0.1412	0.0058	0.0137	0.0270	0.0412	0.0108
T (˚C)	0.0153	-0.0005	0.0053	-0.0009	0.0074	0.0017
P (mm/mo)	0.0025	0.0000	0.0002	0.0005	0.0008	0.0001
Millet	0.0414	0.0083	0.0756	0.0043	0.0357	0.0136
T (˚C)	0.0004	0.0010	0.0173	0.0006	0.0059	0.0066
P (mm/mo)	0.0011	0.0003	0.0019	0.0003	0.0011	0.0006
Millet and Sorghum	0.0447	0.0642	0.0794	0.0418	0.0687	0.1459
T (˚C)	-0.0005	0.0026	-0.0019	-0.0031	0.0058	-0.0083
P (mm/mo)	0.0000	-0.0004	-0.0001	-0.0001	0.0000	0.0000
Wheat	0.0616	0.6106	0.3328	0.0496	0.1382	0.1111
T (˚C)	-0.0093	-0.0576	-0.0920	-0.0114	-0.0410	-0.0387
P (mm/mo)	-0.0001	0.0019	0.0005	-0.0008	-0.0003	0.0001

Table 7 continued.

	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11
Fruits/Vegetables and Maize	0.2922	0.0775	0.3461	0.1678	0.1296	0.2344
T (˚C)	0.0221	0.0073	0.0365	0.0138	0.0166	0.0258
P (mm/mo)	0.0029	0.0003	0.0012	0.0012	0.0004	0.0017
Fruits/Vegetables	0.0849	0.0607	0.1601	0.0520	0.2424	0.1048
T (˚C)	0.0087	0.0098	0.0223	0.0095	0.0196	0.0237
P (mm/mo)	0.0003	-0.0001	0.0005	0.0005	-0.0015	0.0006
Ground nuts and millet	0.0010	0.2901	0.0013	0.1121	0.0418	0.0371
T (˚C)	0.0011	-0.0091	0.0016	-0.0193	-0.0022	-0.0044
P (mm/mo)	0.0000	-0.0026	-0.0003	-0.0050	-0.0004	-0.0028
Maize	0.3777	0.2849	0.3479	0.3070	0.0910	0.3874
T (˚C)	-0.0143	-0.0198	-0.0517	-0.0259	-0.0153	-0.0478
P (mm/mo)	-0.0034	-0.0027	-0.0023	-0.0026	-0.0009	-0.0020
Maize and ground nuts	0.0311	0.1310	0.1164	0.2040	0.0013	0.1715
T (˚C)	0.0036	0.0144	-0.0030	0.0320	-0.0004	0.0148
P (mm/mo)	0.0002	0.0022	0.0014	0.0049	0.0000	0.0028
Millet	0.0146	0.0894	0.0028	0.0625	0.0877	0.0167
T (˚C)	0.0033	0.0042	0.0005	-0.0025	0.0002	-0.0025
P (mm/mo)	0.0008	0.0029	-0.0004	0.0006	0.0025	0.0000
Millet and Sorghum	0.0947	0.0357	0.0185	0.0546	0.0354	0.0398
T (˚C)	0.0047	-0.0001	-0.0050	0.0006	-0.0083	-0.0074
P (mm/mo)	0.0003	0.0000	0.0000	0.0004	-0.0003	-0.0001
Wheat	0.1038	0.0306	0.0070	0.0399	0.3708	0.0083
T (˚C)	-0.0293	-0.0067	-0.0013	-0.0081	-0.0102	-0.0021
P (mm/mo)	-0.0011	0.0000	-0.0002	0.0000	0.0002	-0.0002

Table 7 continued.

	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Fruits/Vegetables and Maize	0.1094	0.4095	0.1617	0.1369	0.3651
T (˚C)	0.0088	0.0336	0.0082	0.0287	0.0278
P (mm/mo)	0.0005	0.0018	0.0013	0.0006	0.0027
Fruits/Vegetables	0.0518	0.1241	0.0501	0.1162	0.0886
T (˚C)	0.0066	0.0131	0.0041	0.0280	0.0126
P (mm/mo)	0.0001	0.0002	0.0002	0.0003	0.0003
Ground nuts and millet	0.0060	0.0000	0.0048	0.0015	0.0020
T (˚C)	0.0010	0.0000	0.0000	0.0010	0.0011
P (mm/mo)	-0.0003	0.0000	-0.0002	-0.0001	-0.0001
Maize	0.4791	0.3453	0.4752	0.4022	0.3157
T (˚C)	-0.0304	-0.0404	-0.0309	-0.0134	-0.0274
P (mm/mo)	-0.0043	-0.0020	-0.0054	-0.0023	-0.0033
Maize and ground nuts	0.2190	0.0699	0.2123	0.0189	0.0577
T (˚C)	0.0253	0.0019	0.0267	0.0021	0.0068
P (mm/mo)	0.0034	0.0006	0.0033	0.0002	0.0002
Millet	0.0148	0.0023	0.0149	0.0568	0.0196
T (˚C)	0.0020	0.0001	0.0002	0.0116	0.0008
P (mm/mo)	0.0007	0.0001	0.0008	0.0014	0.0010
Millet and Sorghum	0.0587	0.0266	0.0470	0.1151	0.0708
T (˚C)	0.0019	-0.0043	0.0015	-0.0034	-0.0002
P (mm/mo)	0.0002	-0.0003	0.0002	-0.0002	0.0001
Wheat	0.0611	0.0224	0.0339	0.1523	0.0805
T (˚C)	-0.0151	-0.0040	-0.0097	-0.0545	-0.0214
P (mm/mo)	-0.0002	-0.0004	-0.0002	0.0001	-0.0010

Table 8: AOGCM Scenarios

	Current	2020	2100
Summer Temperature (°C)			
CCC	25.7	1.4	6.0
PCM	25.7	0.7	2.2
Winter Temperature (°C)			
CCC	22.4	2.2	7.3
PCM	22.4	1.1	3.1
Summer Rainfall (mm/month)			
CCC	149.8	-4.6	-33.7
PCM	149.8	-4.7	-4.7
Winter Rainfall (mm/month)			
CCC	12.8	1.1	3.5
PCM	12.8	18.8	21.6

Table 9: Climate Change Impacts on Probability of Irrigation Choice by AEZs (%)

	Africa	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Baseline	0.501	0.564	0.488	0.488	0.477	0.510
2020						
CCC	0.038	0.010	0.036	0.026	0.030	0.029
PCM	-0.025	0.099	-0.055	-0.186	-0.090	-0.076
2100						
CCC	0.155	0.036	0.144	0.091	0.116	0.120
PCM	-0.019	0.107	-0.023	-0.168	-0.064	-0.046

	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11
Baseline	0.480	0.479	0.517	0.515	0.513	0.559
2020						
CCC	0.026	0.056	0.026	0.050	0.061	0.033
PCM	-0.147	-0.012	-0.076	-0.027	-0.020	-0.072
2100						
CCC	0.107	0.207	0.150	0.193	0.208	0.153
PCM	-0.123	-0.025	-0.071	-0.008	-0.059	-0.058

	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Baseline	0.432	0.470	0.421	0.498	0.492
2020					
CCC	0.030	0.026	0.027	0.028	0.030
PCM	-0.028	-0.160	-0.039	-0.051	-0.167
2100					
CCC	0.132	0.119	0.123	0.114	0.126
PCM	-0.008	-0.147	-0.019	-0.025	-0.142

Table 10a: Climate Change Impacts on Probability of Crop Choice by AEZs by 2020 (%)

	Africa	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Fruits& vegetables &maize	0.181	0.073	0.089	0.449	0.237	0.151
CCC	0.052	-0.073	0.104	-0.013	0.053	-0.104
PCM	-0.006	-0.073	0.128	-0.138	0.111	-0.088
Fruits & vegetables	0.079	0.137	0.071	0.081	0.060	0.080
CCC	-0.032	-0.136	-0.032	0.019	-0.004	-0.066
PCM	0.043	-0.134	0.057	0.145	0.225	-0.007
Groundnut &Millet	0.114	0.000	0.024	0.000	0.015	0.000
CCC	-0.063	0.134	-0.024	0.000	0.027	0.000
PCM	-0.089	0.002	-0.019	0.000	-0.012	0.015
Maize	0.338	0.102	0.314	0.347	0.405	0.488
CCC	-0.162	-0.099	0.160	-0.046	-0.006	-0.095
PCM	-0.123	-0.101	0.074	-0.291	-0.172	-0.230
Maize&Groundnuts	0.141	0.006	0.014	0.027	0.041	0.011
CCC	-0.101	-0.005	-0.013	-0.019	-0.040	-0.010
PCM	-0.069	0.061	0.045	-0.021	-0.003	0.065
Millet	0.041	0.008	0.076	0.004	0.036	0.014
CCC	0.034	-0.008	-0.076	0.089	0.000	-0.014
PCM	0.054	-0.008	0.106	0.223	0.013	0.471
Millet&Sorghum	0.045	0.064	0.079	0.042	0.069	0.146
CCC	0.176	0.021	0.141	-0.018	0.056	0.188
PCM	0.088	-0.030	-0.058	0.131	-0.051	-0.114
Wheat	0.062	0.611	0.333	0.050	0.138	0.111
CCC	-0.096	0.167	-0.261	-0.012	-0.086	0.100
PCM	-0.027	0.283	-0.333	-0.050	-0.112	-0.111

Table 10a continued.

	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11
Fruits& vegetables &maize	0.292	0.078	0.346	0.078	0.346	0.168
CCC	0.007	-0.012	0.163	-0.012	0.163	0.035
PCM	-0.005	-0.013	-0.001	-0.013	-0.001	0.009
Fruits & vegetables	0.085	0.061	0.160	0.061	0.160	0.052
CCC	-0.032	-0.045	-0.082	-0.045	-0.082	0.012
PCM	0.222	-0.006	-0.009	-0.006	-0.009	0.099
Groundnut &Millet	0.001	0.290	0.001	0.290	0.001	0.112
CCC	0.000	-0.269	-0.001	-0.269	-0.001	-0.019
PCM	0.040	-0.266	-0.001	-0.266	-0.001	-0.104
Maize	0.378	0.285	0.348	0.285	0.348	0.307
CCC	0.003	-0.170	-0.218	-0.170	-0.218	-0.170
PCM	-0.311	-0.017	-0.153	-0.017	-0.153	-0.054
Maize&Groundnuts	0.031	0.131	0.116	0.131	0.116	0.204
CCC	-0.030	-0.021	-0.111	-0.021	-0.111	-0.184
PCM	-0.023	-0.004	-0.066	-0.004	-0.066	-0.112
Millet	0.015	0.089	0.003	0.089	0.003	0.062
CCC	0.050	-0.083	0.225	-0.083	0.225	0.004
PCM	0.100	-0.056	0.227	-0.056	0.227	-0.056
Millet&Sorghum	0.095	0.036	0.018	0.036	0.018	0.055
CCC	-0.040	0.429	-0.017	0.429	-0.017	0.253
PCM	0.000	0.151	-0.009	0.151	-0.009	0.184
Wheat	0.104	0.031	0.007	0.031	0.007	0.040
CCC	0.043	0.172	0.041	0.172	0.041	0.070
PCM	-0.023	0.211	0.013	0.211	0.013	0.034

Table 10a continued.

	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Fruits& vegetables &maize	0.130	0.234	0.109	0.410	0.162
CCC	0.001	0.339	-0.026	-0.070	-0.039
PCM	-0.072	0.135	-0.008	-0.239	-0.022
Fruits & vegetables	0.242	0.105	0.052	0.124	0.050
CCC	-0.221	-0.018	-0.031	-0.056	-0.011
PCM	-0.096	0.104	0.064	0.047	0.072
Groundnut&Millet	0.042	0.037	0.006	0.000	0.005
CCC	0.060	-0.037	0.045	0.000	0.100
PCM	-0.039	-0.037	0.042	0.000	0.059
Maize	0.091	0.387	0.479	0.345	0.475
CCC	-0.050	-0.199	-0.252	-0.114	-0.234
PCM	-0.089	-0.169	-0.094	-0.298	-0.114
Maize&Groundnuts	0.001	0.172	0.219	0.070	0.212
CCC	0.075	-0.167	-0.214	-0.062	-0.207
PCM	0.230	-0.115	-0.172	-0.049	-0.169
Millet	0.088	0.017	0.015	0.002	0.015
CCC	-0.088	0.063	0.031	0.314	0.051
PCM	-0.088	0.067	0.056	0.481	0.039
Millet&Sorghum	0.035	0.040	0.059	0.027	0.047
CCC	0.286	-0.028	0.306	-0.012	0.189
PCM	0.103	0.000	0.124	0.080	0.127
Wheat	0.371	0.008	0.061	0.022	0.034
CCC	-0.065	0.048	0.141	0.001	0.153
PCM	0.050	0.015	-0.012	-0.022	0.008

Table 10b: Climate Change Impacts on Probability of Crop Choice by AEZs by 2100 (%)

	Africa	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Fruits& vegetables &maize	0.181	0.073	0.089	0.449	0.237	0.151
CCC	0.228	-0.073	0.450	0.329	0.304	0.097
PCM	0.012	-0.073	0.168	-0.219	0.027	-0.098
Fruits & vegetables	0.079	0.137	0.071	0.081	0.060	0.080
CCC	0.018	-0.133	0.087	0.048	0.063	0.018
PCM	0.051	-0.135	0.078	0.176	0.182	-0.017
Groundnut &Millet	0.114	0.000	0.024	0.000	0.015	0.000
CCC	-0.067	0.001	-0.024	0.000	0.058	0.000
PCM	-0.072	0.002	-0.012	0.000	0.055	0.035
Maize	0.338	0.102	0.314	0.347	0.405	0.488
CCC	-0.245	-0.097	-0.094	-0.263	-0.239	-0.060
PCM	-0.188	-0.101	-0.005	-0.315	-0.227	-0.300
Maize&Groundnuts	0.141	0.006	0.014	0.027	0.041	0.011
CCC	-0.078	-0.001	-0.013	-0.025	-0.038	-0.008
PCM	-0.065	0.079	0.026	-0.022	-0.029	0.041
Millet	0.041	0.008	0.076	0.004	0.036	0.014
CCC	-0.024	-0.008	-0.076	-0.003	-0.025	-0.014
PCM	0.098	-0.008	0.142	0.387	0.162	0.576
Millet&Sorghum	0.045	0.064	0.079	0.042	0.069	0.146
CCC	0.129	0.037	-0.029	-0.040	-0.018	-0.012
PCM	0.086	-0.043	-0.065	0.043	-0.054	-0.126
Wheat	0.062	0.611	0.333	0.050	0.138	0.111
CCC	-0.019	0.275	-0.302	-0.047	-0.105	-0.022
PCM	-0.027	0.280	-0.333	-0.050	-0.118	-0.111

Table 10b continued.

	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11
Fruits& vegetables &maize	0.292	0.078	0.346	0.168	0.130	0.234
CCC	0.320	0.030	0.551	0.166	0.035	0.640
PCM	-0.095	-0.013	0.111	0.027	-0.055	0.246
Fruits & vegetables	0.085	0.061	0.160	0.052	0.242	0.105
CCC	0.036	0.103	-0.109	0.047	-0.203	-0.044
PCM	0.233	0.012	-0.004	0.090	-0.099	0.129
Groundnut &Millet	0.001	0.290	0.001	0.112	0.042	0.037
CCC	0.003	-0.276	-0.001	0.020	-0.034	-0.037
PCM	0.047	-0.236	-0.001	-0.062	-0.038	-0.037
Maize	0.378	0.285	0.348	0.307	0.091	0.387
CCC	-0.234	-0.157	-0.345	-0.233	-0.078	-0.378
PCM	-0.322	-0.089	-0.244	-0.110	-0.089	-0.257
Maize&Groundnuts	0.031	0.131	0.116	0.204	0.001	0.172
CCC	-0.031	0.044	-0.116	-0.157	0.151	-0.171
PCM	-0.027	0.020	-0.089	-0.079	0.260	-0.147
Millet	0.015	0.089	0.003	0.062	0.088	0.017
CCC	-0.015	-0.086	-0.001	-0.031	-0.088	-0.017
PCM	0.256	-0.027	0.233	-0.040	-0.088	0.078
Millet&Sorghum	0.095	0.036	0.018	0.055	0.035	0.040
CCC	-0.086	0.316	-0.011	0.194	0.193	-0.031
PCM	-0.053	0.163	-0.012	0.159	0.069	-0.020
Wheat	0.104	0.031	0.007	0.040	0.371	0.008
CCC	0.006	0.026	0.031	-0.006	0.024	0.037
PCM	-0.040	0.170	0.007	0.015	0.039	0.008

Table 10b continued.

	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Fruits& vegetables &maize	0.109	0.410	0.162	0.137	0.365
CCC	0.043	0.448	0.035	0.187	0.391
PCM	-0.012	-0.156	-0.066	-0.033	-0.105
Fruits & vegetables	0.052	0.124	0.050	0.116	0.089
CCC	-0.002	-0.042	0.012	0.040	0.030
PCM	0.040	0.073	0.051	0.000	0.207
Groundnut&Millet	0.006	0.000	0.005	0.001	0.002
CCC	0.067	0.000	0.115	-0.001	0.001
PCM	0.068	0.000	0.101	0.021	0.037
Maize	0.479	0.345	0.475	0.402	0.316
CCC	-0.272	-0.291	-0.274	-0.098	-0.228
PCM	-0.177	-0.314	-0.198	-0.160	-0.294
Maize&Groundnuts	0.219	0.070	0.212	0.019	0.058
CCC	-0.199	-0.068	-0.189	-0.017	-0.057
PCM	-0.162	-0.052	-0.170	0.035	-0.039
Millet	0.015	0.002	0.015	0.057	0.020
CCC	0.015	0.001	0.029	-0.057	-0.020
PCM	0.077	0.470	0.119	0.312	0.278
Millet&Sorghum	0.059	0.027	0.047	0.115	0.071
CCC	0.340	-0.026	0.235	-0.029	-0.068
PCM	0.194	0.002	0.168	-0.095	-0.022
Wheat	0.061	0.022	0.034	0.152	0.080
CCC	0.008	-0.022	0.038	-0.025	-0.049
PCM	-0.028	-0.022	-0.006	-0.079	-0.061

Fig 1: Agro-Ecological Zones of Africa

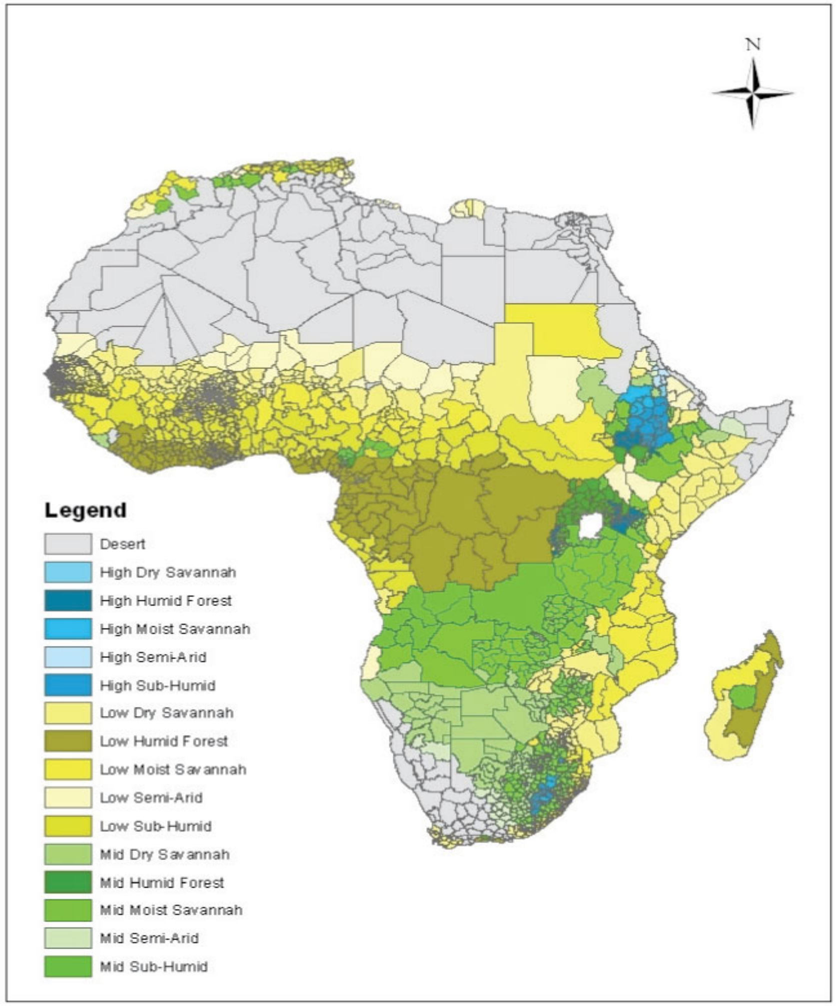
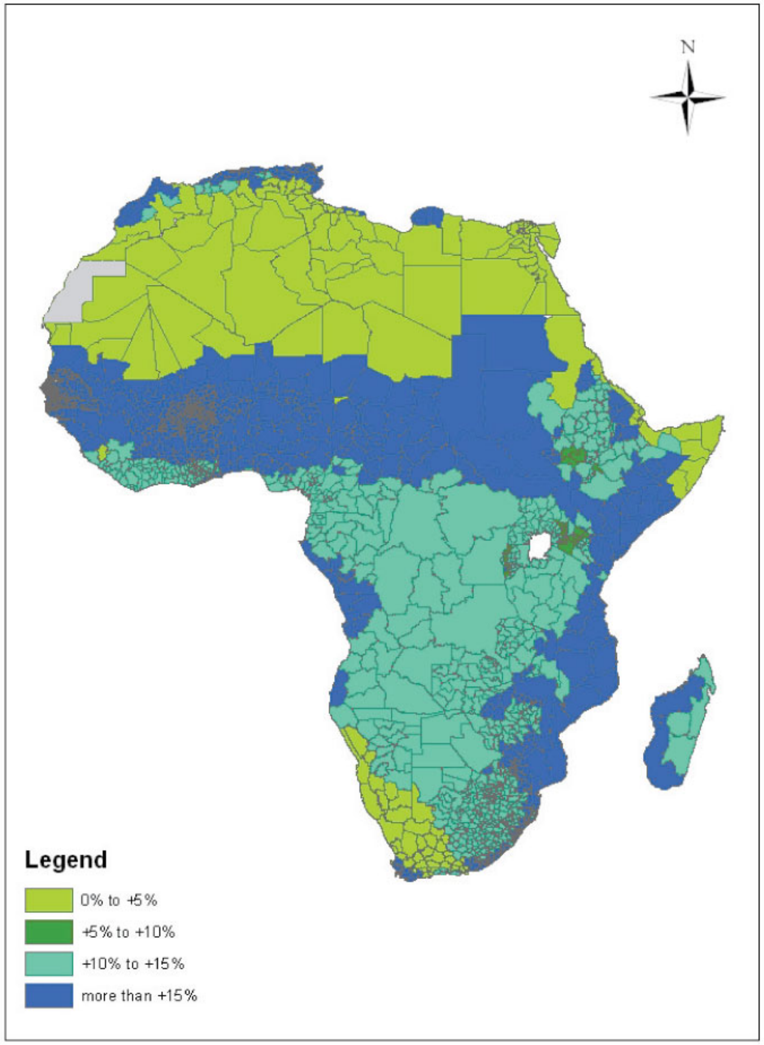


Fig 2: Change in Probability to Choose Irrigation in 2100 under CCC (Left), and under PCM (Right)



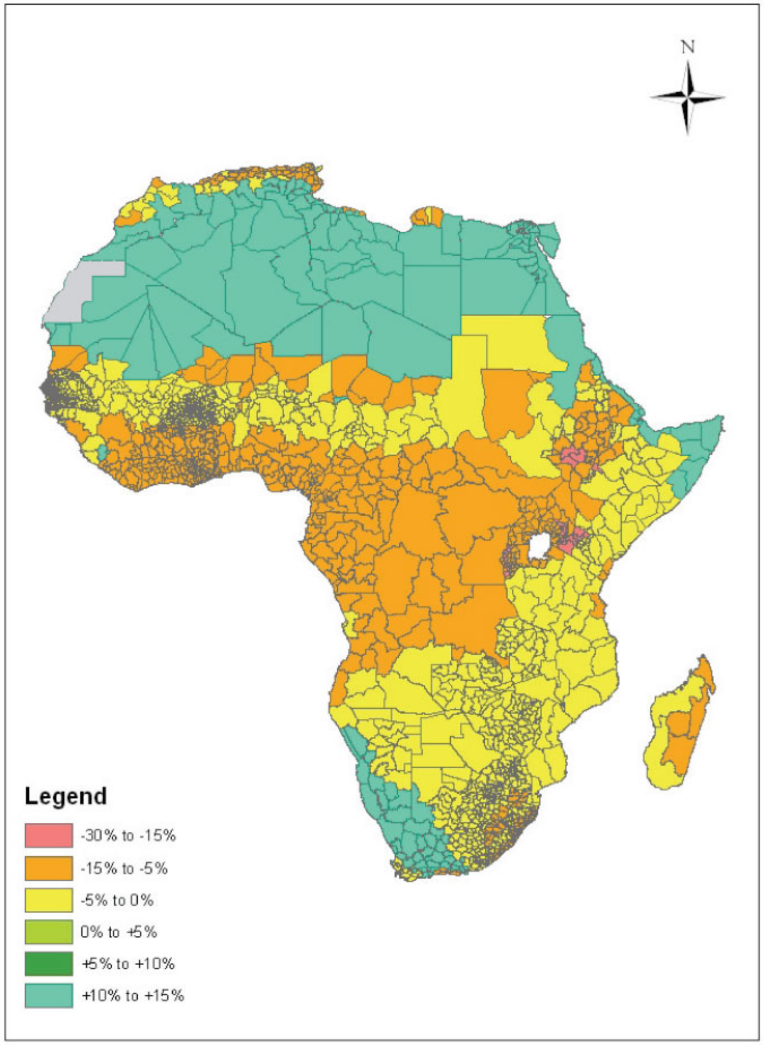
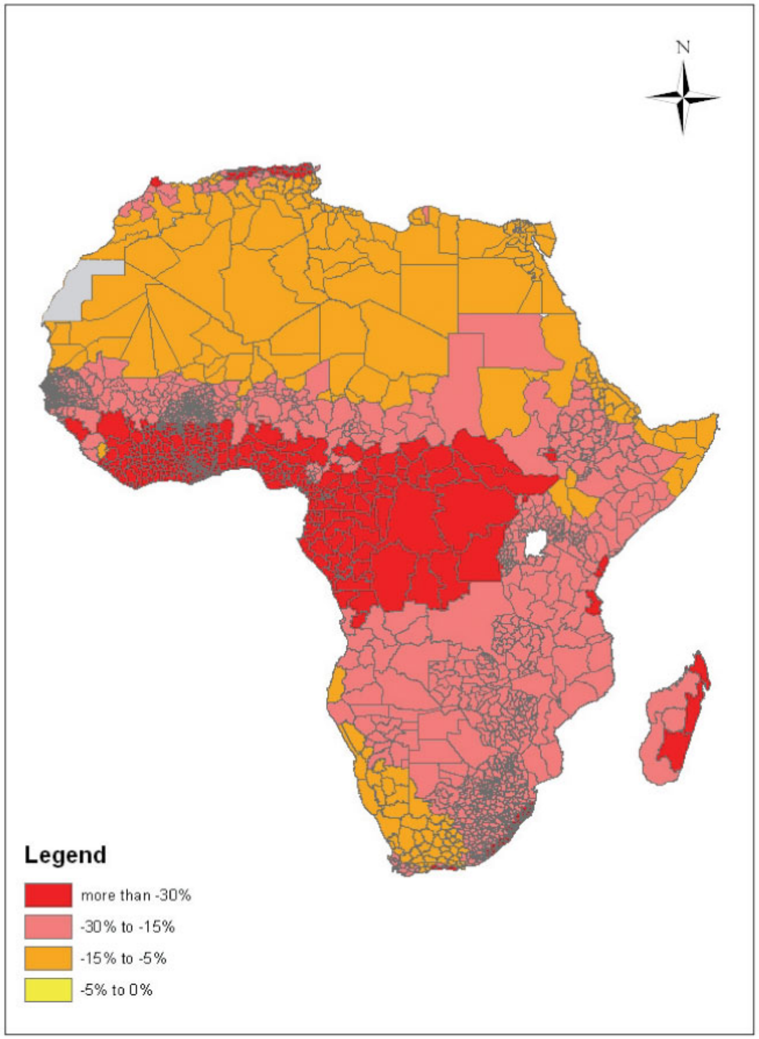


Fig 3: Change in Probability to Choose Maize in 2100 under CCC (Left), and under PCM (Right)



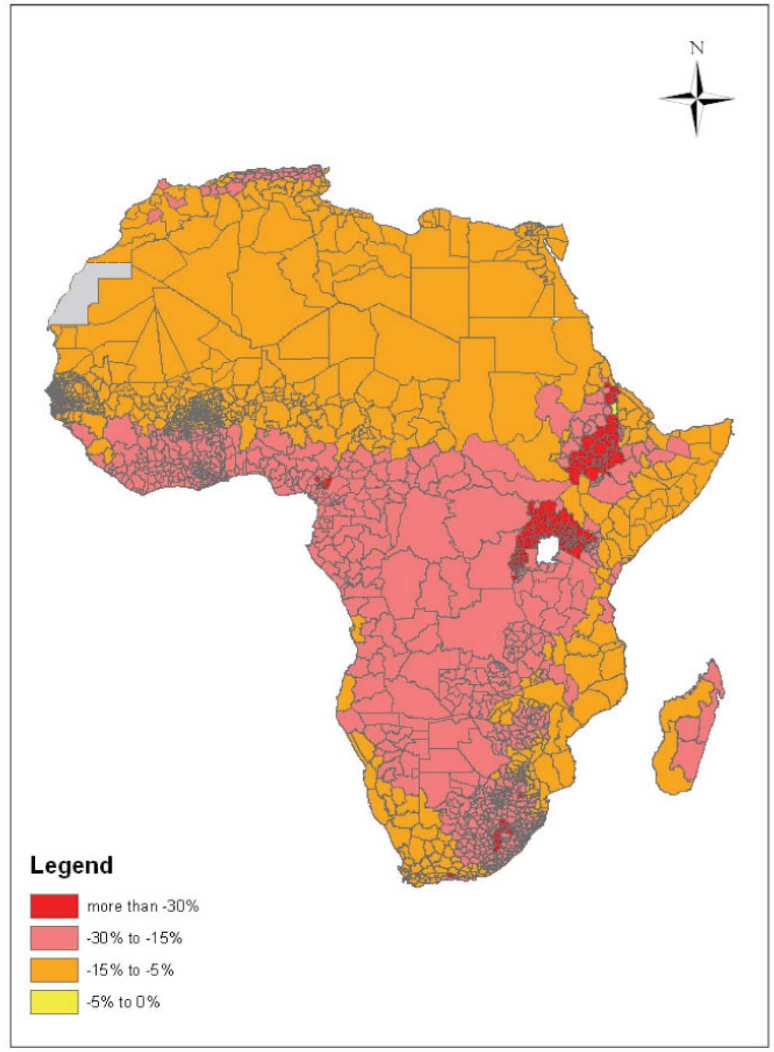


Fig 4: Change in Probability to Choose Fruits & Vegetables in 2100 under CCC (Left), and under PCM (Right)