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Water Requirements for Corn Yields in the Northern Regions of Cameroon Using AquaCrop Model

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Authors' contributions

This work was carried out in collaboration between all authors. Author FCD designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors AL and CT managed the analyses of the study. Author AL managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study is based on the use of the FAO AquaCrop model to determine the amount of water needed to improve corn yields in Northern Cameroon.

Study Design: The regions of Garoua (9˚18'N - 13˚24' E), Kaélé (10˚05'44"N - 14˚26'37"E) and Maroua (10˚35'N - 14˚19'E) were considered for this purpose. This region corresponds to a semi-arid zone in the Northern Cameroon in Central Africa.

Place and Duration of Study: The climate data used in this work were collected in the meteorological stations of Garoua, Maroua and Kaélé from 1979 to 2004 during the AMMA (African Monsoon Multidisciplinary Analysis) project. The phenology data of maize crops were obtained from the Institute of Agricultural Research for Development (IARD) which is the national institute.

Methodology: The software used here is AquaCrop, developed by a group of experts at the Food and Agriculture Organization (FAO) for prediction of agricultural production under conditions of water limitation. Two simulations were carried out to determine the impact of climate change on

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agricultural yields and to determine the amount of water needed to mitigate this impact. The first consists of estimating yields in the dry and rainy seasons. The second consists of the estimation of the yields that are in the dry season or in the rainy season by using the irrigation. Hence, we have estimated the quantities of water needed for irrigation for each season over the region.

Results: The yields of the maize crop are most important during the rainy season and are close to 2.32 ton/ha. If irrigation is done during this season a rate of 72.15 mm, these yields are improved to 2.56 ton/ha. In the dry season, yields are close to 0.15 ton/ha. When irrigation is done with an average rate of 427.03 mm, yields are considerably improved and are relatively close to those obtained in the rainy season (2.37 ton/ha).

Conclusion: This study allows farmers to cultivate in all seasons to preserve and improve food security in the future years.

Keywords: Semi-arid; irrigation; AquaCrop; maize crop; North Cameroon.

1. INTRODUCTION

For millennia, the climates of the terrestrial globe vary to the epochs and places. However, over the past decades, Climate changes have shown clear signs of acceleration [1]. These changes are manifested by the increase in the temperature of the earth's surface and the temperature of the oceans; the disturbance of the different climates of the globe, the reduction of the surface of arctic oceanic glaciers, the retreat of continental glaciers, etc. [2]. The consequences of this phenomenon are related to health, economy, and environment…. Although these climatic changes are generally weak at the equator and greatly increase towards the poles of the earth globe, their effect is important for these countries around the equator. This is because, these countries are developing countries and their populations depend to their natural environment and the development projects of these countries are also in general based on agriculture [3]. Indeed, agriculture is a practice heavily dependent on water resources and climatic conditions. Its interest is not only limited to satisfying farmers but it also plays a decisive role in the socio-economic and socio-political development of a country.

In Central Africa, Cameroon and the Democratic Republic of Congo, for example, play a significant role in agricultural production and each contributes for 36% to sub-regional agricultural Gross Domestic Product (Agritrade, 2011). Nowadays, agricultural production has become very sensitive to climatic fluctuations. Thus, adaptation to climatic variability becomes a fundamental option for strengthening the resilience capacities of natural and human systems. This requires improving production systems and adaptive capacities [2]. It is, therefore, necessary to make studies in view to harvest in quantity and quality whatever the type of crop, climate and type of region. For example, simulation models have been used for decades to analyse crop responses to environmental stresses and to test alternative management practices [4,5]. Models often present substantial complexities are rarely used by most FAO's target audience. FAO developed an easier model called AquaCrop which can simulate the yield of corn in irrigation cases. It differs from other models in its ability to balance precision, simplicity and robustness. It focuses on water, the use of standardised water productivity (WP) values for evaporative demands and CO_2 concentrations, gives a high extrapolation of capacities for various locations, seasons and climates. AquaCrop can also be used for future climate scenarios and in addition, it uses canopy cover instead of the foliar index [6].

It is possible to apply this model to various agricultural systems in other parts of the world. It has been successfully used for a good profitability of cotton crops in Syria and Spain ([7] and [8]), maize in Zimbabwe [9], wheat in the winter [10] and cabbages in the Keiyo Highlands in Kenya [11]. To our knowledge, no such work has been carried out for maize crops in Central Africa. In 2016, maize production for Cameroon was 2.16 million tonnes increased from 310,000 tonnes in 1967 to 2.16 million tonnes in 2016 growing at an average annual rate of 4.79 % (https://knoema.com/atlas). The maize (*Zea mays* L.) is not only a staple crop that is consumed as dry fermented dough; it is often also roasted, used as corn porridge and for a large number of other uses in this country. Maize also provides an economic safety net as much of it can be sold directly or converted into corn beer, which is an important contribution to the local economy in many rural areas [12]. This crop is further important because it is mainly grown by small-scale subsistence farmers who constitute more than 35% of the rural population. Due to their small scale of production and poverty, these farmers lack the capacity to be able to adjust their farming systems to climate and land use shocks. Therefore, the urgent need to increase maize production is controlled by either climate or land use changes inter alia. The results of Epule and Bryant [13] show that maize production in Cameroon is more likely responsive to land use change than rainfall and temperature. However, for the climatic variables, maize production is more responsive to temperature variations than precipitation.

Corn is the first crop that has been used for calibration and validation of the AquaCrop model. Data from 6 cropping seasons, collected from experimental plots in Davis, California, were initially used to calibrate and validate the model [14]. Thus, the prototype 2.4 of AquaCrop thus rigged was tested with data from other regions of the world other than those of Davis: Bushland in Texas, Gainesville in Florida and Zaragoza in Spain. These last three regions were selected per climatic conditions and soil to spatialize the model. However, the simulation of severe water stress cases, especially when they occur in the maturation phase, prove difficult [14].

Here, we determine the amount of water needed to improve corn yields in Northern Cameroon by using the FAO AquaCrop model. This document is organised as follow: in section 2 presents the study area, the data used and methodology. Section 3 presents results and discussion; and the section 4 summary.

2. MATERIALS AND METHODS

2.1 Material and Methods

2.1.1 Study areas

Three regions of Northern Cameroon have been studied in this work: Garoua, Maroua and Kaélé (Fig. 1). The region of Garoua is located at 9˚18’N latitude, 13˚24' E longitude and altitude 249 metres above sea level. River Benue River in Cameroon traverses Garoua. It extends to 65576 m^2; the climate is Sudanian type with six months of rainy season and six months of dry season. The annual average temperature is 28˚C and the annual rainfall is around 1006 mm. The crops used grown are cotton, maize, rice, millet, peanuts, cowpeas and vegetables. The second region of Maroua is located at 10˚35’N and 14˚19'E with the altitude of 242 m. The climate here is warm and dry, almost semi-desert and the rains are rare with an annual average temperature of 28.21˚C. The average annual precipitation is around 799 mm where the soils are arid and sandy. The main agricultural products in this region are cotton, maize, rice, millet, peanuts, cowpea and sorghum. The last zone of Kaélé is at the latitude 10˚05'44” N, the longitude 14˚26'37’’E at the altitude 389 m. It is located under the southern Sahel strip in the sudano-sahelian zone. The climate there is the sudano-sahelian type with three months of rain (September to November) and nine months of dry season (December-August) with an annual average temperature of around 29.14°C. Rainfall is high during the rainy season (700 to 905 mm per year) which sometimes causes flooding. In this last region, the soil is arid and undergoes erosion during the rainy season. The main agricultural products are cotton, maize, rice, millet, peanuts, cow-peas, sorghum and vegetables. Fig. 1 shows a map of Cameroon with the location of the study regions.

2.1.2 Climate and plant data

The climate data used in this work were collected in the meteorological stations of Garoua, Maroua and Kaélé from 1979 to 2004 during the African Monsoon Multidisciplinary Analysis (AMMA) SOP3 project. The phenological data of maize crops studied in this work were obtained from the Institute of Agricultural Research for Development (IARD). Table1 summarises these data.

2.1.3 Presentation of AquaCrop model

As noted the introduction section, AquaCrop is software developed by an expert group of FAO for the prediction of agricultural production under conditions of water limitation. At the entrance of this software, four factors should be given: climate, plant, soil and irrigation in the considered region. The output files are stored in the SORT subdirectory of the AquaCrop folder and these output files contain information about: the development of crops and production, the water content of the soil at different depths of the soil profile; salinity of soils at different depths of the soil profile; soil moisture content in soil and root zone profiles; the salinity of the soil in the profile of the soil and the root zone; various parameters of the soil water balance; the quantity of water needed for irrigation [15].

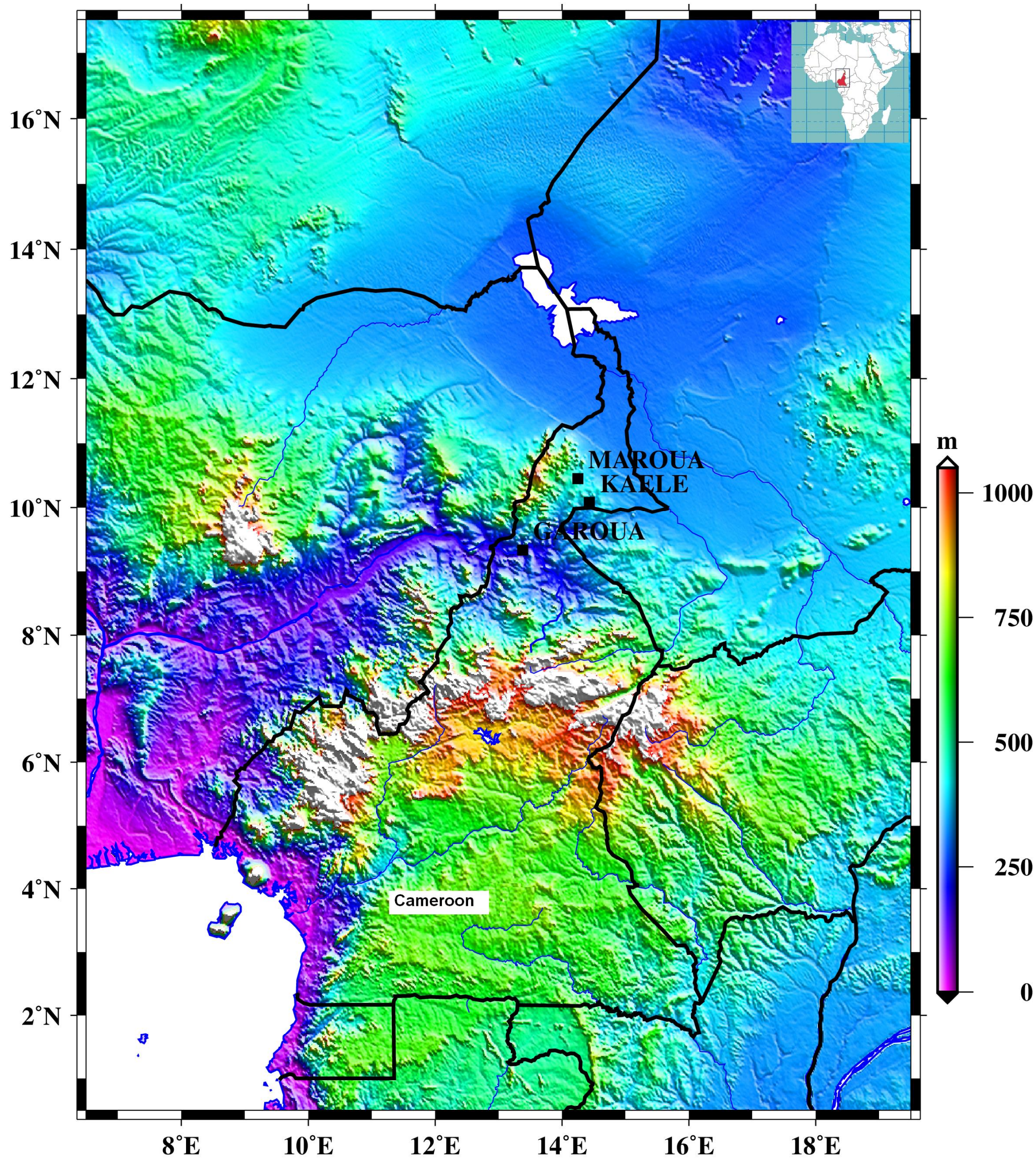


Fig. 1. Map of Cameroon showing the three regions studied and topography. Also show at the top the position of Camroon in the Africa continent.

Table 1. Phenological data for the maize variety studied (CMS9015) developing by IARD [16]

Nature	Potential Yield	Seed-to-maturity cycle	Adaptation area/ regions in Cameroon	Particularity
Composite	3 - 4 ton/ha	90 - 95 days	Center, South, East, Coastline, North, Far North, South Est.	Intermediate and therefore adapted to areas with low rainfall

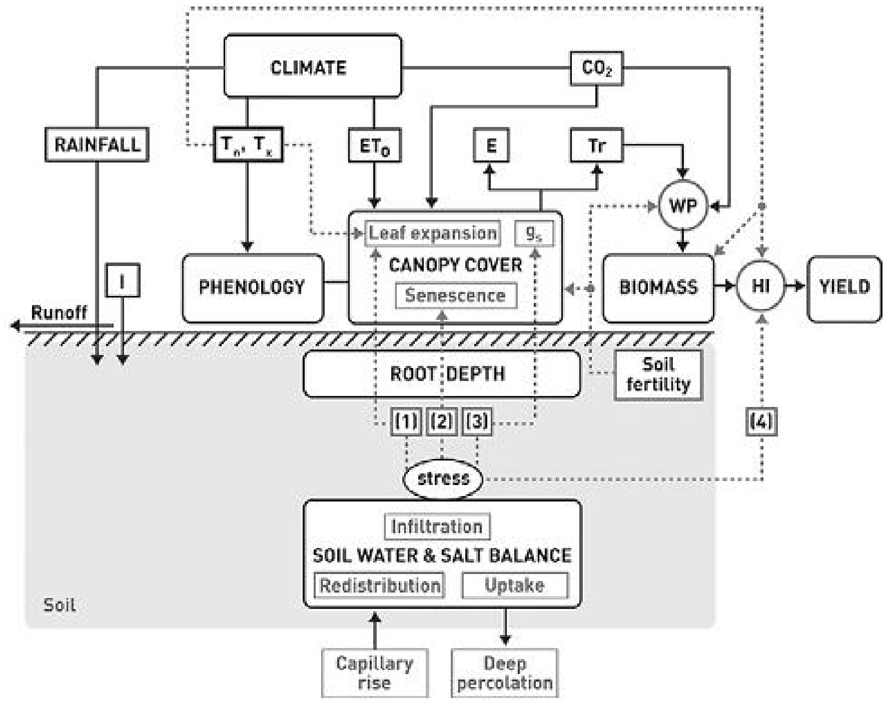


Fig. 2. Diagram showing the operating principle of the AquaCrop model, with I: irrigation; Tn: minimum air temperature; Tx: maximum air temperature; Eto: reference of evapotranspiration; E: soil evaporation; tr: transpiration of canopy; g_s: stomatal conductance; WP: water productivity; HI: harvest index; CO_2, atmospheric concentration of carbon dioxide; (1), (2), (3), (4) are respectively the water response functions on leaf expansion, senescence, stomatal conductance and crop index [6].

Table 2. Reference parameters used in this work

	Value	Unit	Comment
Minimum of temperature	10	°c	/
High threshold temperature	30	°c	/
Duration of cycle	125	days	95 days
The average size of canopy of young plant with 90% emergence Cco	0.25	%	/
Planting method	/	/	Direct
Initial Coverage	/	/	Cover of the canopy
Maximum Canopy Coverage	85	%	Well covered
Number of plants per hectare	50000	Plant/ha	/
The time from sowing to emergence	7	days	/
Sowing time to maximum canopy cover	45	days	/
Sowing time to maximum rooting depth	45	days	/
Sowing time to beginning of senescence	75	days	/
Sowing time to maturity	95	days	/
Sowing time at flowering	65	days	/
Maximum allowed increase	36	days	/
Length of flowering stage	10	days	/
Minimum effective rooting depth	0.5	m	/
Productivity of standardized water for ETo and CO_2 (gram / m²) WP *	17	g/m^2	/
Harvest reference index (%) HI_O	25	%	/

2.2 Description of the Experimental Protocol

2.2.1 Parameters used in this work

The parameters that have been considered in this work are summarised in Table 2.

For the determination of the HI crop index, we have fixed an HIo interval while basing in the "grain corn" form of the crops. Then we simulated some agricultural yields with these HIo and finally compared these yields with the observed yields in the field. The ETo reference evapotranspiration was evaluated in the ETo calculation software from meteorological data using the Penman-Montenith FAO equation [17].

2.2.2 Experimental protocol

Two simulations were carried out to determine the impact of climate change on agricultural yields and to determine the amount of water needed to mitigate this impact:

1- the first approach consisted of estimating yields in the dry and rainy seasons;
2- the second, consisted of the estimation of the yields that were in the dry season or in the rainy season if irrigation. The second simulation also allowed us to have the quantities of water needed for irrigation in each season.

3. RESULTS AND DISCUSSION

Figs. 3.1, 3.2 and 3.3 show yields obtained using the AquaCrop model in rainy season, rainy season with irrigation, dry season and dry season with irrigation for twenty-six consecutive years (from 1979 to 2004) respectively in the towns of Maroua and Garoua, and for sixteen consecutive years in the city of Kaélé (1970-1985).

Yield response to water describes the relationship between crop yield and water stress as a result from an insufficient supply of water by rainfall or irrigation during the growing period. In the FAO Irrigation & Drainage Paper n. 33 [18] an empirical production function is used to asses the yield response to water:

$$\left(1-\frac{Y}{\mathrm{Yx}}\right)=\mathrm{Ky}\left(1-\frac{\mathrm{ET}}{\mathrm{ETx}}\right) \quad (1)$$

where Yx and Y are the maximum and actual yield respectively, (1-Y/Yx) the relative yield decline, Etx and ET the maximum and actual evapotranspiration respectively, (1- ET/ETx) the relative water stress, and Ky the proportionality factor between relative yield decline and relative reduction in evapotranspiration. Fig. 3 shows that during the rainy season, the yields are maximum with an average value of 2.32 tons/ha at Maroua, 2.40 at Garoua and 2.20 at Kaélé. These values are close of those obtained in the difference region since agriculture activities take place only during the rainy season. If the irrigation was done during this wet season, these yields increased and become 2.6 ton/ha at Maroua, 2.6 at Garoua and 2.5 at kaélé (green tapes in the figures 3.1 to 3.3). During the dry season, yields were very low (0.3 ton/ha in Maroua, 0.1 at Garoua and 0.04 at kaélé, blue tapes) and when irrigation is done during this season, the yields are close to those of the rainy season with an average value of 2.2 tons / ha in Maroua, 2.6 in Garoua and 2.7 in kaélé (cyan tapes). The quantities of water used to irrigate the land for the simulation during the rainy season are around 78.8 mm for Maroua; 68.60 mm for Garoua; 69,05 mm for Kaélé and during the dry season these quantities are 453.3mm for Maroua; 395.9 mm for Garoua and 431.86 mm for Kaélé. The yeilds obtain here are similar to those found by Tingem et al. [12] in this region.

Table 3. Characteristic parameters for 26 years of the period 1979-2004 (for a: Maroua and b: Garoua) and the period 1970-1985 (for c: Kaélé) of simulated yield per the seasons: rainy season, rainy season with irrigation, dry season, dry season with irrigation

(a)

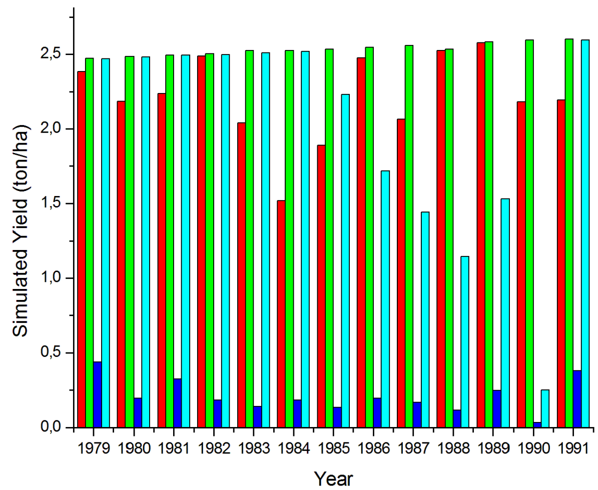
	Rainy season	Rainy season with irrigation	Dry season	Dry season with irrigation
Average in ton/ha	2.320	2.606	0.286	2.187
Standard deviation in ton/ha	0.290	0.083	0.213	0.658
Coefficient of variation in %	12.521	3.216	74.450	30.103

(b)

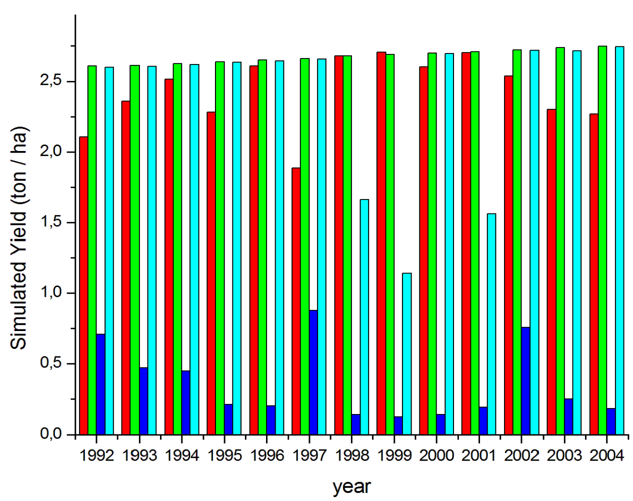
	Rainy season	Rainy season with irrigation	Dry season	Dry season with irrigation
Average in ton/ha	2.428	2.605	0.123	2.556
Standard deviation in ton/ha	0.433	0.083	0.159	0.276
Coefficient of variation in %	17.839	3.190	122.435	10.794

(c)

	Rainy season	Rainy season with irrigation	Dry season	Dry season with irrigation
Average in ton/ha	2.176	2.458	0.038	2.368
Standard deviation in ton/ha	0.204	0.045	0.109	0.261
Coefficient of variation in %	3.391	1.837	284.244	11.006



(a)



(b)

Fig. 3.1. Simulated yield in rainy season (red), rainy season with irrigation (green), dry season (blue) and dry season with irrigation (cyan) for 26 years: (a) 1979-1991 and (b) 1992-2004 for the region of Maroua.

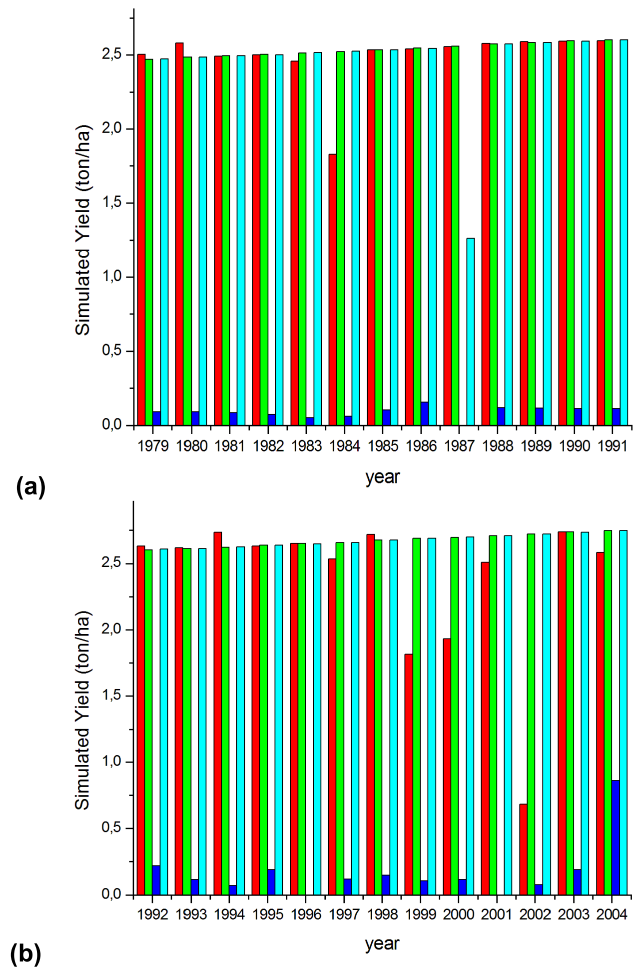


Fig. 3.2. Simulated yield in rainy season (red), rainy season with irrigation(green), dry season (blue) and dry season with irrigation (cyan) for 26 years: (a) 1979-1991 and (b) 1992-2004 for the region of Garoua.

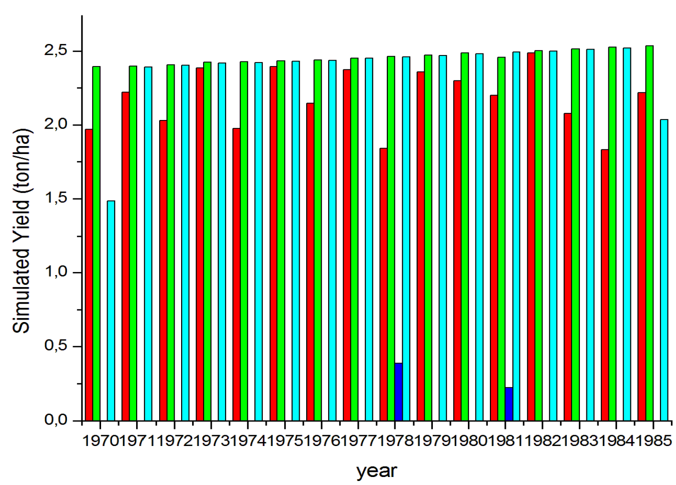


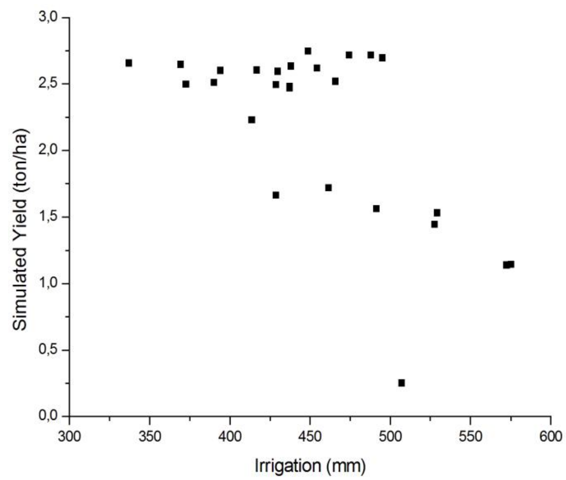
Fig. 3.3. Simulated yield in rainy season (red), rainy season with irrigation (green), dry season (cyan) and dry season with irrigation for 16 years (1970-1985) for the region of Kaélé.

To study the sensitivity of the water, the Fig. 4 show the impact of irrigation on maize plant yields during the dry season over these three regions.

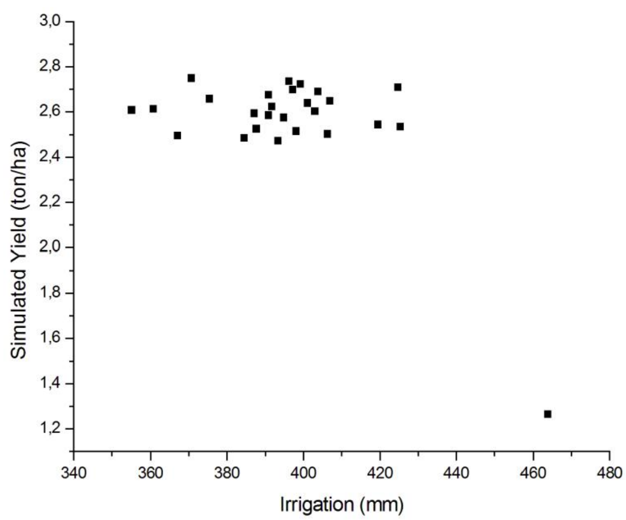
The figures show that when the quantities of irrigation water are between 300 mm and 500 mm, the yields are better and become low when the water quantities are greater than 500 mm for the three cities. The small quantities observed are certainly due to the excess water in the root zone which inhibits the development of the plant.

The statistical analysis in the table 3 give the degree of variation in yields studied for the rainy season, the rainy season with irrigation, the dry season and the dry season with irrigation for the twenty-six consecutive years (1979 to 2004) respectively in the towns of Maroua, Garoua and for sixteen consecutive years in the city of Kaélé (1970-1985).

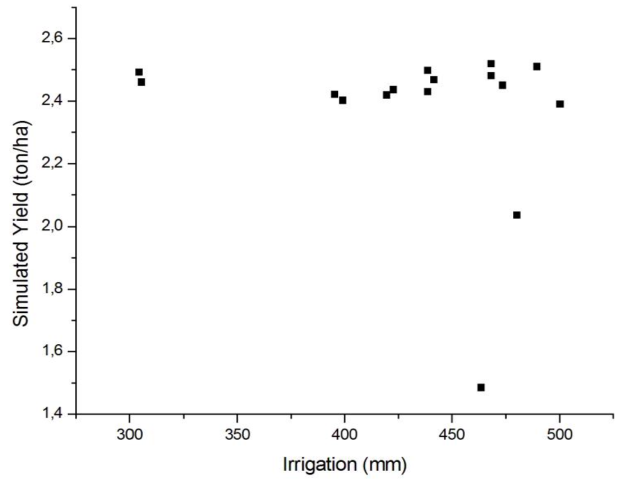
Table 3 shows that the coefficient of variation is very high in the dry season (about 75% for Maroua, 12.2% for Garoua and 28.4% for kaélé). The coefficient decreases to 30% for Maroua, 11% for Garoua and 11% for Kaélé if irrigation is done during this season. This coefficient of variation is close to 13% (Maroua); 18% (Garoua) and 3% (kaélé) in the rainy season and decreases to 3% for Maroua, 3% for Garoua and 2% for kaélé if irrigation is done. It thus appears that the variations in yields are due firstly to the climatic variability and secondly to the water supply to the plants.



(a)



(b)



(c)

Fig. 4. Diagram showing the yields of maize plants yields with the quantities of irrigated water in the region of (a) Maroua, (b) Garoua and (c) Kaélé during the dry season.

4. CONCLUSION

Having reached the end of our work or it was question of estimating using the model AquaCrop of the quantities of water necessary for a good yield of corn in the regions of north Cameroon and therefore the objective is part of the will of help producers to use climate information in planning and decision making to maximize agricultural yields and ensure food security. Best corn yields were obtained in the rainy season with irrigation. The amounts of irrigation water are on average around 72.15 mm in the rainy season and on average around 427.03 mm in the dry season. Thus, these results indicate that it is possible to cultivate maize plants in the regions of Maroua, Garoua and Kaélé with a high yield; and certainly, in far north Cameroon generally and not just in July as during the rainy season. In terms of perspective, it will be useful to analyses, using the projection model, the impact of the climate change on the corn yield over this region.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the Word Meteorological Organization (WMO) protocol.

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COMPETING INTERESTS

The authors declare no competing interests for this work

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