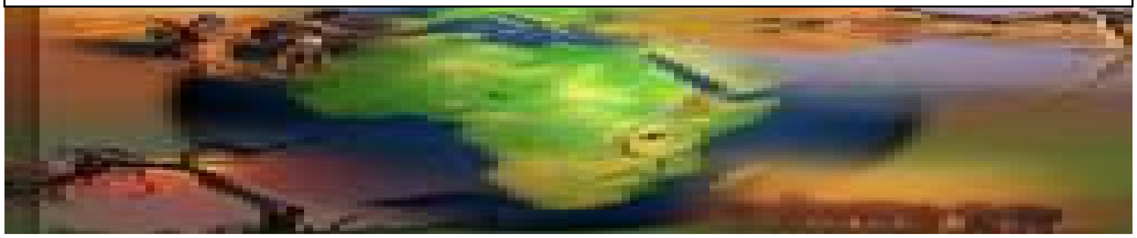


Climate change and crop water use and productivity in Senegal[1]

This study examined the impact of climate change on selected crop water use and production in several districts in Senegal. It also analyzed and evaluated strategies for adapting to climate change so as to mitigate its negative effects on agriculture in Senegal, which occupies 70% of the country's working population and contributes 11% of the GDP.

The research implemented by a national team 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 team adapted the FAO's CROPWAT program to assess potential and actual crop water use, focusing on millet and groundnuts, and also on maize as an alternative for diversification.

Crop coefficient and soil parameters adapted to Senegal conditions were added to the model. The IPCC findings on climate change were used as inputs into the CROPWAT model to assess the impact of climate change on agriculture in Senegal. The evaluation was carried out in seven of the country's representative agricultural regions.

Case study areas, farming systems and crops studied

The districts for this study were chosen in a north/south gradient (Figure 1), to represent the spatial rainfall variations. Diourbel and Kaolack are located in the center of the agricultural basin, inside the northern Sudanese zone (with an average annual rainfall of 400 to 600mm), with sandy soils.

In the south, Kolda represents the sub-Guinean area (with an average annual rainfall of 900 to 1000mm) where the soil type is clay.

Irrigation and flooded crops are found along the river valleys of northern Senegal, on the northern coast (Niayes) and in the southern part of the country (Casamance).

Of the crops cultivated in the seven agro-ecological zones, 96% are rainfed. Millet is a traditional crop grown throughout Senegal, as a staple food in the rural areas. There are several varieties, for example one with a 90-day growth cycle is cultivated in Diourbel and one with a 120-day growth cycle in

[1] This Policy Note is prepared by S Perret based on Diop (2006), Analysis of crop water use in Senegal with the CROPWAT model, *CEEPA Discussion Paper No. 34, CEEPA, University of Pretoria.*

Kolda. It is produced essentially for local consumption

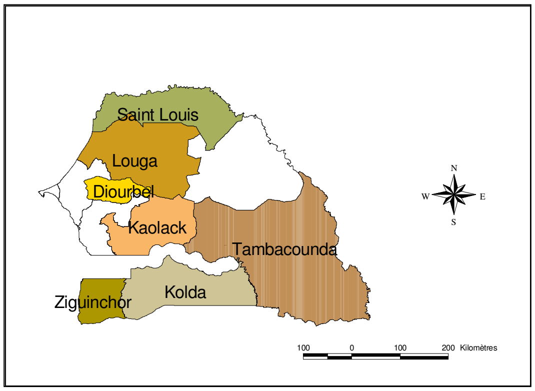


Figure 1: Districts used in the study

Food crops in Senegal are millet, sorghum, maize, beans and rice, and cash crops are groundnuts, cotton, sugar cane and tomatoes. The two main crops, in term of production and cropped area, are millet and groundnuts, covering respectively 42.9% and 28.1% of the total cropped area in the country. They were therefore chosen for this study.

Groundnuts are cultivated essentially during the rainy season, approximately from June to October. Despite being in two different agro-ecological zones, Diourbel and Kolda have almost the same proportion of total groundnut production (11%), but the area cultivated is higher in Diourbel (12.5%) than in Kolda (8.5%) in terms of proportion.

Groundnuts are considered a cash crop because they are transformed into vegetable oil by local factories and the oil is exported. However, part of the yield is transformed into dough and used in the preparation of certain local dishes.

Maize is cultivated essentially in areas where average annual rainfall is more than 500mm. It is therefore found mostly in the southern half of Senegal. It is also cultivated in the irrigated areas, along the Senegal River. The produce is sold in the local markets. Only 2.9% of the total cropped area is under maize, and 35.72% of this area is in Kolda.

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 (ETa or actual crop water use), after having estimated the stress factor Ks from the ratio of actual to potential yield.

The input data for the model are monthly climatic parameters including minimum and maximum temperature, humidity, sunshine and wind speed. CROPWAT calculates reference evaporation ETo and maximum crop evapotranspiration ETm from crop coefficient Kc. The water stress coefficient Ks further lowers ETm to actual evapotranspiration ETa owing to lack of water. Ks is determined via a comparison between actual yields Ya and maximum yields Ym, using a yield response factor Ky.

Data were obtained from the Meteorological Department of Senegal for the 1961–1990 period for the following parameters: rainfall, minimum and maximum temperature, sunshine and wind speed. Calculations were done using the mean value of each parameter. A continuous decrease in rainfall is observed at the end of the 1960s, from 1971 in Diourbel and from 1975 in Kolda. This matches the observations of other authors working in the whole Sudano-Sahelian zone

Climate change scenarios for each site were created by combining the output of three equilibrium $2xCO_2$ General Circulation Models (GCMs) with the daily climate data for each site. These three GCMs used in this study to create the climate change scenarios are at the high end of the IPCC range (1.5^oC to 3.5^oC).

Outputs of these three GCMs were used to evaluate the impact of climate change on millet. The modified climate data were incorporated into the CROPWAT model and used to evaluate the potential impact of climate change on water needs in Senegal.

Crop water use and productivity in Senegal, assessment of the impact of climate change

Table 1 provides the complete results of the analyses done for millet. The maximum yield of millet for small farms was 794kg/ha in Diourbel and 1234kg/ha in Kolda.

The actual crop evapotranspiration is 166mm for Diourbel and 324mm for Kolda. The crop water requirement is 353mm, so compared with the crop evapotranspiration this implies a higher quantity of irrigation water is needed in Diourbel (35mm).

The lowest crop evapotranspiration is observed at Saint-Louis (135mm), where the moisture stress factor (Ks) is 0.35. Comparison between districts shows that the value of ETm is higher in the central agro-ecological zones, represented by Kaolack and Tambacounda, and the southern ones, represented by Kolda and Ziguinchor, with more than 300mm. Low values are obtained for ETa in the northern part of the country, with less than 200mm.

A similar analysis was done for groundnut. The maximum yields obtained for groundnuts are 727kg/ha in Diourbel and 1100kg/ha in Kolda. The ETa is 327mm for Diourbel and 350mm for Kolda. The comparison between ETm and ETa shows that the crop water requirements are satisfied for more than 60%. Irrigation water requirements are, as for millet, higher in Diourbel than in Kolda. In the other districts, the value of actual evapotranspiration reveals three situations: the extreme north, represented by Saint-Louis, with very low values, i.e. poor yields; the central area, represented by Kaolack, with medium value and acceptable yields; and the southern area, represented by Ziguinchor (and Kolda), with high values and very good yields.

The maximum crop water requirement is reached between 50 and 80 days after crop emergence (Figure 7) and the variety considered has a 110-day growing cycle.

Finally, calculations were also applied to maize. The maximum yield in Kolda between 1960 and 2004 (1237kg/ha) was used to evaluate the crop actual evapotranspiration (ETa) for maize, which is 350mm, whereas the moisture stress factor is 0.80. This means that the water needs of maize were 68% satisfied during the 1961–1990 period.

To analyze the impact of climate change on crop water use, the effects of an increase of 1.5°C for Senegal were calculated, and these results were compared with the actual crop water use of millet, using the figures for the 1961–1990 period (as shown in Figures 2 and 3). Millet was selected since it covers 42.9% of the total cropped area in Senegal.

The results reveal that a 1.5°C increase in temperature has no effect on actual evapotranspiration of millet in the districts of Diourbel, Kolda, Louga Saint-Louis and Kaolack. However, a reduction in millet evapotranspiration is observed in the districts of Ziguinchor and Tambacounda.

Conclusions and policy implications

Crop water use is higher in the southern part of Senegal (represented by Kolda), where rainfall is abundant and the soils have more organic and mineral richness, than in the northern part (represented by Diourbel), where water resources are poor and soils less fertile. Thus values for actual evapotranspiration of crops are low in the north and high in the south. For example, in the case of millet a 1.5°C increase in temperature had no effect in the northern part of the country, but caused a reduction in the actual evapotranspiration, and consequently in the yield, in the southern part.

The outputs of the CROPWAT model confirm that the districts located in the southern half of the country have a better potential for crop growth. However, it is in this area that an increase in temperature has a negative impact on millet, causing a reduction in yield.

Such results call for increased support for agricultural systems in that potentially productive southern region. Adapted crops and varieties should be promoted to counter the negative effects of increased temperatures, in order to sustain rural livelihoods and food security.

Table 1: Crop water use and production of millet in the study districts

District	ETo (mm)	ETm (mm)	Ya (kg/ha)	Ym (kg/ha)	ETa (mm)
Diourbel	383	266	500	794	166
Kolda	556	445	900	1234	324
Kaolack	422	406	800	1136	325
Saint-Louis	426	300	384	1100	159
Tamba	554	435	733	1138	365
Ziguinchor	513	421	678	847	388
Linguere (reg. Louga)	403	280	300	637	195

Figure 2 : Modeling the ETa of millet during the 1961-1990 period

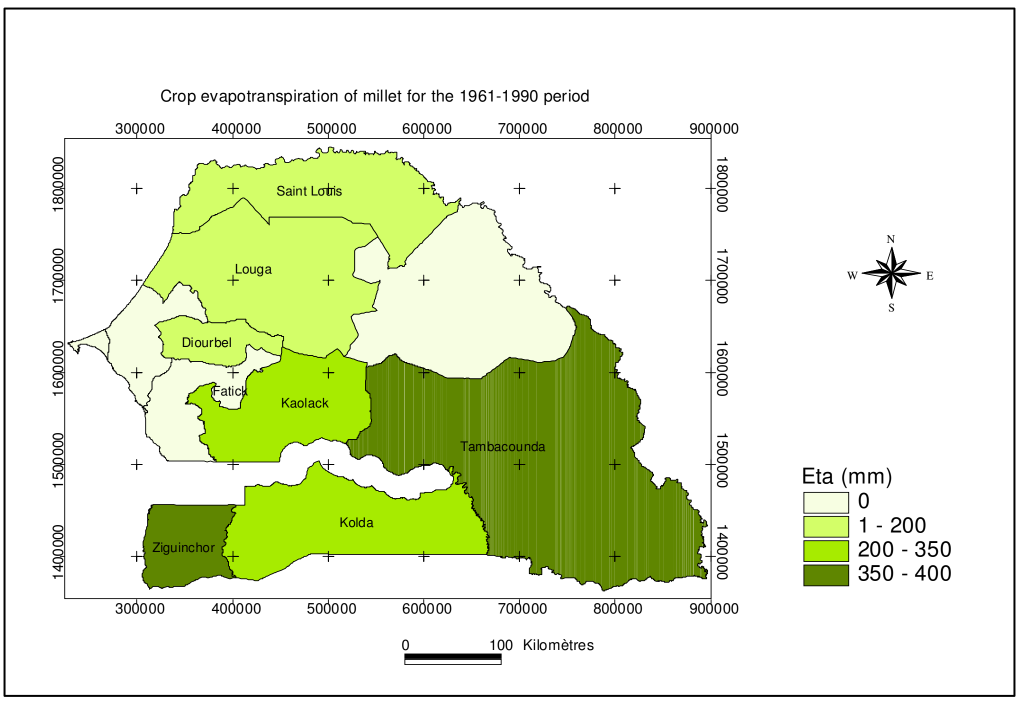
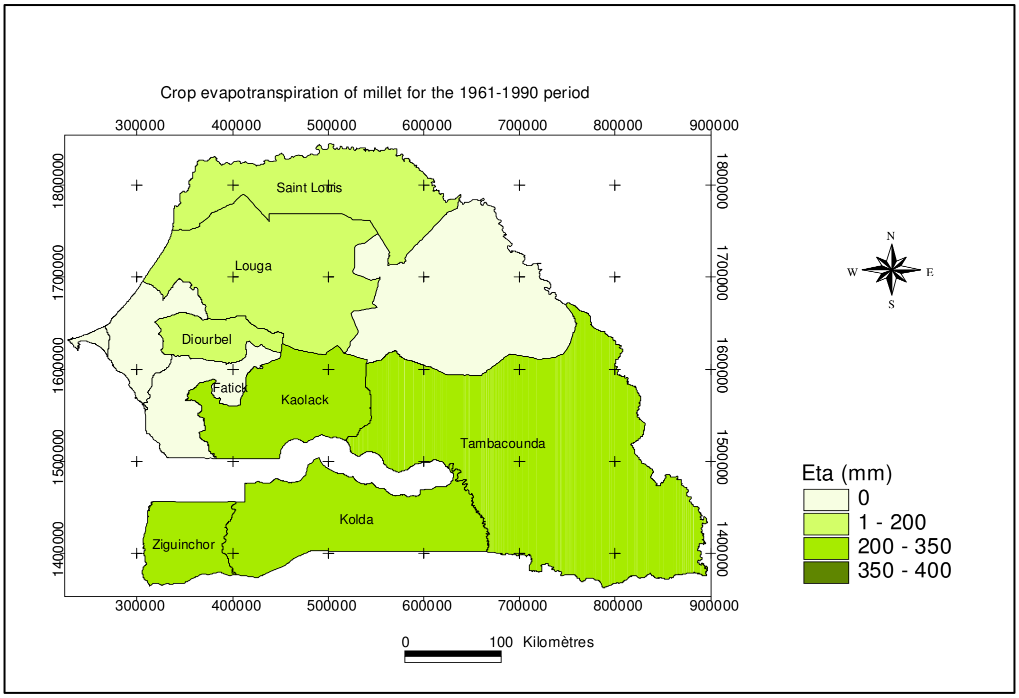


Figure 3: Modeling the ETa of millet for a scenario of 1.5°C increase in temperature



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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