

# ANALYSIS OF CROP WATER USE IN SENEGAL WITH THE CROPWAT MODEL

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## **PREFACE**

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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## **EXECUTIVE SUMMARY**

This study was part of the Global Environment Facility/World Bank Project: *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*. The objective was to study crop water use with the FAO CROPWAT model and evaluate the impact of climate change on crops. The study focused on millet and groundnuts (the main crops in Senegal), and also on maize, which is being developed with the policy of diversification introduced a few years ago.

To run the CROPWAT model, we used the FAO climate and crop data, combined with crop coefficients from Dancette (1983) and soil parameters given by Forest (1982). 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.

Crop water use is higher in the southern part of Senegal (represented by Kolda), where rainfall is abundant and the soils have some 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.

## **1. Introduction**

Crop growth and water use simulation modeling is part of the project *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa* supported by the GEF, the World Bank and CEEPA, University of Pretoria.

The districts for this study were chosen in a north/south gradient (see 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), where soil type is sandy. In the south, Kolda represents the sub-Guinean area (with an average annual rainfall of 900 to 1000mm) where the soil type is clay.

In Senegal, agriculture occupies 70% of the working population and contributes 11% of the GDP. Of the crops cultivated in the seven agro-ecological zones, 96% are rainfed. Millet, the staple food in the rural areas, is the main cereal. 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 Kolda.

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).

## **2. Methodology**

Diourbel is located in the center of the agricultural basin of the country and represents the diversity of crops in this zone. Kolda represents the sub-Guinean zone, where rainfall is not really a constraint on agriculture and where there are some flooded crops.

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 (see Figure 2), from 1971 in Diourbel and from 1975 in Kolda. This matches the observations of other authors working in the whole Sudano-Sahelian zone (Fontaine 1991; Moron 1994; Camberlin & Diop 1999).

The other climatic data are summarized in Tables 1 and 2. The mean values are calculated between 1961 and 1990. These data show that humidity and wind speed are higher in Kolda while the maximum temperature is higher in Diourbel.

## **3. Soil data**

The soil types were determined from the Senegal soil map (Michel & Sall 1983) and the GEF Project Database. Soil moisture availability figures were obtained from measurements made by Forest (1982) for the main soil types in Senegal. In Diourbel the soil is sandy and the average soil moisture is 80 mm/m, while Kolda has clay soils and the average soil moisture is 100 mm/m.

#### 4. Crop selection

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 (RNA 2000). They were therefore chosen for this study. General aspects of crop water requirements are well described by Doorenbos and Pruitt (FAO 1975) and by Dancette (1983).

##### 4.1 Millet

Millet is a traditional crop grown throughout Senegal. It is produced essentially for local consumption. A 90-day cycle was used for modeling crop water use in Diourbel where the rainy season lasts 90 days, and a 120-day cycle in Kolda where the rainy season lasts about 110/120 days. The crop coefficients ( $K_c$ ) used were calculated by Dancette (1983) in Bambeby (Figure 3), using the following equation :

$$K_c = \frac{ETM}{ETP} \quad (1)$$

where  $K_c$  is the crop coefficient

ETM is the maximum evapotranspiration

ETP is the potential evapotranspiration.

(The Penman method is used for ETP calculation. The details of this equation are given in Monteith 1965.)

The maximum of  $K_c$  value intervenes during the flowering period, between 40 and 60 days after sowing, or 70 to 90 days after sowing, according to the variety.

The area occupied by millet varies in each selected district from year to year. The average in the 1961–1990 period was 2.438.608km<sup>2</sup> (56% of the total area) for Diourbel and 85.950km<sup>2</sup> (33% of the total area) for Kolda.

The maximum yield of millet for small farms was 794 kg/ha in Diourbel and 1234 kg/ha in Kolda. This information can be used to evaluate the crop's actual evapotranspiration, using the following equation :

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{ET_a}{ET_c}\right) \quad (2)$$

where:

Ya is actual crop yield

Ym is the mean crop yield

Ky is the yield response factor

ETa actual evapotranspiration

ETc is the maximum evapotranspiration.

Using Equation 2, the actual crop evapotranspiration computed by the FAO CROPWAT model is 166mm for Diourbel and 324 mm for Kolda (Table 3). 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).

In the other districts, the estimated values for variables used to assess actual crop water use are summarized in Table 4. The lowest crop evapotranspiration is observed at Saint-Louis (135mm), where the moisture stress factor (Ks) is 0.35.

Comparison between Tables 3 and 4 shows that the value of Etcrop is higher in the central agro-ecological zones, represented by Kaolack and Tambacounda, and the southern ones, represented by Koda and Ziguinchor, with more than 300mm. Low values are obtained for ETactual in the northern part of the country, with less than 200mm.

## **4.2 Groundnuts**

Groundnuts are cultivated essentially during the rainy season, approximately from June to October. Several varieties are cultivated across the country, but the 55-437 is cultivated more in the central agro-ecological zones and the 73-33 more in the southern ones. The parameters of these two varieties are used in this study. Despite being in two different agro-ecological zones, Diourbel and Kolda have almost the same proportion of total groundnut production (11%) (Figure 4), but the area cultivated is higher in Diourbel (12.5%) than in Kolda (8.5%) in terms of proportion (Figure 5).

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.

The Kc used to run the model are described in Figure 6. The maximum water requirement, indicated through the crop coefficient, occurs between 45 and 60 days after crop emergence for the 55-437 variety and between 70 and 90 days after crop emergence for the 73-33 variety (Figure 6). Moisture stress during this period is responsible for a reduction in yield.

### *CROPWAT estimation*

In Table 5, the maximum yields obtained for groundnuts are 727 kg/ha in Diourbel and 1100 kg/ha in Kolda. These values are used in Equation 2 to calculate actual crop evapotranspiration, which is 327mm for Diourbel and 350mm for Kolda. The comparison between Etcrop and ETactual 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 (Table 6):

- 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 Ziguichor (and Kolda), with high values and very good yields.

### **4.3 Maize**

This crop is cultivated essentially in areas where 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.

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.

The maximum yield in Kolda between 1960 and 2004 (1237 kg/ha) is used in Equation 2 to evaluate the crop actual evapotranspiration for maize, which is 350 mm, whereas the moisture stress factor is 0.80 (Table 7). This means that the water needs of maize were 68% satisfied during the 1961–1990 period. Previous studies showed that at this level the yields of a crop will be good.

## **5. Impact of climate change on agriculture**

Using GCMs (General Circulation Models), Gitay et al. (2002) show that the increase in temperature at the end of the 21st century will be between 1.4°C and 5°C. But the increase will be higher on the continents than over the ocean, and higher at high latitudes than at low latitudes. Going on these predictions, we considered an increase of 1.5°C for Senegal and compared the crop water use of millet with the figures for the 1961–1990 period.

The effect of this climate change was examined for millet, which occupies 42.9% of the total cropped area in Senegal. ETa is the indicator of yield used to evaluate the impact of change on agriculture, because it is related to the yield through Equation 2.

The spatial variability is shown using Arc Gis. Comparison of the maps in Figures 8 and 9 reveals 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.

## 6. Conclusion

The modeling approach is very useful for evaluating crop water use across a country. 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.

## REFERENCES

- Camberlin P & Diop M, 1999. Inter-relationship between rainfall, sea surface temperatures and groundnut yields in Senegal. Unpublished report, Institut Sénégalais de Recherches Agricoles, Senegal.
- Dancette C, 1983. Estimation des besoins en eau des principales cultures pluviales en zone soudano-sahélienne. *Agronomie Tropicale* 38(4) : 281–294.
- FAO (Food and Agriculture Organization), 1975. Guidelines for predicting crop water requirements. Authors, Doorenbos J & Pruitt WO, Irrigation and Drainage Paper 24. Rome, Italy.
- Fontaine B, 1991. Variations pluviométriques et connexions climatiques: L'exemple des aires de mousson indienne et ouest africaine. *Sécheresse* 4(2): 259–264.
- Forest F, 1982. Evolution de la pluviométrie en zone soudano-sahélienne au cours de la période 1940-1979. Conséquences sur le bilan hydrique des cultures pluviales au Sénégal. *L'agronomie Tropicale* 1: 17–23.
- Gitay H, Suárez A, Watson RT & Dokken DJ, 2002 : Les changements climatiques et la biodiversité. GIEC (Intergovernmental Panel on Climate Change – IPCC).
- Michel P & Sall M, 1983 : *Modèle et sols du Sénégal*. Atlas du Sénégal, 2<sup>ème</sup> éd., Jeune Afrique, Paris, pp. 4–7.
- Monteith JL, 1965. Evaporation and the environment. In *The Movement of Water in Living Organisms*. Proceedings of the XIXth Symposium of the Society for Experimental Biology, Swansea. Swansea: Cambridge University Press, pp. 205–234.
- Moron V, 1994. Guinean and Sahelian rainfall anomaly indices at annual and monthly scales (1933–1990). *International Journal of Climatology* 14 : 325–341.
- RNA (Recensement Nationale Agricole – National Agricultural Census), 2000. Recensement de l'agriculture 1998–99. Vol. 4, Rapport général du recensement sur l'agriculture pluviale. Projet GCP/SEN/048/NET, FAO.

## **APPENDIX: Basis for calculation**

Climate data

FAO data base

### **Eto data**

FAO data base

### **Crop data**

FAO data base and Kc calculated by Dancette (1983)

### **Soil data**

For Diourbel, Kaolack, Saint-Louis and Louga

CROPWAT 7.0	Soil Data		
Dior	1.0E+0002		
15	200		0

For Koda , Tamba and Ziguinchor

CROPWAT 7.0	Soil Data		
DECK	1.0E+0002		
10	110		0

The percentage of total planted area in the cropping pattern is given by the Statistical Data Division of Senegal.

**Table 1: Climatic parameters of Diourbel (1961–1990)**

<b>Month</b>	<b>Max temp (°C)</b>	<b>Min temp (°C)</b>	<b>Humidity (%)</b>	<b>Wind spd (Km/d)</b>	<b>Sunshine (Hours)</b>	<b>Solar rad (MJ/m2/d)</b>	<b>ETo (mm/d)</b>
January	34.1	14.1	31	78	8	18	3.92
February	36.1	16.1	34	78	8.3	20	4.49
March	38	17.5	38	104	9.1	22.8	5.66
April	39.2	18.8	42	121	9.8	24.6	6.43
May	39.5	20.3	52	60	9.5	24	5.44
June	38.5	23	59	60	8	21.4	5.05
July	35.3	23.8	68	60	7.2	20.3	4.64
August	33.5	23.8	77	43	6.1	18.8	4.12
September	33.8	23.2	77	35	6.8	19.5	4.14
October	36.1	22.5	64	26	7.2	18.8	3.89
November	36.1	18.7	43	43	8.3	18.7	3.63
December	33.5	15.5	37	60	7.9	17.3	3.43
Average	36.1	19.8	51.8	64	8	20.4	4.57

**Table 2: Climatic parameters of Kolda (1961–1990)**

<b>Month</b>	<b>Max temp (°C)</b>	<b>Min temp (°C)</b>	<b>Humidity (%)</b>	<b>Wind spd (Km/d)</b>	<b>Sunshine (Hours)</b>	<b>Solar rad (MJ/m2/d)</b>	<b>ETo (mm/d)</b>
January	34	15.1	52	86	9.1	20	4.26
February	37.2	15.8	48	130	9.7	22.4	5.69
March	39	18.5	48	86	9.3	23.3	5.53
April	39.5	21.6	46	86	10.2	25.3	6.04
May	38.7	23.3	56	130	9.6	24	6.35
June	35	23.6	69	156	8.4	21.9	5.54
July	31.6	23.1	79	112	7.7	20.9	4.57
August	30.7	23	83	147	7	20.1	4.37
September	31.1	22.5	83	86	7.4	20.5	4.28
October	32.5	22.3	84	112	8.3	20.7	4.41
November	34.1	18.6	82	86	8.7	19.7	4.13
December	33.5	13.2	68	112	8.4	18.5	4.16
Average	34.7	20.1	66.5	110.8	8.7	21.4	4.9

**Table 3: Crop water use for millet in Diourbel and Kolda**

District	Crop	Eto (mm)	Etcrop (mm)	Ky	Ya (kg/ha)	Ym (kg/ha)	Ks	Area cropping intensity (ha)	Etactual (mm)
Diourbel	Millet	383	266	1	500	794	0.63	135887	166
Kolda	Millet	556	445	1	900	1234	0.72	80957	324

**Table 4: Crop water use for millet in other districts**

Districts	Eto (mm)	Etcrop (mm)	Ky	Ya Kg/Ha)	Ym (Kg/Ha)	Ks	Area cropping intensity (ha)	Etactual (mm)
Kaolack	422	406	1	800	1136	0.70	303957	325
Saint-Louis	426	300	1	384	1100	0.35	76255	159
Tamba	554	435	1	733	1138	0.64	71226	365
Ziguinchor	513	421	1	678	847	0.80	14270	388
Linguere (reg. Louga)	403	280	1	300	637	0.47	138977	195

**Table 5: Crop modeling output for the 1961–1990 period**

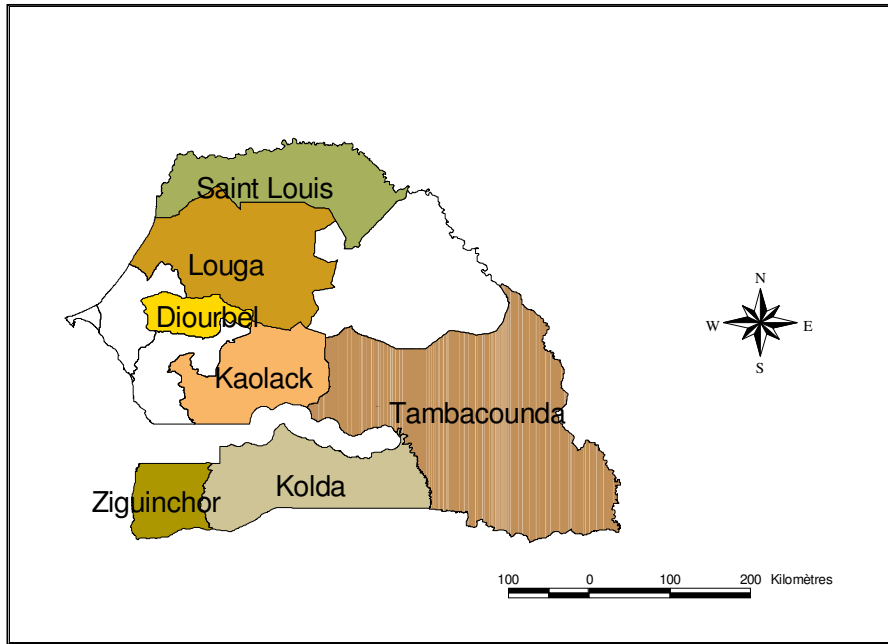
District	Crop	Eto (mm)	Etcrop (mm)	Ky	Ya (kg/ha)	Ym (kg/ha)	Ks	Area cropping intensity (ha)
Diourbel	Groundnuts	394	278	0.70	727	1184	0.74	78968
Kolda	Groundnuts	549	431	0.70	1100	1339	0.74	83151

**Table 6: Crop modeling output for the 1961–1990 period for groundnuts**

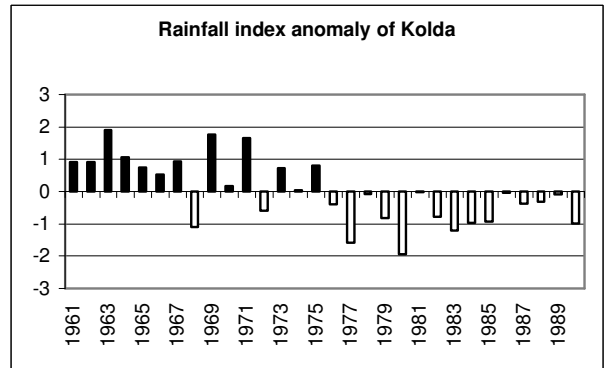
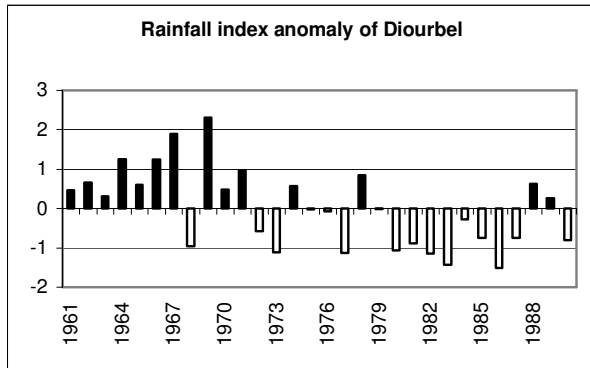
Districts	ET <sub>o</sub>	ET <sub>crop</sub>	K <sub>y</sub>	Y <sub>a</sub>	Y <sub>m</sub>	K <sub>s</sub>	Area cropping intensity (ha)	ET <sub>actual</sub>
Kaolack	411	376	0.70	1000	1289	0.68	26973	296
Saint-Louis	427	304	0.70	440	1372	0.03	5286	155
Tambacounda	544	420	0.70	1030	1328	0.68	64121	309
Ziguinchor	503	421	0.70	1050	1554	0.54	19998	388
Linguere (reg. Louga)	414	381	0.70	600	1087	0.36	100996	206

**Table 7: Crop modeling output for maize (1961–1990)**

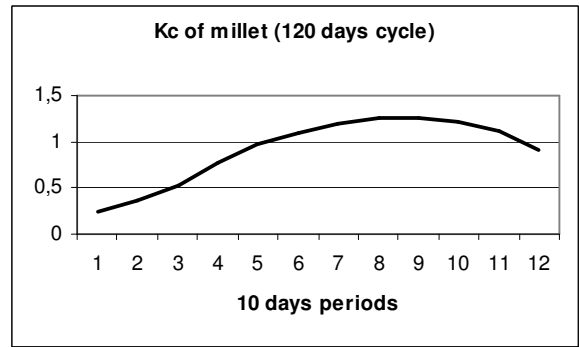
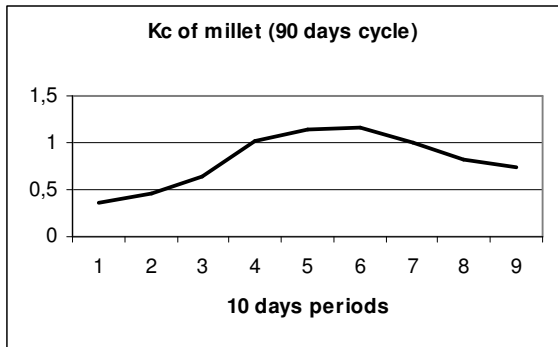
District	ET <sub>o</sub> (mm)	ET <sub>crop</sub> (mm)	K <sub>y</sub>	Y <sub>a</sub> (kg/ha)	Y <sub>m</sub> (kg/ha)	K <sub>s</sub>	Area cropping intensity (ha)
Kolda	637	509	1.25	929	1237	0.80	31490



**Figure 1: Districts used in the study**

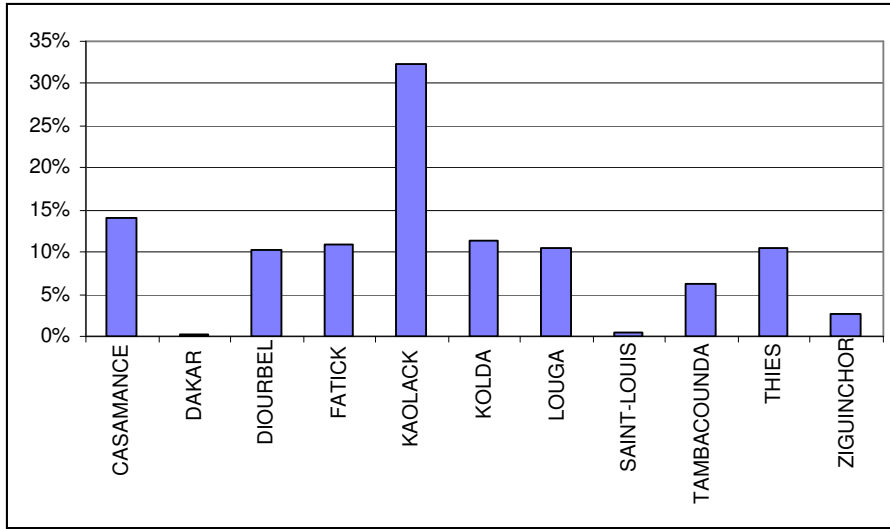


**Figure 2: Evolution of rainfall anomalies in Senegal (1961–1990)**

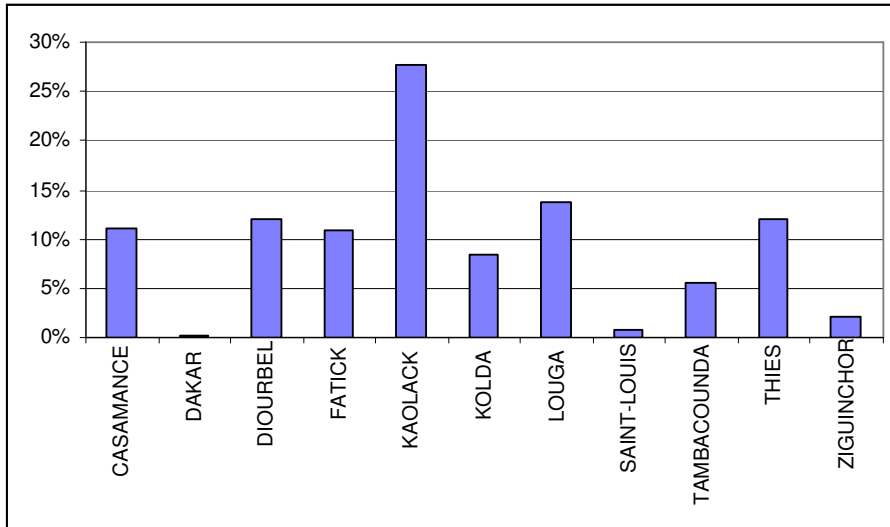


Source: Dancette (1983)

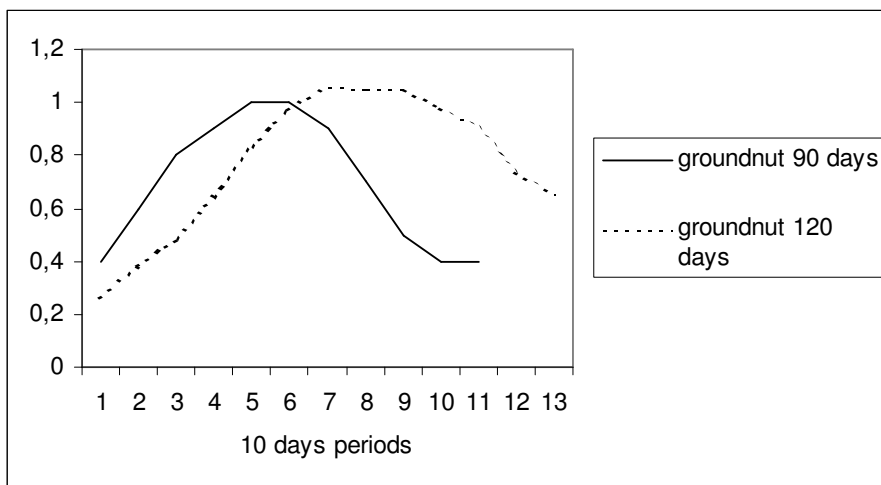
**Figure 3: Evolution of millet crop coefficients**



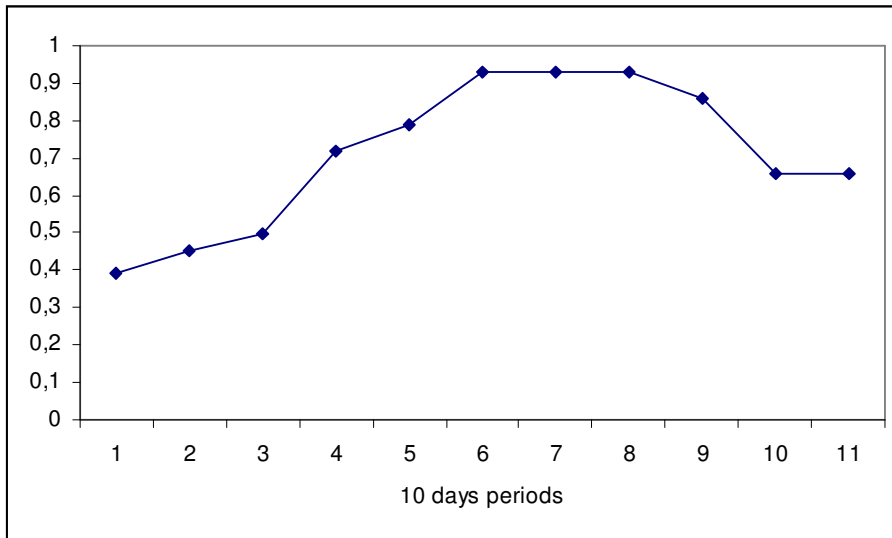
**Figure 4: Proportion of districts in total groundnut production**



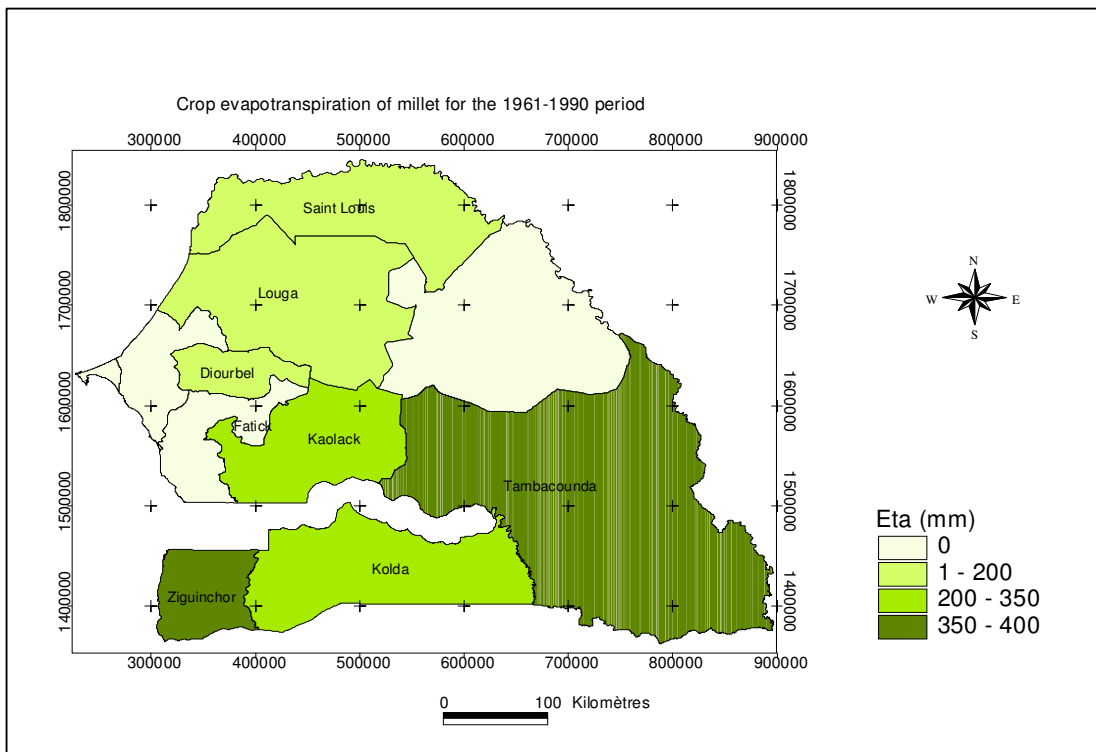
**Figure 5: Proportion of districts in total groundnut cropped area**



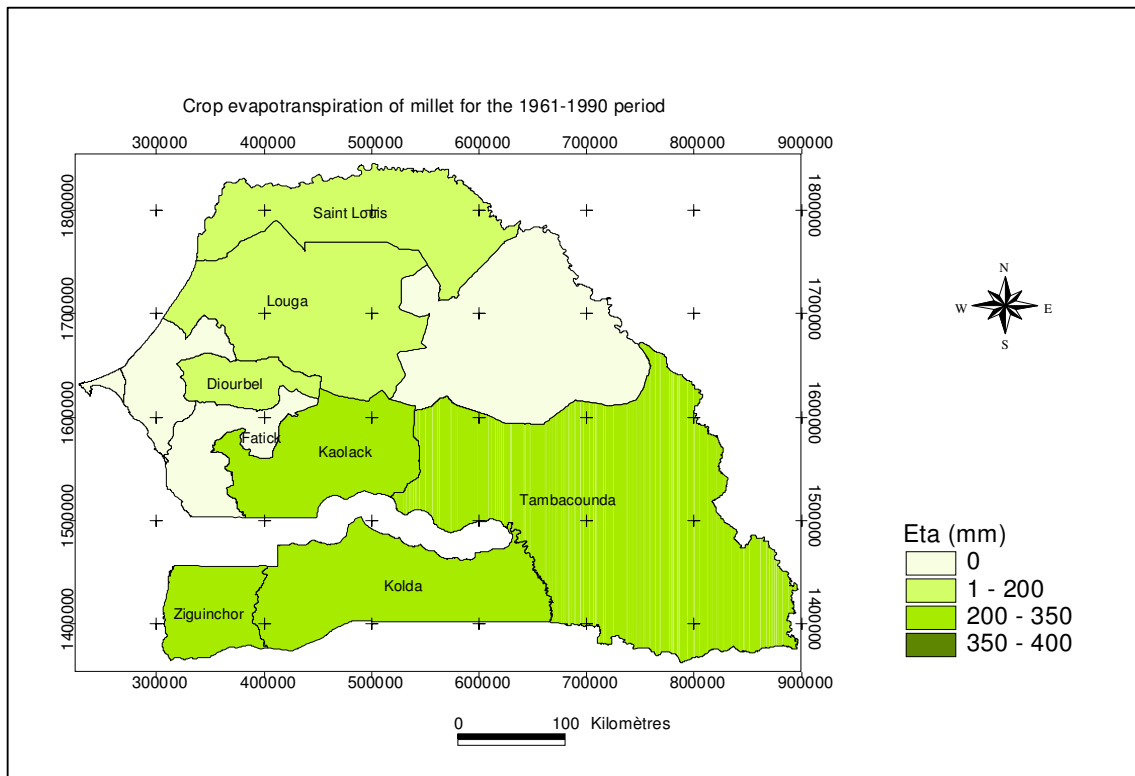
**Figure 6: Crop coefficients of groundnuts**



**Figure 7: Crop coefficients of maize**



**Figure 8 : Modeling the ETA of millet during the 1961-1990 period**



**Figure 9: Modeling the ETa of millet for a scenario of 1.5°C increase in temperature**