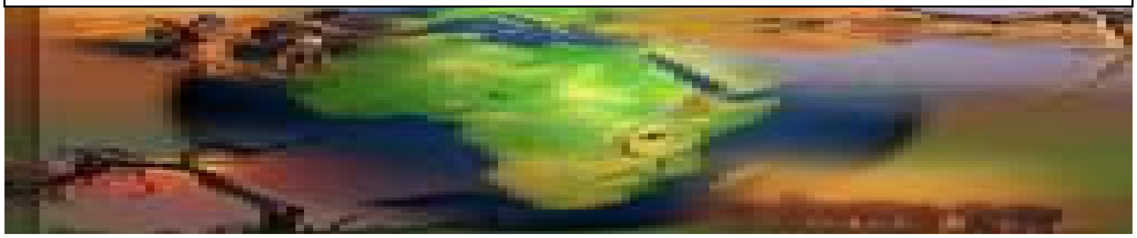
CLIMATE CHANGE AND AFRICAN AGRICULTURE
Policy Note No. 38, August 2006, CEEPA



Climate change and crop water use and productivity in Africa[1]

The core research activity of this GEF/World Bank project adopts the cross-sectional (Ricardian) approach to assess the economic impacts of climate change on African agriculture. This approach uses statistical analyses of data across geographic areas to separate the effect of climate attributes from that of other factors (such as soil quality and use of economic inputs) explaining production differences across regions, and uses the estimated statistical relationships to predict future impacts of climate change. To further increase the understanding of climate effects on crop agriculture a parallel analysis of crop yield response and water use employing crop growth simulation models and climate scenario analyses was undertaken. Crop modeling offers a powerful alternative tool to experimentation for studying in a very short period of time the possible consequences of changing conditions on the physiological development and growth of crops. Thus, modeling is commonly used to analyze the possible effects a change in climate will have on agriculture. Also, modeling, in general, compensates for scarcity of data, which is a particularly acute problem with this type of analysis where it is typically hard to obtain actual observations on all the details required within short time periods. However, as these impacts are manifold and the interactions among the different factors and processes involved are quite complex to analyze and not always fully understood; modeling is often considered an oversimplification. However, it is one of the best existing tools as it allows users to test many scenarios in a short period of time and if the limitations of the approach are properly recognized the results may provide adequate insights into the climate change impacts on agriculture.

This component of the project implemented by national teams under the FAO leadership developed a unified approach in crop simulation modeling of the relationship between yield and evapotranspiration as the measure of water use by crop agriculture. The country teams adapted the CROPWAT program of the FAO to assess potential and actual crop water use of selected crops in selected districts. The study was conducted in two phases. In the first

[1] This Policy Note is prepared by R Hassan based on Wahaj, Maraux & Munoz (2006), Actual crop water use in project countries: A synthesis at the regional level. *CEEPA Discussion Paper No. 38, CEEPA, University of Pretoria.*

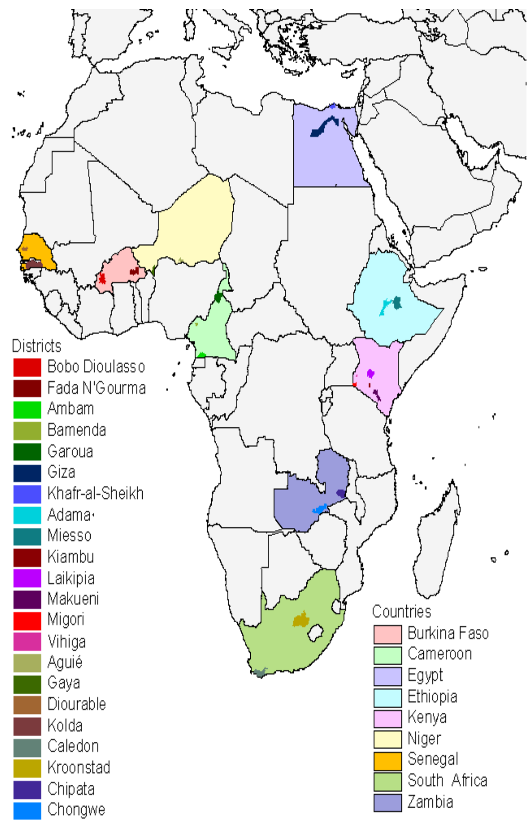
phase, present crop water use was simulated. In the second, country teams were supposed to use climate change scenarios to predict future water requirements of these crops under the various scenarios. For the second phase a particular methodology was developed to take into account changes in both temperature and CO_2 concentrations in the calculation of crop water use under the examined climate change scenarios with the use of CROPWAT.

Farming systems and crops studied

Among the project areas selected to be studied within the countries, Egypt presents the driest environment (with rainfall less than 100mm per year), whereas the wettest locations are in the Bobo Dioulasso district of Burkina Faso (with an average rainfall of about 1000mm per year). In Egypt, unlike the other countries participating in the study, agricultural production is totally dependent on irrigation. There are also large differences in the climatic conditions and agro-ecozones within some countries, such as Ethiopia, Senegal and Zambia.

Subsistence farming systems relying primarily on family labor for crop production are predominant in the majority of the project countries. In Egypt, South Africa, and the Chipata district in Zambia, large-scale farmers practice commercial, mechanized and intensive farming. Maize, millet, groundnuts, sorghum and beans are the main crops grown in the project countries, especially where rainfed agriculture is practiced. In Egypt the main crops are cotton, wheat, maize and citrus fruits. Commercial farmers in South Africa grow fruit such as apples and pears. Five crops, maize, millet, sorghum, groundnuts and beans, were selected for the analysis of present crop water use in at least two districts, each representing a different agro-ecozone in each country (Figure 1).

Figure 1: Selected districts for CROPWAT analysis in the project countries



Simulating crop yield response to evapotranspiration

The program used for simulating crop yield response to water (CROPWAT) is a decision support system developed by the Land and Water Development Division of the FAO. Its main functions are to calculate reference evapotranspiration, crop water requirements and crop irrigation requirements in order to develop irrigation schedules under various management conditions and scheme water supply and to evaluate rainfed production, drought effects and efficiency of irrigation practices. It uses procedures for predicting yields when all the climate, soil and crop parameters are known. This approach allows estimation of actual evapotranspiration (or actual crop water use), after having estimated the stress factor from the ratio of actual to potential yield.

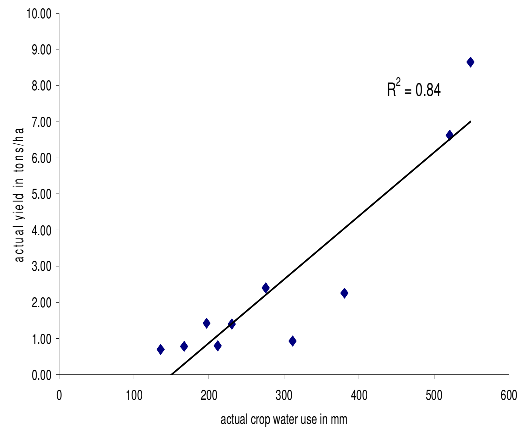
CROPWAT is used together with the CLIMWAT database, which includes monthly average data from a total of 3262 meteorological stations from 144 countries, including all the project countries of this study. Thirty years' average climate data from 1961–1991 was used for assessing potential crop evapotranspiration. Some country teams collected the climate data directly from their respective meteorological stations, others used the CLIMWAT database. Country teams also collected production data for a number of years.

Crop water use and productivity in the project countries

As expected, the results show that the potential crop water requirement is highest in arid and semi-arid areas, and among crops maize has, in general, the highest potential crop water requirement. It is important to note here that the crop water use of the irrigated millet and sorghum is higher than that of rainfed maize, which is also logical as there is more water available for the irrigated crops to evapotranspire.

Crop water use, in general, is directly related to the crop yield. Although the analysis in this report is based on actual data collected from different sources where many factors affected yield, the linear correlation between actual water used by maize and actual yield is very strong (Figure 2). This curve should, in fact be curvilinear. However, since neither crop water use nor actual yield is at its maximum in the selected districts, this segment represents only the initial portion (slope) of the complete polynomial curve.

Figure 2: Maize crop water productivity



In the case of rainfed maize, actual yield increases from 0.8 tons/ha when actual crop water use is 212mm to 2.26 tons/ha when actual crop water use is 381mm. These values are realistic according to the published values for water use efficiency. Among the selected crops, maize is the least drought resistant and needs water particularly at the flowering stage. Figure 2 also shows that maize yield goes to zero below 150mm of evapotranspiration. Growing maize in wet areas, or with timely irrigation, can therefore improve the harvest tremendously.

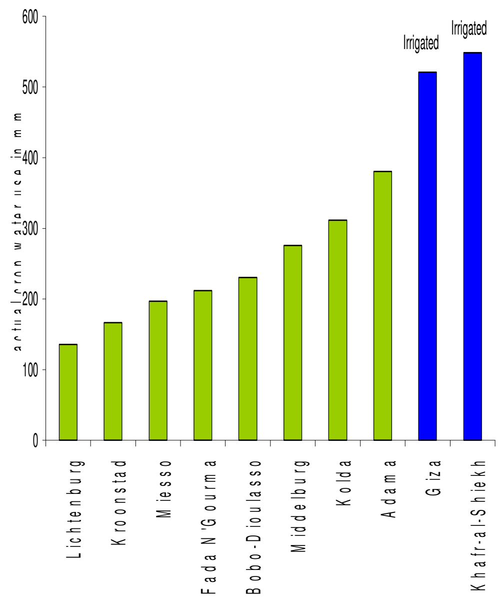
Average crop water productivity values for sorghum, beans and millet are in line with the ranges published by the FAO and elsewhere. These values are slightly lower for groundnuts (Table1). Although the actual reasons for these low figures are not known they are not necessarily due to water use.

Table 1: Average crop water productivity (CWP) of the selected crops

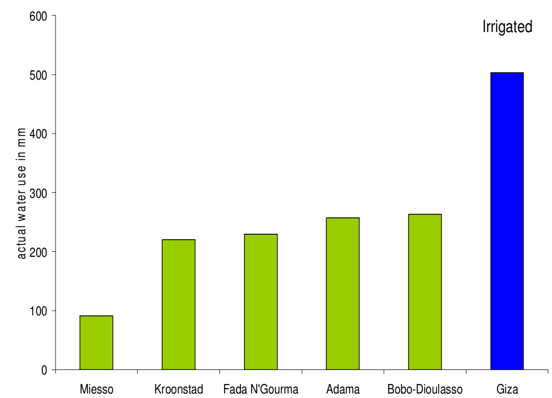
Crop	Average CWP (kg/m^3)	CWP range published by FAO and other (kg/m^3)
Beans	0.44	0.30 – 0.60
Groundnuts	0.50	0.60 – 0.80
Millet	0.21	0.16 – 0.66
Sorghum	0.70	0.60 – 1.00
Maize	0.8	0.8 – 1.6

Maize is by far the most common crop grown in all the selected districts. It has replaced some other, better adapted, crops such as sorghum and millet. It is grown in climates ranging from temperate to tropical and tolerates high temperatures. The ideal temperature for maize ranges from 15°C (frost free) to 45°C. The actual evapotranspiration of maize for selected districts of the project countries is in general rather low, which does not allow it to produce a good yield. Maize (medium maturity) requires between 500 and 800mm of water (depending on the climate) to give the maximum yield. In the selected districts, crop water use by maize is highest for irrigated crops (in Egypt) followed by the crops cultivated in the sub-humid agro-climatic zones of Burkina Faso, Ethiopia and Senegal – in these countries maize is grown mainly by farmers in the southern parts, which are more humid. Evapotranspiration by rainfed maize is least in semi-arid and dry zones because of erratic rainfall, leading to low yields. The crop water productivity of maize is also high compared with other crops grown in the same districts. The average crop water productivity of maize in the districts studied in this project is 0.8 kg/m^{3}, which is in line with the range 0.8 to 1.6 kg/m^3 published by the FAO (Table 1).

Figure 3: Actual crop water use in the selected districts in Africa



Maize



Sorghum

Millet is the only crop that is not irrigated in any of the selected districts. This is because it is drought resistant and therefore more water efficient under dry conditions and can survive long dry spells. The actual evapotranspiration of sorghum increases from semi-arid to sub-humid agro-climatic zones (Figure

3), and in districts with no irrigation it also increases with the increase in total yearly rainfall. Sorghum is one of the most drought resistant crops and is extensively grown under rainfed conditions as a food crop and also as fodder. Crop water use by sorghum is highest in the Giza district of Egypt as the crop is irrigated there.

Groundnuts are also frequently grown under rainfed conditions; however, this crop is less drought resistant than sorghum. Beans grow well in areas with medium rainfall, but the crop is not suited to the humid, wet tropics. Results for the selected districts show that actual crop water use is rather low (200mm) compared with the crop water requirement calculated with CROPWAT (300–500mm), even when the crop is irrigated.

Conclusions and implications

The crop water response analyses showed that actual yield of the different crops – specifically of maize and groundnuts – improves with an increase in actual evapotranspiration. However, the gap remains wide between actual and potential yield and actual and maximum evapotranspiration, especially for rainfed crops. In case of irrigated crops, yields are better even when the crop water use is relatively low as compared to their respective water requirement as a result of flexibility in water supply at the critical growth stages of the crops. Rainfed maize and sorghum seem to be performing better in terms of crop water use in the sub-humid climate as compared to semi-arid Sahelian climatic conditions, as a result of better rainfall. This corroborates the well-known fact that water is among the main limiting factors in several African farming systems and therefore irrigation could play an important role in agricultural development.

In general, the study results give realistic values for maize, sorghum, millet, beans and groundnuts evapotranspiration and actual yield. The average values for crop water productivity (CWP) for these crops are within the common published ranges. Maize and sorghum appear to be the most water efficient crops grown in the districts. Maize, however, is the crop that is the most sensitive to water stress among the crops studied and should therefore be grown only where good availability of water can be guaranteed. It should be grown under irrigation or in rainfed areas where rainfall is reliable and the crop needs can be adequately satisfied. This unfortunately is not the case in most of the districts studied.

If information about the current low reliability of rainfall patterns is combined with recent studies on possible changes in surface water availability, the interest in increasing the area under irrigation increases. In fact, de Wit and Stankiewicz (2006) predict that by the end of this century 25% of Africa will have reduced surface flows owing to diminishing rainfall.

The results of the first phase of this study may be used as an initial picture, to which climate change scenarios can be applied. For this purpose, the FAO has developed under this project a draft methodology that would allow CROPWAT to be used to analyze the effect of climate change on crop water requirements.

The analysis proposed in the draft methodology follows three steps:

1. Assessing change in the duration of different growth stages as affected by increased or decreased level of temperature and CO_2 concentration in the atmosphere

2. Calculating crop water requirement by using the projected climate data and the new growth stages from step 1 in CROPWAT

3. Recalculating the actual crop water use as described in the methodology section of this report.

This draft methodology has been used by the South African country team to calculate the impact of climate change on the crop water requirements of maize for three districts – Lichtenburg, Kroonstad and Middelburg. The results of this are summarized in Policy Note No. 21 of this series.

References

De Wit M & Stankiewicz J, 2006. Changes in surface water supply across Africa with predicted climate change. *Science* 311(5769): 1917–21

http://www.sciencemag.org/cgi/content/abstract/311/5769/1917

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.

CEEPA
The Centre for Environmental Economics and Policy in Africa
University of Pretoria

THE WORLD BANK