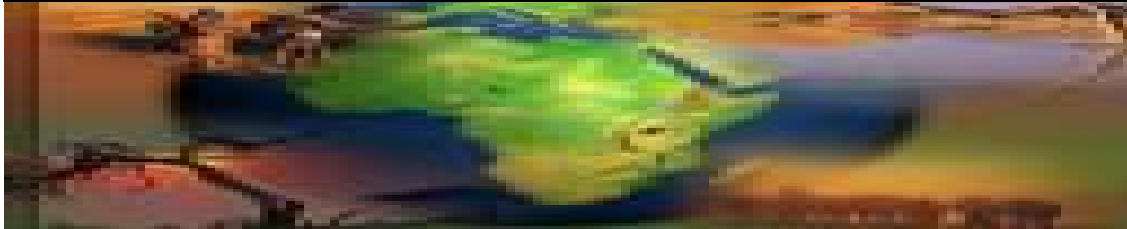


## CLIMATE CHANGE AND AFRICAN AGRICULTURE

*Policy Note No. 14, August 2006, CEEPA*



### **Sensitivity of cropland density and distribution in Africa to climate change<sup>1</sup>**

Since the emergence of agriculture, farmers have developed techniques to overcome the biological and physical constraints that climate and land pose for the production of crops, including irrigation, land terracing and fertilization. Despite these agricultural management practices, crops remain ultimately dependent on ecological conditions, such as the intra-seasonal distribution of precipitation and temperature, soil fertility and length of growing season. While cropping in boreal regions is limited by low temperatures and a short growing season, cropping in tropical and subtropical regions tends to be limited by inadequate moisture conditions and high temperatures.

Recent work on the impacts of climate change suggests that countries in tropical latitudes will experience negative effects

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<sup>1</sup> This Policy Note is prepared by R Hassan based on Lotsch (2006), Sensitivity of cropping patterns in Africa to transient climate change, *CEEPA Discussion Paper No. 14, CEEPA, University of Pretoria.*

on economic development as a consequence of further warming and changes in precipitation patterns. This study investigates the sensitivity of current cropping patterns in Africa to seasonal perturbations in climate and assesses the potential impact of transient climate change suggested by climate model scenarios.

### **Current cropping patterns in Africa**

Available data on cropping systems in Africa lacks consistency and geographical coherence. This is because alternative mapping approaches using different data and algorithms result in different depictions of cropping patterns in terms of both location and density.

Due to these discrepancies, several sources of remote sensing-based land cover maps were used in this study. These data sources include land cover data developed at Boston University based on the National Aeronautics and Space Administration (NASA) Moderate Imaging Spectroradiometer (MODIS) instrument, the Global Land Cover Facility (GLCF) data from the University of Maryland, the 2000 Global Land Cover (GLC2K) produced by the European Union's Joint Research Center, and the Global Land Cover Characterization (GLCC) created by the

United States Geological Survey<sup>2</sup>. Each of these sources provides categorical labels of land use (e.g. croplands, cropland mosaic, forest, shrublands) at the scale of one square kilometer. The information on agricultural land use provided by the GLCC data was used by the LandScan project at the Oak Ridge National Laboratory (ORNL) and International Food Policy Research Institute (IFPRI) as the basis for estimating agricultural extent at the landscape level. Lastly, the Center for Sustainability and Global Environment (SAGE) at the University of Wisconsin inter-calibrated remote sensing based estimates of cropland extent from GLCC with available agricultural statistics at the national and sub-national level. For this analysis, these six sources of land use data – MODIS, GLCF, GLC2K200, ORNL, IFPRI and SAGE – were reprocessed using a consistent definition of land use and the aggregate extent and share of croplands was calculated for each grid cell.

The discrepancies in estimates of cropland extent from different sources of land cover data highlight the importance of accounting for the effect of these estimates in climate change impact analyses. For instance, the estimates of cropland extent for West Africa range from 1.52 million hectares (MODIS) to 12.20 million hectares (GLC2K) and from 0.78 million hectares (MODIS) to 10.77 million hectares (ORNL) for southern Africa.

## **Explaining variations in land use patterns**

This analysis used global land cover inventories derived from satellite observations in conjunction with ancillary statistical data on land use and agricultural activity. Satellite based estimates provide a spatially explicit and unbiased picture of the distribution of croplands and can be updated frequently at relatively low cost.

For large geographic regions the suitability of land for cropping is largely determined by ecological and physical parameters. Thus, to explain current land use in Africa an empirical modeling (logistic regression) approach is used that relates cropping patterns (measured as the share of cropland) to a set of explanatory variables. This empirical model predicts the probability of cropping (cropland fraction) as a function of seasonal climate patterns, and soil and terrain properties. This specification assumes that socio-economic variables play a secondary role in determining the distribution of croplands at the spatial scale such as the one chosen for this analysis (continent).

Mean annual conditions of climate provide a first-order approximation of land suitability for cropping, but intra-seasonal climate patterns play an equally critical role for crop cultivation and management. Climate is therefore empirically defined using a vector of seasonally adjusted climate variables that correspond to various stages of the cropping cycle. The specific data sources used to parameterize the model variables are briefly described below.

*Seasonal climate:* The basis for the characterization of geographic and intra-

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<sup>2</sup> Sources of these data are adequately cited in the full report by Lotsch (2006).

annual (seasonal) climate patterns was a dataset of multi-decadal observations of temperature and precipitation made at meteorological stations throughout Africa. To characterize salient intra-annual climate variation at each location, precipitation and temperature observations were converted to long-term (1961–2000) monthly averages.

*Growing period:* The length of the growing season is a critical determinant of cropping systems. Growing season length provides a simple index for delineating the cold and dry threshold dates during the growing season that cannot be resolved from monthly records. To estimate growing season length for each grid cell, time series of vegetation activity derived from multi-temporal satellite observations of vegetation greenness (Tucker et al. 2005) were used to determine the onset, peak and end of the growing period.

*Soil and terrain:* Land characteristics were derived from a global soil dataset (Global Soil Data Task 2000). Chemical properties of soils were characterized using the ratio of organic and non-organic compounds, which are indicative of soil fertility, and are derived from carbon and nitrogen concentrations in the soil (C: N ratio).

*Population patterns:* Estimates of population densities.

### **Sensitivity of cropping patterns to seasonal perturbations in climate**

The results show that, for current climate conditions, the cropland models predict higher cropland share (with the exception of GLC2K) with increases in seasonal precipitation, whereas increases in temperature are associated with lower

cropland share. Interesting patterns are revealed in the seasonal breakdown of climate effects. While increases in precipitation during spring, summer and fall tend to have a positive marginal effect, additional rainfall during winter is negative. This is intuitive, as moisture requirements are most critical during the crops' main growing season, but are less important during soil preparation and regeneration. Temperature coefficients, on the other hand, exhibit the reverse seasonal pattern, in which warmer temperatures during the winter are positive, but higher temperatures during spring, summer and fall tend to decrease cropping.

The ability of soils to retain water and store heat, and higher soil fertility (C: N ratio), both make it more probable that land will be used for cropping. The effect of changes in growing season length is very small, which is not surprising as these effects are known to be most important at higher latitudes. Also, steeper slopes tend to reduce the density of croplands. Lastly, population density tends to increase with cropland density and highlights the high degree of subsistence farming across the region. In more mechanized systems, an inverse relationship has been observed in cross-sectional analysis (Mendelsohn et al. 2006), where cropping areas are characterized by lower population density.

### **The spatial distribution of croplands in Africa**

To understand the impact of geographic changes in climate on cropping it is important to model the spatial distribution of croplands as accurately as possible. While the marginal effects are similar in direction and magnitude for all

six models, the spatial patterns of predicted cropland share reflect the way the different land cover maps disagree in their depiction of cropping patterns (Table 1). The areas of disagreement are mostly in regions that have sparse cropping patterns (semi-arid zones) or are characterized by mixtures of croplands and natural or forest vegetation at fine spatial scales. As a consequence, the models tend to underestimate croplands in areas with a high probability of cropping, such as eastern Africa, and to overestimate in areas with low probability of cropping.

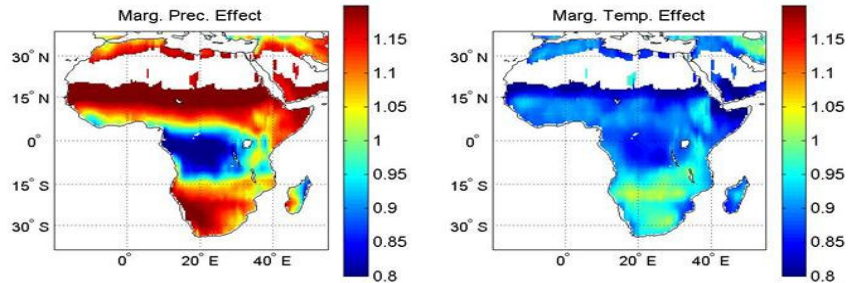
Figure 1 shows the marginal effect of precipitation (left panel) and temperature (right panel) calculated as the average across all six cropland models. Clearly, land use is most responsive to changes in climate in arid and semi-arid regions in subtropical latitudes, where increases in precipitation have a positive effect on the suitability of land for cropping. The opposite is the case in humid tropical latitudes, where increases in seasonal rainfall have a negative effect.

Increases in temperature, on the other hand, have largely negative marginal impacts throughout the African continent, with the exception of areas in southern and eastern Africa, where higher altitudes have a cooling effect on temperature. It is noteworthy that the marginal effect of changes in seasonal precipitation patterns is geographically more differentiated than the marginal effect of temperature, and shows that cropping systems in Africa are not expected to benefit from an additional rise in seasonal temperatures (assuming constant or decreasing levels of precipitation).

## Impacts of projected climate trends

This section discusses the way spatially differentiated projections of future climate provided by an ensemble of seven coupled AOGCMs are expected to affect croplands in Africa. The models used to evaluate the impact of climate change on cropland distributions in Africa for 2010–2099 are: (1) CCSR, (2) CCC, (3) GFDL, (4) CSIRO, (5) HCCPR, (6) MPIM and (7) NCAR. These models provide dynamic pathways of climate up to 2099 at a monthly time step. The model runs chosen for this analysis are based on the A2 emission scenario defined by the IPCC.

To characterize cropping pattern changes in Africa, the un-weighted mean of climate model projections was used in each of the six cropland models to predict changes in cropland area for 2010–2039, 2040–2069 and 2070–2099 in each region and for the continent as a whole. As far as the aggregate cropland area in Africa is concerned, different CRMs reveal a somewhat heterogeneous pattern, with some models showing increases and others showing decreases. However, towards the later periods of the century, most models agree on significant losses of cropland area across the continent. Considering the average change predicted by all CRMs, croplands are expected to decrease by 4.3% during the first 30-year period, and by 9.4% and 18.3% by the middle and end of the century.



**Figure 1: Geographic patterns of cropland sensitivity to precipitation and temperature. Positive marginal effects are shown in yellow-to-red colors, and negative marginal effects in green-to-blue colors.**

A more detailed look at the contribution of each sub-region to this overall pattern reveals that the highest relative loss is likely to occur in the northern and eastern part of the continent, whereas the western part (western Sahel) may experience increases in cropland share, according to some CRMs. Again, while the earlier decades reveal heterogeneous patterns across the region, the later part of the period is characterized by losses of croplands in practically all sub-regions, with some cropland losses exceeding 30% in parts of the continent.

With the exception of the CCC model, all AOGCMs show substantial losses in cropland area in the national aggregate and increasing cropland area losses towards the end of the century. The strongest and most consistent loss of cropland is in the northern and eastern part of the continent and gains of cropland area are in western and southern Africa during the first period. However, this intermittent increase in

cropland area is offset later in the century (Table 1).

Figure 2 shows a geographic representation of results based on the SAGE cropland model and the NCAR, CCSR and CCC climate models (2010–2039 period only). For reference, the actual and modeled distributions of croplands based on the SAGE model are depicted in the left and center panels in the top row, respectively, and the spatial patterns arising from an ensemble prediction of climate models are shown in the right panel in the top row. Figure 2 shows that despite differences in the model projections from various AOGCMs, general patterns of cropland sensitivity can be discerned. That is, while subtropical latitudes may experience increases in croplands at the margins due to relative increases in precipitation, eastern and northern Africa are likely to experience the highest relative and absolute losses in cropland area early in the century.

## Conclusions and policy implications

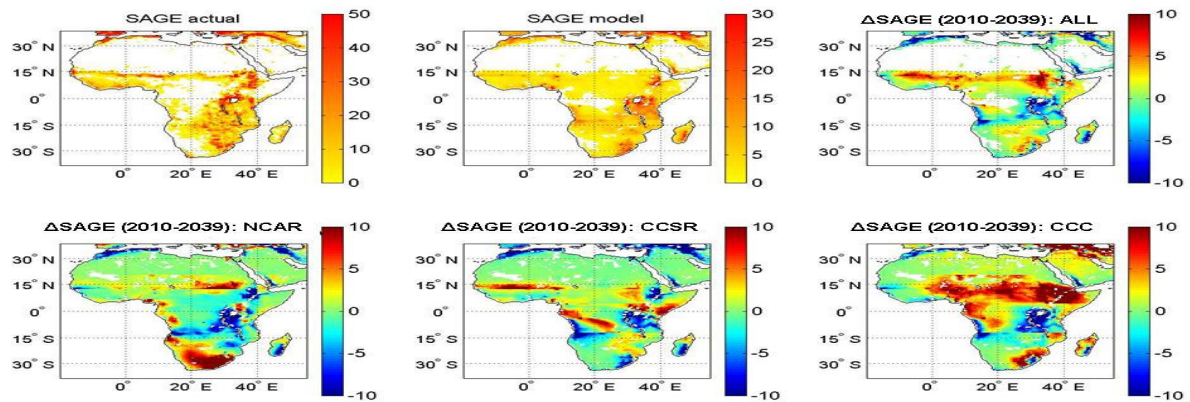
The analysis presented here shows that current cropping patterns in Africa can be predicted reasonably well using a reduced set of geophysical variables including long-term seasonal temperature and precipitation and soil characteristics.

Analysis of the impacts of various climate change scenarios showed that despite significant discrepancies in alternative depictions of cropland share at the sub-regional level, the seasonal effects of precipitation and temperature changes are relatively consistent across models. Geographically distinct patterns of climate sensitivity characterize different agro-ecological zones.

Specifically, changes in precipitation in semi-arid and humid regions have opposing effects, but the majority of the African continent has a unidirectional sensitivity to changes in temperature (with exceptions in some parts of southern and eastern Africa). This is consonant with the notion that increases in temperature tend to have negative effects on agriculture in tropical latitudes, and changes in precipitation largely affect the tail ends of precipitation regimes. It is important to note, however, that this analysis is concerned only with the allocation of land to cropping and does not consider climate impacts on crop yield and agricultural productivity.

**Table 1: Changes in cropland area (%) for different climate models**

	<i>CCC</i>	<i>HCCPR</i>	<i>CSIRO</i>	<i>MPIM</i>	<i>GFDL</i>	<i>NCAR</i>	<i>Mean</i>	
<b>2010-2039</b>								
<i>Africa</i>	-11.1	22.9	-14.6	-11.5	-7.6	-5.3	-2.6	<b>-4.3</b>
North	-35.8	28.7	-6.0	-19.8	-4.0	-42.7	-7.1	<b>-12.4</b>
West	12.6	36.2	-11.6	-8.0	9.7	29.1	20.7	<b>12.7</b>
East	-19.3	18.7	-21.7	-23.4	-29.9	-4.6	-24.4	<b>-14.9</b>
Central	36.5	32.2	-41.5	37.9	6.5	-44.0	-43.1	<b>-2.2</b>
South	-6.1	-4.4	-5.6	1.5	10.3	-1.0	24.6	<b>2.8</b>
<b>2070-2099</b>								
<i>Africa</i>	-13.9	-3.9	-32.3	-29.8	-23.5	-12.5	-12.5	<b>-18.3</b>
North	-61.2	-4.5	-28.7	-36.6	-25.8	-49.6	-13.0	<b>-31.3</b>
West	79.5	-11.7	-30.0	-35.7	4.5	18.6	1.6	<b>3.8</b>
East	-30.4	-6.2	-43.4	-38.7	-51.0	-11.8	-31.7	<b>-30.4</b>
Central	-8.4	18.7	-50.8	5.3	-11.5	-50.2	-49.4	<b>-20.9</b>
South	-13.3	-7.8	-17.0	-11.5	-2.4	1.2	11.9	<b>-5.6</b>



**Figure 2: Long-term changes in cropland share predicted by climate models**

East Africa is expected to experience the highest absolute loss in cropland share due to a relatively high density of croplands today, whereas less densely cultivated areas will remain characterized by sparse cropping patterns despite positive changes at the margins. Subtropical regions experience the least relative change due to positive perturbations in precipitation and temperature. Despite uncertainties in these estimates, the results make it clear that policy interventions in regard to land management, food policy, markets or poverty, intended to mitigate the impacts of climate change on agro-ecosystems, need to be tailored to each sub-region, and that climate change needs to be considered when making long-term investments in agricultural infrastructure such as irrigation or the development of markets.

Ricardian analyses for Africa (Kurukulasuriya & Mendelsohn 2006) suggest that agricultural productivity exhibits a negative or a U-shaped relationship with cropland density. That is, the marginal effect of increasing cropland does not result in higher land productivity in low-density systems,

whereas in areas of higher cropping probability the effect is small or slightly positive. In other words, expansion of croplands as a result of more favorable climate is a meaningful policy only in productive agro-ecosystems, but will perpetuate low agricultural productivity and, by extension, poverty (Mendelsohn et al. 2006) in marginal cropping areas. However, this policy raises issues of the opportunity costs associated with converting from non-cropping land uses (urban, forest, etc.) to agriculture.

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

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

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