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Simulation of the future climate in the agro-pastoral zone of cotton production of the Municipality of Banikoara in North Benin

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Abstract
Climate change is one of the most important challenges for human society and, to a large extent, affects agricultural forecasts with consequences for food and nutritional security. Indeed, in order to develop more adequate adaptation strategies in the short, medium and long term in response to the problems, this study aims to simulate future climate variability up to 2050 and to estimate the associated general agroclimatic indices (ACI) in the cotton producing agropastoral zone of the Banikoara Commune in North Benin. In addition to information on the state of soil quality in this zone, rainfall and temperature were collected from 1971 to 2010. Twelve climatic scenarios were constituted and tested, completed by the calculation of agro-climatic indices using DSSAT (Decision Support System for Agrotechnology Transfer) and Crop-Model. The results show that, with reference to the period 1971-2010, temperatures will rise by 1° to 3°C. On the other hand, rainfall during the agricultural season will decrease compared to the period from April to October according to the scenarios of increase in average temperature (by 1°C, 1.5°C and 2°C). The ACI s estimated for 2050 with reference to the values obtained during the period 1971-2010 reveal their deterioration and indicate a negative impact not only on yield patterns but also on crop quality.

Keywords: *Climate change, Food security, Future projection, Agro-climatic indices, Banikoara.*

I. INTRODUCTION

Global warming and major floods pose a great threat to all humanity ([1], [2]), and in particular to developing countries in Asia and Africa ([3]). They affect all vital sectors of the economy and mainly agriculture ([4]). The projection of the future climate situation (mainly rainfall and temperature) through the different scenarios is hardly in favor of any agricultural prosperity. In Sub-Saharan Africa [5] showed under various climate scenarios, a considerable decrease in cassava (-26%), groundnut (-15%) and maize (-11%) yields by 2025, while the populations of most of these African countries will double ([6]). Mitigation and adaptation measures are increasingly being observed to address climate change at lower cost ([7]). Mitigation measures aim at limiting climate change while adaptation measures aim at reducing the vulnerability of natural and socio-economic systems.

During the last two decades in Benin, many studies have been conducted on strategies to adapt agricultural systems to the effects of climate change ([8], [9], [10], [11], [12]) in a context where arable land is permanently degraded. Strategies include: increasing the use of drip irrigation with high pressure on surface water resources, changing the agricultural calendar, adoption of short cycle crops, multiple sowing, use of chemical fertilizers, adoption of new or improved varieties and the use of intercropping techniques); in response to the effects of climate change such as : The use of new or improved varieties and the use of intercropping techniques); in response to the effects of climate change such as: severe droughts, delayed rains, reduced rainfall, shorter rainy season, early cessation of rains, reduced dew, frequency of rain abortion, aggressive rains, heavy flooding). The objectives of these strategies are to improve agricultural yields and contribute to food and nutritional security on the one hand, and on the other hand to improve the socio-economic conditions of farmers who represent 61.1% of the rural population ([13]). The amount of this work is testimony to the evolutionary and progressive nature of climatic phenomena in the country. According to [14], agricultural activities in the cotton zone are strongly confronted with the effects of climate change. This worrying situation calls into question agricultural policies in terms of productivity. It requires a review of the adaptation strategies put in place ([4], [12]) and anticipation of possible future adverse climatic effects. Thus, it is necessary to examine the extent of the vulnerability of this agricultural area to changes in climatic parameters, especially temperature and rainfall. To assist policy makers and actors involved in agriculture in the cotton producing agropastoral area of Benin, this study proposes to simulate the future climate up to 2050 and to determine the variation of agroclimatic indices in order to effectively adjust mitigation and adaptation strategies, and to develop more adequate agricultural policies.

II. MATERIALS AND METHODS

A. Study area

The cotton-producing agropastoral zone of the commune of Banikoara in northwestern Benin. It is located between 2º05' and 2º46' East and between 11º02' and 11º34' North and covers an area of 4397.2 km² with about 49% arable land and 50% protected areas (W National Park and the Atacora hunting area). This zone is strongly influenced by the Sudano-Sahelian climate and an uneven spatio-temporal rainfall distribution has been observed in recent decades ([15]), which impacts vegetation, the hydrographic network, the conservation of wet pasture in the dry season and agriculture. The types of soils encountered are: poorly evolved mineral soils, poorly leached ferruginous soils, hydromorphic soils, low denatured ferralitic soils that support all rainfed crops, leached tropical ferruginous soils and impoverished tropical ferruginous soils ([16]). The population, estimated at 223138 inhabitants in 2013, is mainly composed of Bariba (37.1%), Peulh (26.5%) and Dendi (20.1%) respectively farmers and breeders ([17]).

B. Data

The data used are: rainfall and temperature collected at the Agency for the Safety of Air Navigation (ASECNA) for the Municipality of Banikoara over a period of 40 years from 1971 to 2010 and complete with documentary research in order to obtain qualitative information relating to the types of soil in the study area.

C. Data analysis method

a) Scenarios used and basic assumptions

Twelve (12) basic scenarios composed of a pair of temperature and length of the growing season (instead of rain) were formulated and retained (Table 1) on the basis of the following considerations: (i) amplitudes of change simulated by climate models; (ii) the general trends of climatic variables observed by the meteorological stations of the localities of the agro-pastoral zone of cotton production and (iii) the reasonable choice to approach the food risk analysis by pessimistic scenarios (precautionary principle).

TABLE I: Climatic scenarios in the agro-pastoral cotton production zone by 2050

Growing Season Duration Scenarios	Thermal scenarios +1 °C	+1.5 °C	+2 °C
-10 %			
-15 %			
-20 %			
-25 %			

Legend: : Certain scenario; : Likely scenario; : Critical scenario; : Extreme scenario

Then, information from [18] was used to create a soil evolution scenario based on three soil types: (i) ferruginous sesquioxide and concretion soil on granito-gneiss with neutral to basic pH (6.7), referred to as S1 in the present study ; (ii) soil formed of a superposition of S1, ferralitic soil with concretions and armour of clay-sandy texture and evolved horizons, characterized by internal drainage and a neutral to basic pH (5.5, 6.5), designated S2 in the present study, and (iii) hydromorphic soil with little humus on alluvium, with pseudogley with spots, designated S3.

In the absence of reliable certainty on the evolution of soil quality in Benin by 2050, it is assumed that current and future agricultural policies would induce an increase in the average quantity of fertilizer consumed per hectare and an improvement in soil conservation techniques. However, should public decision-makers fail to introduce innovations in this direction, the future crop index (2050) of S2 and S3 is assumed to be equivalent to that of S1 today, taking into account the average duration of depletion (30 years) of tropical soils cultivated without amendment (Ludlow quoted by [19]). The trend of the reference state of the soil factor in the simulation of future yield is constructed as in Table 2.

TABLE 2. Assumptions of soil quality status for crop yield simulation

		S1	S2	S3
Agronomic potential	**Current**	**Average to good**	**Excellent growth medium, good for any crop**	**Very fertile good for any culture**
	FSC	Infertile	Average	Average to good
	FAC	Good	Good to very good	Very good
Cultural Index	***Actuel***	0.75	1.00	1.00
	FSC	Less than 0.5	0.75	0.75 – 1.00
	FAC	0.75 – 1.00	1.00	1.00

Legend: **FSC** = Future situation without improvement of soil conditions; **FAC** = Future situation with improvement of soil conditions

The combination of the basic climate scenarios and soil assumptions results in the generation of thirty-six (36) possible yield scenarios per crop.

b) Determination of the growing season

The characteristics of the growing season (duration, beginning and end) were determined using the Crop-Model (DSSAT V3.5). Monthly FTEs were calculated using the Penman-Monteith formula. Then, using an integrated function of the Crop-Model, the monthly FTE values were extrapolated to daily values. The same principle was adopted for rainfall heights. From there, the following conditions were established in the Crop Model:

$DSC = P_i > ETP_i/2$, with $i = 1, \ldots, 365$, $FSC = P_k < ETP_k/2$, with $k = 365 - j$ and, $j = 1, \ldots, 365$ with i, j, k = days in Julian date. DSC = Start of Growing Season in Julian date, FSC = End of Growing Season in Julian date.

Consequently, all climatic conditions prevailing during the growing season are calculated (temperatures, vapour pressure, global radiation, etc.) to simulate the biomass production of the crops selected in this study (Table 3).

TABLE 3. Sequences and characteristics of the growing period of the crops

Pre-wet period	This period begins with the actual installation of the rainy season. It is defined as the period when the cumulative precipitation (P) is less than the cumulative Potential Evapotranspiration (PTE), but greater than the cumulative PTE/2. It is the phase of field preparation, sowing periods, germination and crop run-up.
Wet period	It begins at the end of the pre-wet period and is characterized by a precipitation accumulation that is much higher than the accumulation of evapotranspiration. The wet period ends when the evapotranspiration curve becomes higher than the precipitation curve again. We then enter the post-wet period. The wet period is the phase of full plant growth because usually their water needs are largely met.
Post -wet period	It marks a return to evaporation deficit conditions. At this period, the precipitation curve becomes lower than the evapotranspiration curve, but higher than the ETP/2 curve. The post-wet phase theoretically ends when rainfall becomes less than FTE/2; however, it can be considered as extending until the depletion of the soil's useful water reserves, hence the fact that some believe that the growing season may extend a few days after the post-wet period (FAO, 1984 and 1986; Frere and Popov, 1987).

Empirical scenarios (dry and wet analogues) and data extracted from HadCM2 and CSIRO-Tr on the basis of SRESA2 scenarios allowed the projection of climate parameters to the 2050 horizon.

III . RESULTS

A. *Future temperatures (2050) in the cotton zone of Banikora*

Depending on the scenarios considered, the monthly temperature values obtained are illustrated in Fig. 1.

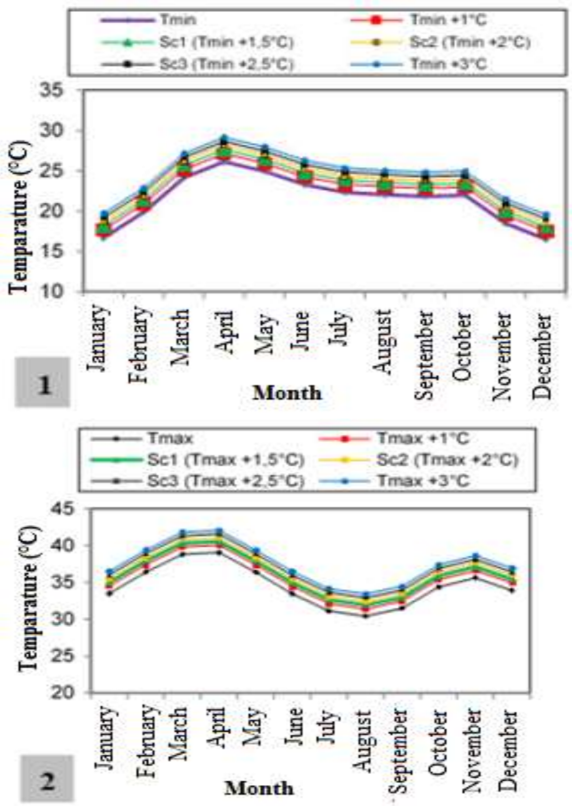

Fig. 1: Future evolution of minimum (1) and maximum (2) monthly temperatures by 2050 in the commune

Examination of Figure 1 shows that the temperature regimes (average, minimum and maximum) in the cotton producing agropastoral zone of Banikoara commune will be identical under the different climate scenarios. However, the temperature values will increase between 1 and 3°C with reference to the values of the period 1971-2000. From the analysis in Figure 2, it appears that the magnitude of the anomalies in mean minimum temperature which is -2.08 to +2.5 °C and mean maximum temperature which is -1.76 to 2.12 °C in the commune of Banikoara, with some nuances, confirm the tendency to thermal warming.

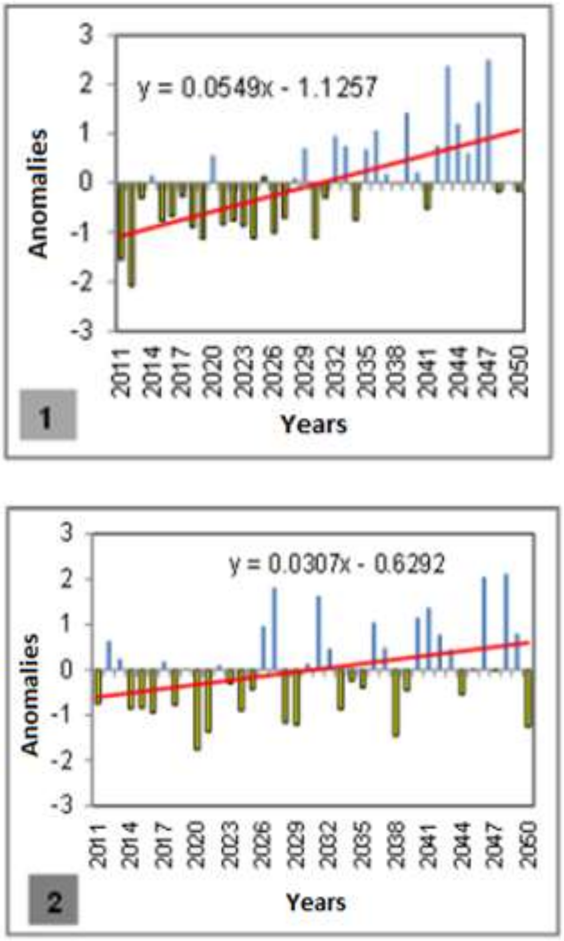

Fig. 2: Probable evolution of the minimum (1) and maximum (2) temperature indices by 2050

Pluviométrie future dans la Commune de Banikoara à l'horizon 2050

La pluviométrie mensuelle de la zone à production cotonnière de la commune Banikora connaitra des variations assez importantes selon les différents scénarii (Fig. 3).

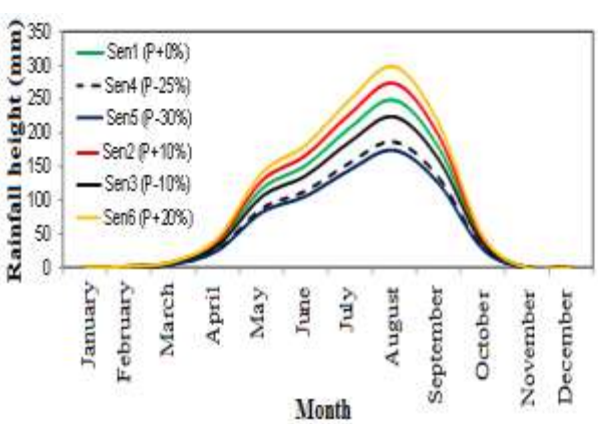

Fig. 3: Seasonal Rainfall Scenarios in the Study Area

Future rainfall patterns will not change fundamentally as the unimodal regime will be maintained. However, rainfall in the months of the agricultural season (April-October) will change. Under scenarios 3, 4 and 5, rainfall in these months will decrease compared to the baseline period (1971-2010).

B. Variation in general agro-climatic indices in Banikoara

The general agroclimatic indices estimated at the Banikoara stations are summarized in Table 4.

TABLE 4. Change in agro-climatic indices (1971-2010 and 2050) in Banikoara.

	Climate 1971-2010	Future climate (2050)	Difference in days
NJS	206	199	-7
NJI	63	67	+4
NJH	126	116	-10
DSC	17 may	11 may	-6
FSC	19 oct	10 oct	-9
DuSC	190	173	-17

Examination of the data in Table 4 leads to the conclusion that almost all of the indices could deteriorate by 2050 with reference to the values obtained over the period 1971-2010. Correlatively to the NJI which would experience an increase of 11 days, the other indices, notably the length of the growing season (DuSC), the beginning of the growing season (DSC), the end of the growing season (FSC), the number of wet days (NJH) could experience a significant reduction that could impact agricultural yields. This alteration in the values of the general agro-climatic indices, in a context of climate change, will certainly have negative impacts on crop specific indices.

IV . DISCUSSION

A. Future climates in the cotton producing agropastoral zone

Temperatures have a global upward trend and are in line with the trends highlighted at the local ([19], [20], [21]) and regional and global scales (Paturel et al., 1996; Newman, 2016). Maximum temperatures will vary from 32.29 to 36.1°C, i.e. a fluctuation of 3.81°C. Minimum temperatures will vary between 22.2 and 24.3°C, a fluctuation of 2.1°C. This thermal fluctuation is best illustrated by the alternation of positive and negative thermometric anomalies. [19] and [21] explain that a thermal increase is a source of additional stress for plants and soils, which can significantly reduce agricultural yields in different agro-ecological zones. Future rainfall regimes will not undergo any fundamental change because the unimodal regime will be maintained. However, the rains in the months of the agricultural season (April-October) will change. Under scenarios 3, 4 and 5, rainfall in these months will decrease compared to the baseline period (1971-2010). In other words, rainfall could decrease in height at the sensitive phases of the calendar; agricultural (beginning, core and end). Scenarios 2 and 6 predict an increase in rainfall in August-September as the growing season approaches its end. Under these conditions, this increase may also cause crop rotting or flooding that is detrimental to the crops ([19], [22]).

Scenarios show that by 2050, the cotton-producing agropastoral zone of Banikoara Commune will be marked by monthly and seasonal changes in the context of projected climate change. These changes will affect the values of the agro-climatic indices that determine crop yield patterns.

B. Variation in agroclimatic indices (TSI) in Banikoara Commune

The calculated TSIs indicate an increase for almost all cash and cereal crops in the Banikoara cotton-producing zone, and provide information not only on yield patterns but also on crop quality. According to [23], an increase in TSIs is linked to a rise in temperature and would hamper the metabolism and growth of many cereal crops. Thus, additional heat stress may reduce yields in the area. Higher minimum temperatures as well as higher maximum temperatures will generally harm many crops ([24], [25]). It is also evident that crop yields will decrease even with a minimal increase in temperatures associated with the alteration of the water status, which will lead to a change in the organic matter of already irrationally exploited soils. Moreover, the decline in yields will be accentuated by the further deterioration of the health status of producers and the shrinking of their livelihoods due to climate change. Indeed, ecological conditions with future climates would allow the development of certain germs. The resurgence of certain diseases then fought against is very likely due to the new ecological conditions ([26]). Diseases such as cerebrospinal meningitis could experience a resurgence in the dry analogous scenario because of the dry seasons that have become very long. The altered health status of producers could prevent them from being able to devote themselves to field work. Such a situation would only aggravate the decline in agri-food production. To these factors will inevitably be added the spread of weeds and crop pests due to rising temperatures ([27]); this will further weaken the yield potential of these crops and would thwart any hope of improved yields in the context of an increase in atmospheric CO2. In tropical latitudes, weeds as well as cryptogamic diseases and crop pests are likely to develop more rapidly ([23]) because they will now have a short cycle under high temperature conditions ([28]). As a result, leaves, stems and roots of plants will be subject to vigorous attacks. This context will deprive them of any possibility of normal growth, as the respiratory function of the crops will be disrupted. Thus, there will be an increased risk of crop losses ([2]).

V . CONCLUSION

This study carried out in the cotton producing agropastoral zone of the commune of Banikoara focuses on possible future climate variability up to 2050 and the associated general agroclimatic indices. It reveals that rainfall and temperature parameters have undergone significant variation over the period 1971-2010 and will undergo more until 2050 (increase in mean monthly temperature between 1 and 3 °C with mean minimum temperature anomalies of -2.08 to +2.5 °C and mean maximum of -1.76 to 2.12 °C; rainfall in the months of the agricultural season, April to October will experience changes). Taking into account the regression of agro-climatic indices, yields of cash and cereal crops will decline by 2050. Faced with these problems that threaten agricultural production and the food security of the local population, the development of new adaptation strategies that are more appropriate and planned for the short/long term is necessary and these must be linked to the main crops of the area such as maize, sorghum, millet, fonio, cassava and yam.

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