CLIMATE CHANGE AND AFRICAN AGRICULTURE
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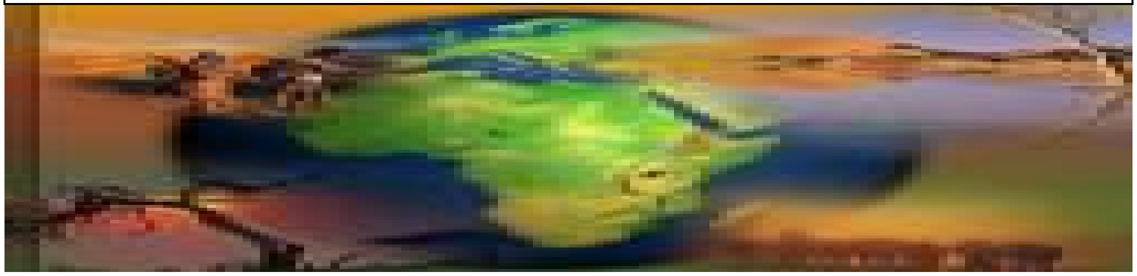

Impacts of climate change on crop farming in South Africa[1]

Statistical evidence suggests that South Africa has been getting hotter over the past four decades, with average yearly temperatures increasing by 0.13°C per decade between 1960 and 2003. There has also been an increase in the number of warmer days and a decrease in the number of cooler ones. Moreover, the country's average rainfall, estimated at 450mm per year, is well below the world's average of 860mm, while evaporation is comparatively high. In addition, surface and underground water resources are limited.

Climate change, which may make temperatures climb and reduce the rains and change their timing, may therefore put more pressure on the country's scarce water resources, with implications for agriculture, employment and food security.

These changes in temperature, together with the already scarce water resources in the country, are expected to have a significant effect on all sectors of the economy, in particular agriculture. For example, anecdotal evidence suggests that climate change could lead to a fall of about 1.5% in the country's gross domestic product (GDP) by 2050 – a fall roughly equivalent to the total annual foreign direct investment in South Africa at present. Moreover, climate change and the resulting loss of biodiversity could do irreparable damage to the country's tourism industry, which is worth an estimated R100 billion per annum (about US$15 billion).

But agriculture is expected to be most affected by these changes because it is highly dependent on climate variables such as temperature and precipitation, and also because of the semi-arid nature of the country, with increased farming on marginal lands. Domestic agriculture is of course the main source of food for the country's population of 46.9 million. Not only South Africa but also the sub-region will be affected, given that more than half of the region's staple, maize, is produced in South Africa.

This study attempts to assess the economic impact of the expected changes in the climate on crop farming in the country. It uses a cross-sectional

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[1] This Policy Note is prepared by R Hassan based on Benhin (2006), Climate change and South African agriculture: Impacts and adaptation options, *CEEPA Discussion Paper No. 21, CEEPA, University of Pretoria.*

approach (Ricardian) to measure the relationship between net revenue from growing crops and climate in South Africa. 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. Analyses that do not include adaptation (such as the early agronomic studies) overestimate the damages associated with any deviation from the optimum. Using selected climate scenarios, the study also attempts to predict the extent to which projected climate changes will affect net revenue from crop farming in South Africa.

The Ricardian model

The Ricardian method is a cross-sectional approach to measuring determinants of land value. The principle follows Ricardo's original observation that land rents would reflect the present value of future net productivity of farmland (Ricardo 1817). The model uses actual observations of farm performance in different climatic regions to measure how long-term farm profitability varies with local climate while controlling for other factors. By regressing farm values on climate and other control variables we are able to measure the marginal contribution of each variable to land value.

The data and variables included

Because land markets are imperfect and agricultural farm values in the developing world are weakly documented, net farm revenue per hectare is commonly used as the response variable instead of land values. In this study the focus is on crop net revenues.

The analysis uses cross-sectional data at the household and district levels on farm activities, climate, soils and hydrology. These datasets are discussed below.

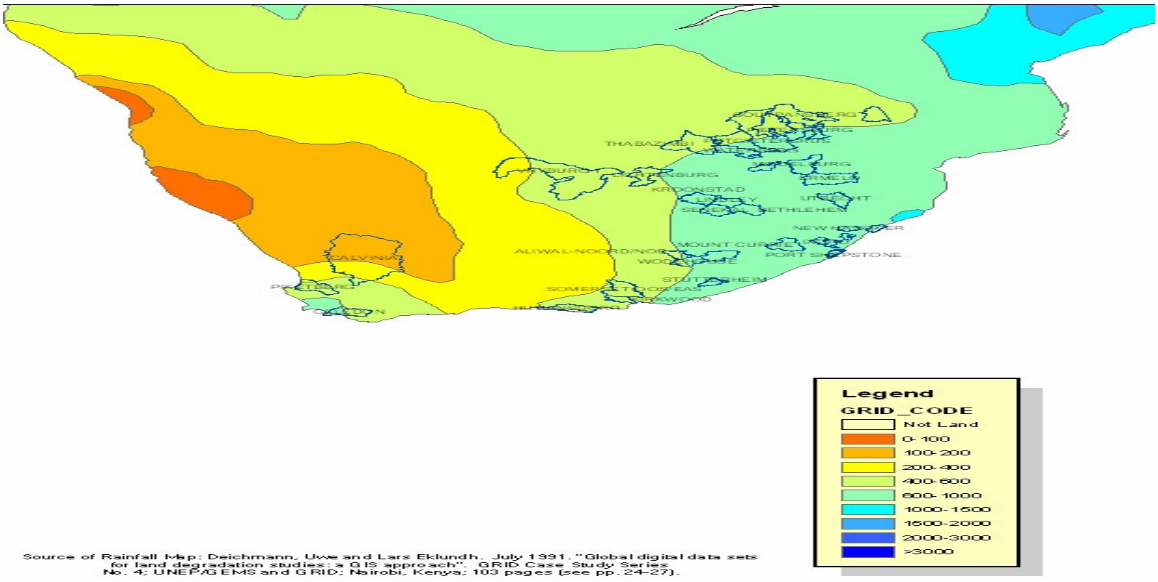
Farm household data: A farm survey was administered to collect information on farmers' production activities during the 2002/03 season, interviewing 416 farm households in 17 districts (Figure 1) across the nine provinces. Of these, 53% were large-scale and 47% small-scale farmers, and 29% were involved in crop farming only with maize as the major crop, 27% in livestock farming only, and 44% in mixed farming**.** The average farm size ranged from 50ha to 1,537ha for large-scale farmers and 1ha to 40ha for small-scale farmers.

The study relied on monthly temperature data collected from US Department of Defense satellites. The monthly precipitation data came from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003).

Soil data was obtained from the FAO (2003) and hydrological data was predicted from a hydrological model for Africa (Strzepek & McCluskey 2006) that calculated the water flow through each district in the surveyed countries.

The dependent variable was measured as crop net revenue per hectare of cropland calculated as gross revenue from crops less total variable cost of production (Figure 2). The cost of household labor was not deducted but its effect was controlled for by including household size as a proxy for household labor as a regressor in the model.

Figure 1: South African rainfall gradient and sample districts



Source of Rainfall Map: Deichmann, Uwe and Lars Eklundh. July 1991. "Global digital data sets for land degradation studies: a GIS approach". GRID Case Study Series No. 4; UNEP/GEMS and GRID; Nairobi, Kenya; 103 pages (see pp. 24-27).

The net revenue model for South Africa was estimated using seasonal climate means for summer, fall, winter and spring. Given that there are two major farming seasons in the country, the study also examined the marginal impacts of temperature and precipitation for the summer farming season (December to May) and the winter farming season (June to November).

Of the 26 major soil categories defined by the FAO, about ten are found in South Africa. The influence of four main types of soil identified as important in South Africa (vertisols, acrisols, arenosols and xerosols) was tested. Two relevant hydrology variables, runoff and flow, were tested in the model. The mean runoff was estimated at about 10mm/month. The data also indicated that Limpopo Province has the highest mean annual runoff, followed by Mpumalanga and KwaZulu-Natal. The Eastern Cape and Western Cape have the lowest runoff. The analyses also included other socioeconomic variables.

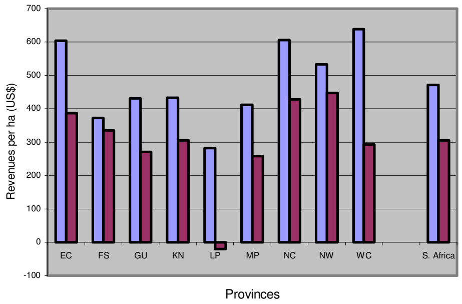


Figure 2: Mean gross and net revenues in the nine provinces (US$/ha)

Sensitivity of farm revenue to climate

The study explored two specifications of the Ricardian model. The first includes only climate, soil and hydrology variables and is referred to as the 'without adaptation' model. The second includes the relevant socio-economic variables and is referred to as the 'with adaptation' model. This was to assess the extent to which these additional variables increase or decrease the effect of climate on the crop sector.

Estimated results indicated that climate variables of temperature and precipitation are very relevant for agricultural activities in South Africa and more so for dryland farming, especially with respect to precipitation. Irrigated farms are cushioned against adverse climate effects by having a substitute for rainwater. Climate impacts were also found to have, to a large extent, a non-linear relationship with net revenue. That is, increases in temperature and precipitation will be beneficial to crop farming but beyond a certain limit the impacts will be negative.

The key implications of the 'without adaptation' models are that the extent and nature of the impact of climate factors on crop net revenues may be influenced by the type of soil and the runoff in a particular farming location. Acrisols and arenosols may enhance crop net revenues and therefore reduce any negative effect of climate change, while vertisols and xerosols may rather reduce crop net revenues and therefore aggravate the negative effect. Runoff will increase net revenues and also reduce the negative effects of climate but only to a certain extent, as excessive runoff may be detrimental to net revenues, as indicated by the negative coefficient of the quadratic term.

In addition to irrigation and farm type, other socio-economic variables tested in the 'with adaptation' models included the area of cropland, a dummy for livestock ownership, access to electricity, access to public extension services and other sources of extension services, distance to crop market, farming experience and household size. The size of cropland area was found to be important, especially for dryland farmers, since a larger area enables them to spread their risk from adverse climate effects. Ownership of livestock was also found to be a possible adaptation option, but its effects are different for irrigated and large-scale farms on one hand and dryland and small-scale farms on the other. Small-scale farmers and dryland farmers, especially the latter, are more likely to switch to livestock farming in response to adverse climate effects. Easy accessibility of markets means relatively higher prices for products and therefore helps to cover additional costs caused by the adverse effects of climate.

Estimated marginal impacts of the climate variables showed that an annual increase of 1°C in temperature will have a positive impact on annual crop net revenues for all farms except dryland ones. A net increase of US$80 per hectare is expected for the whole of South Africa (US$191 for irrigated farms, U$S588 for large-scale farms and US$61 for small-scale farms, but a fall of US$50 for dryland farms). However, what these annual estimates obscure is the seasonal differences in the impacts. Such an increase in temperature will affect crop farm net revenues negatively in the summer farming season but positively in the winter season. The estimates show that including adaptation related variables in the estimation helps to increase the positive impacts while reducing the negative impacts for all the types of farming but not significantly for dryland farms.

Not considering adaptation related variables, estimates indicate that all the farming systems will experience positive annual net revenue impacts from increased precipitation, with the exception of small-scale farms. Again, seasonal differences in the impacts are important. Rainfall in the early part of the summer farming regions would be beneficial, while later rainfall would be harmful. Early winter rainfall will also be beneficial for the winter farming regions. Including adaptation related variables changes the extent of the estimated marginal impacts but not very significantly, except for dryland and small-scale farmers. For dryland farmers, the positive impacts from increased precipitation are reduced while the negative impacts for small-scale farmers are increased. For dryland farmers, the implication is that with adaptation the link between precipitation and crop net revenue weakens and therefore a decrease in precipitation will reduce the drop in crop net revenues.

Table 1: Marginal effects of warming (+1°C) on crop net revenue (US$/hectare)

Without adaptation models: Climate, soil and hydrology variables model

	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer temperature	952.68***	2695.66*	-507.20*	1892.91*	1570.30***
Fall temperature	-1704.2***	-5182.81*	-605.65**	-3279.3	-2595.2***
Summer farming season	-751.53***	-2487.15	-1112.85***	-1386.4	-1024.85
Winter temperature	1561.95***	4420.82**	997.20***	3052*	2496.52***
Spring temperature	-730.56***	-1742.35	65.63	-1077.3**	-1411.2***
Winter farming season	831.39***	2678.47	1062.83***	1974.73	
Annual temperature	79.86	191.31	-50.02	588.34	60.48
Annual elasticity	4.36	6.71	-5.33	26.87	4.04

With adaptation: Climate, soil, hydrology and socio-economic variables model

	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer temperature	918.38***	2671.3***	-682.28***	1302.1***	1589.1***
Fall temperature	-1528.6***	-5308.3***	-197.88	-2177.6**	-2376.1***
Summer farming season	-610.21**	-2637***	-880.15***	-875.42*	-786.94***
Winter temperature	1516.99***	4676.7***	687.02***	2252.7***	2317.18***
Spring temperature	-782.62***	-1780.7***	125.17	-945.37***	-1476.9***
Winter farming season	734.37***	2896***	812.19***	1307.28**	840.32***
Annual temperature	124.16**	259.04***	(-67.96**	431.86***	53.38
Annual elasticity	(6.78)	(9.09)	(-7.25)	(19.72)	(3.56)

Estimated annual elasticities in parenthesis; ***Significance at 1% ** at 5% and *Significance at 10%

Impacts of future climate projections

The study examined the impacts of three climate change scenarios derived by Strzepek and McCluskey (2006) using three different models (CSIRO2, HadCM3 and PCM) and the A2 emission scenarios plausible for South Africa. All three models predict increased temperatures in the range of 2.3°C to 3.9°C by 2050, and even higher levels of 3.9°C to 9.6°C by 2100. All three models also predict falls in precipitation in the range of 2% to 8% by 2050 and 4% to 8% by 2100. The results indicate that, comparatively, dryland farms will be more affected by increased temperatures and decreased rainfall. Comparing large- and small-scale farmers, the latter will also be more affected. These scenarios predict that crop net revenues will fall by 1.7% to 5.3% per hectare for the whole of South Africa, with major differences between dryland and irrigated as well as between small- and large-scale farms (Table 2).

Table 2: Impacts of selected climate scenarios on net revenues (US$/hectare)

	CGCM2 2050	CGCM2 2100	HadCM3 2050	HadCM3 2100	PCM 2050	PCM 2100
Change in temperature °C	3.6	9	3.9	9.6	2.3	5.6
Change in precipitation %	-4	-8	-8	-15	-2	-4
Impacts						
Full sample	-12.88	-40.79	-16.26	-93.24	-5.14	-29.99
	(-4.22)	(-25.65)	(-5.32)	(-30.52)	(-1.68)	(-9.82)
Irrigated	-15.91	-113.99	-20.23	-134.55	-5.34	-41.16
	(-3.4)	(-24.43)	(-4.34)	(-28.84)	(-1.15)	(-8.82)
Dryland	-43.2	-55.24	-44.1	-59.06	-41.63	-46.29
	(-27)	(-34.74)	(-27.74)	(-37.44)	(-26.18)	(-29.12)
Large-scale	-43.11	-220.16	-49.39	-248.21	-20.65	-92.99
	(-12.01)	(-61.41)	(-13.78)	(-69.23)	(-5.76)	(-25.94)
Small-scale	-47.29	-204.6	-52.73	-227.2	-25.05	-93.86
	(-18.61)	(-80.49)	(-20.74)	(-89.39)	(-9.86)	(-36.93)

Note: Percentage changes in parenthesis

Conclusions and policy implications

This study shows that the effects of changes in both temperature and precipitation may be different for the different farming systems in the country, with the most negatively affected being dryland crop farming and small-scale farmers. Irrigation provides a cushion against adverse climate scenarios. The effects would also be different at the provincial levels. This finding is important for knowing how and where to direct the relevant policies for controlling the effects of climate change. Certain soil types, such as vertisols and xerosols, are less productive and therefore aggravate the harmful effects of climate change, while other types, such as acrisols and arenosols, may help reduce them. Runoff will also benefit crop farming, but when it is excessive it can be harmful. In general, adaptations such as irrigation may help reduce the harmful effects of climate change. One significant finding is that there are seasonal differences in the climate effects, and these differences must not be overshadowed by looking only at the mean annual effects. Increased temperatures will be harmful in the summer farming regions but beneficial in the winter ones. The overall annual effects will therefore depend on the relative magnitudes of the positive and negative effects. This means that advantage should be taken of the positive effects, while controlling or reducing the negative effects. If this can be done, temperature changes should be beneficial rather than harmful to the country. Some of the adaptation strategies identified in the study could help achieve this. Changes in precipitation will also have different seasonal effects. Again there is a need to fine-tune policy to take advantage of the relative benefits.

Using selected climate scenarios, the study also predicts that crop net revenues could fall by as much as 90% by 2100 and that small-scale farmers will be the most severely affected. However, if proper adaptations are made these losses could be reduced.

In general, climate change is expected to be harmful to crop farming in South Africa. However, there are expected to be gains and losses specific to each farming system and each province. If policy makers and farmers are able to identify where the gains and losses are, and direct the appropriate policies and adaptation strategies to these areas, the expected overall negative effect may be reduced, and it is even possible that the agriculture sector in South Africa may reap benefits from climate change.

References

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

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

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