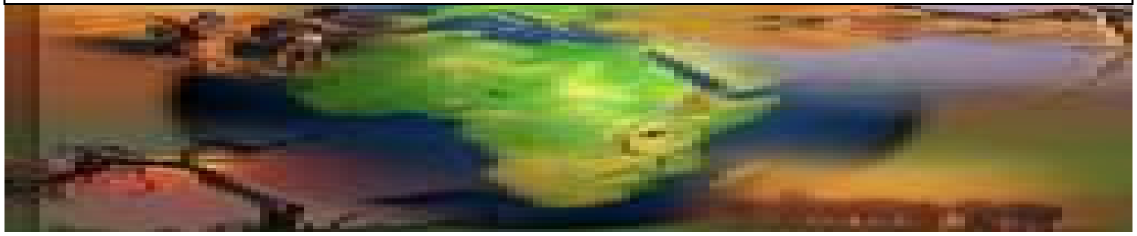
CLIMATE CHANGE AND AFRICAN AGRICULTURE
Policy Note No. 8, August 2006, CEEPA



Measuring the economic impacts of climate change on crop farming in Africa[1]

This study uses a cross-sectional approach to measure the relationship between net revenue from growing crops and climate in Africa by correlating variations in key climate attributes and corresponding variations in net revenue observed across wide spatial spread. In addition to climate attributes this method also controls for the effects of variations in other determinants of crop productivity such as water flows, soils and socio-economic factors on net revenue.

Cross-sectional observations across different climates can reveal the climate sensitivity of farms. The advantage of this empirical approach is that it does not only capture the direct effect of climate on productivity but also reflects farmers' adaptation to local climate. This farmer behavior is important as it mitigates problems associated with deviations from optimal environmental conditions. Analyses that do not include adaptation (such as the early agronomic studies) overestimate the damages associated with any deviation from the optimum. However, while the Ricardian model takes into account the costs associated with different adaptation alternatives, it suffers some limitations.

The data

This study is based on a cooperative research effort among 11 African countries: Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia, and Zimbabwe. The data for the study was collected by national teams. 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 costs. A total of 9597 surveys were administered across the 11 countries in the study. The number of surveys varied from country to country and the final number of useable surveys is 9064.

Data on climate was gathered from two sources. The study used temperature data from satellites operated by the Department of Defense (Basist et al.

---

[1] This Policy Note is prepared by M de Wit based on Kurukulasuriya & Mendelsohn (2006), A Ricardian analysis of the economic impact of climate change on African cropland, *CEEPA Discussion Paper No. 8, CEEPA, University of Pretoria.*

2001). The 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. It is not self-evident how to represent monthly temperatures and precipitation data in a Ricardian regression model. The correlation between adjacent months is too high to include every month. After exploring several ways of defining three-month average seasons, we found that defining winter in the northern hemisphere as the average of November, December and January provided the most robust results for Africa. This assumption 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). These seasonal definitions were chosen because they provided the best fit with the data and reflected the mid-point for key rainy seasons in the sample. We adjusted for the fact that seasons in the southern and northern hemispheres occur at exactly the opposite months of the year.

Soil data was obtained from FAO (2003). The FAO data provides information about the major and minor soils in each location as well as slope and texture. Data concerning the hydrology was obtained from the University of Colorado (Strzepek & McCluskey 2006). Using a hydrological model for Africa, the hydrology team calculated flow and runoff for each district in the surveyed countries.

Determinants of net farm revenue

Net revenue is defined here without household labor costs, the effect of which is alternatively controlled for by including adult and child man-days as an independent variable. Farming in Egypt is predominantly irrigated and technology intensive, leading to significantly higher earnings. Another advantage over the rest of dryland farmers in the sample is that a large proportion of Egyptian farmers also cultivate for two seasons.

The study found that more water flow increases the value of irrigated farms but not dryland farms. Dryland farms are no better off with more water flow because the only water they use comes from on-farm precipitation. Technology variables also matter. Access to modern technology such as electricity and heavy machinery has a positive effect. Use of irrigation increases farm net revenue substantially.

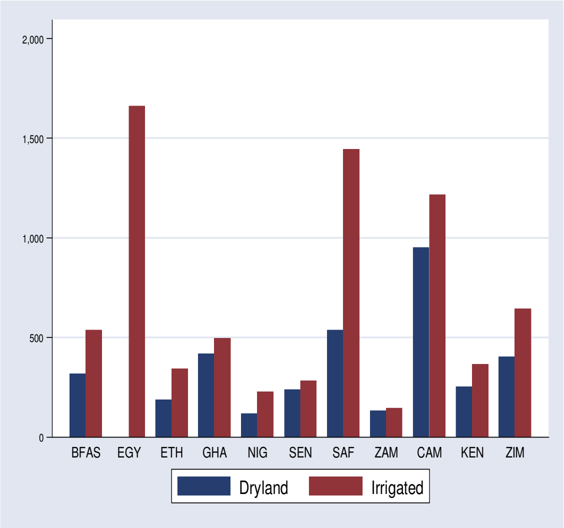


Figure 1: Net farm revenue in US$ per ha of dryland and irrigated cropland by country

The regional dummies included to capture differences across broad regions suggest that West Africa and North

Africa are more productive than southern Africa, but that East Africa is less productive than southern Africa.

Sensitivity to warming and precipitation

In order to provide a better sense of the climate response functions implied by the estimated coefficients, the net revenues of an average farm in Africa (irrigated and dryland farms combined) at different temperatures and rainfall levels were plotted in Figure 2. It is clear that net revenues decline with temperature and rise with precipitation in Africa. The shape of the temperature function, however, is worth noting. Results from similar Ricardian regressions estimated in the United States (a temperate country) implied a hill-shaped function. Because of its hot initial temperature, Africa seems to lie on the right-hand side of this hill, implying warming would have large negative impacts. Although the results in Africa are consistent with a hill-shaped model, they imply that net revenues decline gently rather than precipitously. It is also worth noting that precipitation increases are generally beneficial to crops in Africa because it is so dry to start with.

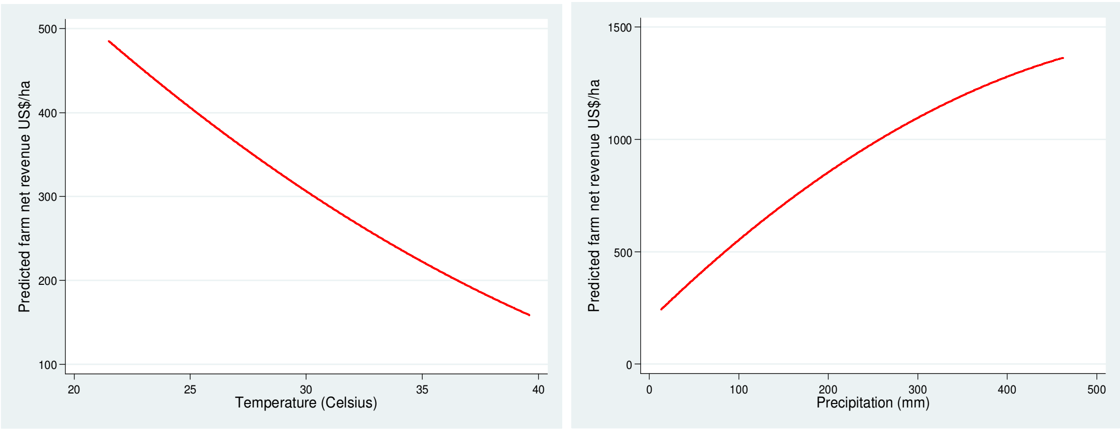


Figure 2: Temperature and precipitation response functions for all farms in Africa

In addition to examining all farms together, the study examined dryland and irrigated farms separately. Dryland farms are especially climate sensitive, as a 10% increase in temperature would lead to an expected 16% decline in net revenue. Irrigated farms appear to be more resilient to higher temperatures. The sensitivity to precipitation for these farm types suggests (as expected) higher revenue per hectare with additional precipitation.

Cropland and climate change

The study also examined some simple climate scenarios to see how Africa would respond to climate change. These scenarios assume that only one aspect of climate changes and the change is uniform across all of Africa. For example, the study examined a 2.5°C warming and found that warming results in predicted losses of $23 billion for dryland, a gain of $1 billion for irrigated cropland, and a loss of $16.4 billion for all African cropland (Table 1).

Table 1: Africa-wide impacts of uniform climate scenarios

Impacts	2.5°C warming	7% lower precipitatio
Dryland		
ΔNet revenue/ha (Percent)	*-16%*	*-6%*
ΔTotal net revenue (billions $)	-23	-4.4
Irrigated		
ΔNet revenue/ha (Percent)	*9%*	*-1.4%*
ΔTotal net revenue (billions $)	1.4	-.21
Total (Africa)		
ΔNet revenue/ha (Percent)	*-11.3%*	*-4.2%*
ΔTotal net revenue (billions $)	-16.0	-5.96

The analysis of the total sample allows land to change between dryland and irrigation as temperature rises, reducing the extent of the damage. A 7% decrease in precipitation would cause net revenues from dryland crops to fall by $4 billion but as expected would have little effect on irrigated crops.

Figure 3 depicts the geographic distribution of impacts from a uniform warming of 2.5°C and 7% decrease in precipitation. Although the warming is assumed to be the same in every district, the impact depends on the initial temperature of the district. The figure shows that net revenues in districts in and near the Sahara desert and in southern Africa fall the most (dark red) with uniform warming. Districts across the equator are much less affected (±$25/ha) relative to per hectare impacts in other regions. Reducing precipitation has a much larger harmful effect on the wetter parts of Africa, where the central humid band of the continent bears the brunt of the damage.

The study also examined three climate change scenarios predicted by Atmospheric-Oceanic Global Circulation Models (AOGCMs) that are consistent with the range of outcomes in the most recent IPCC report. Specifically, the study used the A1 scenarios from the following models: CCC (Canadian Climate Center), CCSR (Center for Climate System Research), and PCM (Parallel Climate Model) to examine the consequences of country level climate change scenarios for 2020, 2060 and 2100.

Examining the path of climate change over time reveals that temperatures are predicted to increase steadily until 2100 for all three models. Precipitation predictions, however, vary across time for Africa. However, it should be noted that because the AOGCMs make geographically detailed predictions the predicted changes for individual countries vary.

The PCM results suggest that with ample rainfall and only a small increase in temperature the net effect on all African farms would be a gain of from $87 to $97 billion per year. However, there are three bands of land stretching from east to west across Africa where net revenues fall moderately: along the Mediterranean coast, from Kenya through West Africa, and across the southern tip of Africa.

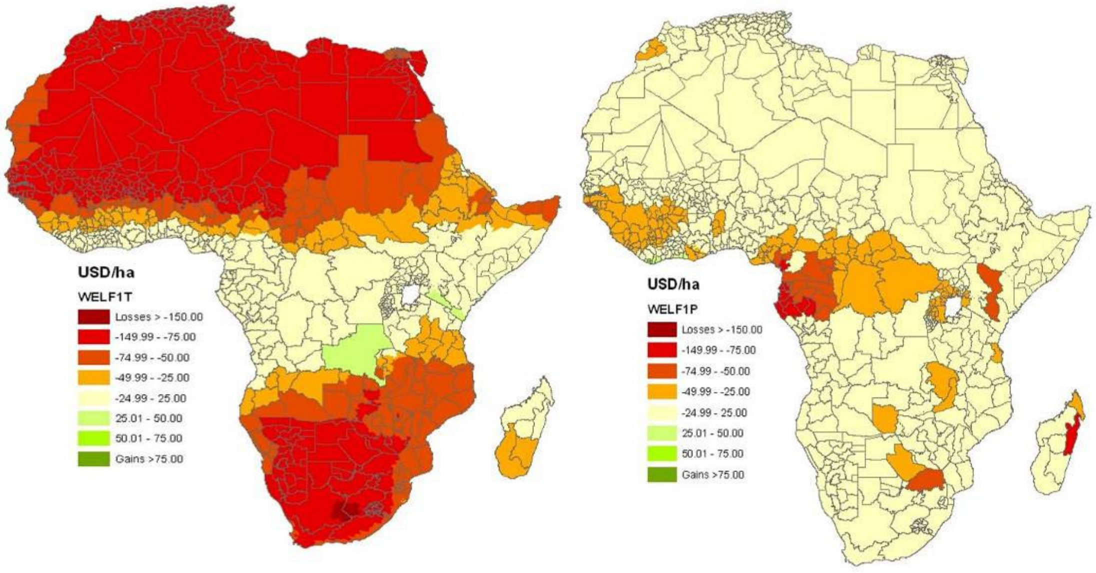


Figure 3: Change in net revenue ($/ha) from warming of 2.5°C and 7% decrease in precipitation

The CCSR results suggest that substantial drying and warming together would generate losses of from $19 to $27 billion beyond 2060 across Africa. The CCC results suggest that a large warming of 6°C would lead to substantial losses across African farms equal to $48 billion by 2100. Irrigated farms are predicted to benefit across all but one of these scenarios, partly because they are climate insensitive and partly because they are located in relatively cool areas. Dryland farms are likely to be affected the most, whether it is a gain of $72 billion or a loss of $44 billion.

It is also helpful to remember where the people are living in order to judge which impacts will be the most severe in human terms. The population map of Africa indicates that West Africa (south of the Sahel), the Mediterranean coastline, and a band across central Africa and a north to south band in eastern Africa are among the most densely populated. These areas coincide with regions that the CCC and CCSR climate predictions suggest will be harmed. Even the impacts from the relatively more favorable climate scenario based on the PCM models suggest that populated regions such as the Mediterranean coastline, southern Africa and central Africa will be severely affected. The results suggest that the impacts on rural populations in Africa from climate change are likely to be significant.

Conclusions and policy implications

This study confirms what scientists have long suspected: that impacts of warming on African agriculture will be significant. Although farmers have some adaptations available to them, such as switching to more heat tolerant crops, if they continue with their current technology warming will have a devastating effect, especially on dryland farmers.

African agriculture appears to be extremely vulnerable to climate change. However, not all of Africa is likely to experience the same effects from it. The humid regions of Africa are likely to be less vulnerable to warming than the drier northern and southern regions. Exactly how climate change will affect individual countries varies a great deal across climate models.

The study suggests that African countries should begin to plan for climate contingencies. Governments should develop contingency plans for various possible climate outcomes. They should anticipate what farmers will do, how markets will react, and what role governments need to play. Governments should be prepared to help people adapt to these new circumstances.

Actions that will make agricultural sectors more resilient to climate change can be taken in advance. Developing new crops and livestock that are more suited to hot and dry conditions will help countries adapt to many current climate conditions as well as future ones. Developing profitable irrigated agriculture systems will reduce the climate vulnerability of the agriculture sector. Developing the economy away from agriculture will reduce the climate sensitivity of the entire economy. Increasing investment in rural areas so that firms and households can explore more alternatives will make adaptation easier.

There is no doubt about the importance of technology. The average dryland farm earns $319/ha whereas the average irrigated farm earns $1261/ha. The more advanced irrigated farms earn even more. Adoption of technology will be very important for the future survival of agriculture in Africa in the face of predicted climate change damages.

References

FAO (Food and Agriculture Organization), 2003. The digital soil map of the world: Version 3.6 (January), Rome, Italy.

Strzepek K & McCluskey A, 2006. District level hydroclimatic time series and scenario analysis to assess the impacts of climate change on regional water resources and agriculture in Africa. CEEPA Discussion Paper No 13, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

World Bank, 2003. Africa rainfall and temperature evaluation system (ARTES). World Bank, Washington DC.

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

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

Centre for Environmental Economics and Policy in Africa (CEEPA)*, University of Pretoria, Room 2-7, Agricultural Annex, 0002 PRETORIA, South Africa. Tel: +27 (0)12 420 4105, Fax: +27 (0)12 420 4958, Web address: www.ceepa.co.za*

Core funding from the GEF and supplementary funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA in support of this project's activities are all gratefully acknowledged. The project was coordinated by CEEPA and managed in the World Bank by the Agricultural and Rural Development Department and World Bank Institute.