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Contribution of Climate Scenarios RCP4.5 and RCP8.5 to the Study of Climate Change Impacts on Cocoa Farming in Côte d'Ivoire

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Abstract

In the particular context of climate change in Cote d'Ivoire and the vulnerability of farmers to its effects, one of the major issues is how these changes could impact cocoa yields of cocoa production areas. Thus, the objective of this study is to sustainably increase the resilience of all cocoa farming stakeholders to the impacts of climate change. The study was carried out in the central and southern areas of Côte d'Ivoire with a focus on eleven localities that have many communities of cocoa producers and a humid climate. The rainfall and temperature observation data using come from the CRU, they cover the historical period from 1971 to 2000 at 0.5˚ × 0.5˚ horizontal scale. As for the RCP4.5 and RCP8.5 climate scenarios, they come from the CORDEX database and cover the 2021-2050 period. The methodology is based on the calculation of climatic indices sensitive to cocoa cultivation which are the number of consecutive dry days (CDD), the number of consecutive wet days (CWD), the amount of rain during the rainy season and the maximum temperature above 33˚C. The results show that for all the localities studied, indices such as CDD and CWD could experience an increase. In addition, the total amount of rain during the long rainy season (April to June) is calculated on the basis of the threshold of 700 mm representing the minimum annual precipitation during the rainy season necessary for good growth of the cocoa tree. It reveals that for the two scenarios the cumulative rainfall will all be greater than 700 mm. Regarding temperatures, the central and southern areas could have a low number of hot days (temperature greater than or equal to 33˚C which is the tolerable threshold for cocoa cultivation). The eleven localities, therefore, remain favorable areas for cocoa cultivation in terms of climatic conditions based on temperature and rainfall, despite the regional dimension of the effects of climate change and the associated constraints.

Keywords

CORDEX, Climate, Indices, Cocoa, Temperature, Precipitation

1. Introduction

In West Africa, agriculture is one of the sectors most vulnerable to the effects of climate change. The region is known to be particularly vulnerable to climate change due, among other things, to high climate variability, dependence on rain-fed agriculture and low adaptive capacity to extreme weather and climate events [1]. Indeed, the extent of climate change and the lack of preparation of West African countries with regard to increasingly recurrent extreme hydro-meteorological events accentuate their vulnerability. In addition, there is an increase in average temperature and extreme events both in frequency and intensity, with increasingly recurrent significant socio-economic impacts [2] [3]. Regarding future temperature projections, it is estimated that they could reach an additional 3˚C under the RCP4.5 scenario and up to 6˚C under the RCP8.5 scenario [4]. This represents a warming of 10% to 60% higher than the global average of the planet [5]. Generally speaking, cocoa production in West Africa is considered a leading sub-sector for economic growth and development [6]. Côte d'Ivoire, the world's leading producer of cocoa beans, provides about 40% of export earnings, thus contributing 15% of its gross domestic product (GDP) and representing more than 10% of its tax revenue. In addition, cocoa farming provides jobs in the secondary and tertiary sectors, where it employs more than a million people [7]. However, this sector, which provides jobs and is the "lung" of the Ivorian economy, is also subject to the effects of climate change, in terms of temperature and rainfall, which are key meteorological parameters impacting cocoa production [8] [9]. Indeed, this crop needs a favorable environment for its good development and good production, which corresponds to the hot and humid climate of forest areas [10]. In addition, several climatic parameters such as rainfall, temperature [9] and insolation considerably influence cocoa production. As a result, climate change could constitute an additional constraint for many farmers to continue to cultivate cocoa in areas where the temperature and rainfall are nowadays favorable to the good development and production of the cocoa tree. Strategies for mitigating and adapting to the effects of climate change in the agricultural sector in general, and particularly in cocoa-growing in Côte d'Ivoire, require a good understanding and evaluation of these present and future changes in the production areas taking into account greenhouse gas (GHG) emission scenarios. It is therefore essential to provide a climate service based on climate scenarios in order to improve yield and resilience in this crop. GHG emissions scenarios provide plausible descriptions of likely future GHG developments taking into account several variables such as socio-economic development, technological changes, energy, land use changes, emissions of GHGs and air pollutants [11]. These GHG emission scenarios that often follow concentration trajectories according to the variables listed above are known as Representative Concentration Pathways (RCP) [11]. These RCP emissions scenarios are used in climate models (global and regional) to produce climate simulation data for the climate (present and future) useful for understanding and studying global warming, climate change and their impacts and proposing mitigation and adaptation strategies.

The general objective of this study is to assess the potential risks of climate change on cocoa farming in the cocoa growing regions (southern and central regions) of Côte d'Ivoire. This article is organized as follows: first a description of the study area, data and methodology in Section 2, followed by the results and discussion in Section 3. Finally, a conclusion is given at the end.

2. Study Area, Data and Methods

2.1. Study Area

The climate in Côte d'Ivoire is governed by the displacement of the Intertropical Convergence Zone (ITCZ) which controls the different seasons of its rainfall regime [12] [13]. Cocoa production in Côte d'Ivoire is carried out between longitudes 2.30˚W and 8.30˚W and latitudes 4˚N and 9˚N covering an area of 170.320 km^2 [14], where climatic conditions are favorable to a good growth and productivity of the cocoa tree. It extends as shown in **Figure 1**, from the southernmost part of Côte d'Ivoire and limited to the North by the pre-forest savannah area commonly called "V" Baoulé and to the South by the Atlantic Ocean [15]. Rainfall is generally bimodal with 2 rainy seasons (April-July and September-October) and 2 dry seasons (December-May and August) and cumulative rainfall between 1500 and 1200 mm/year. The average annual temperature varies from 27˚C to 31˚C. This cocoa production area represents approximately 53% of the territory. Thus, the current cocoa production areas in Côte d'Ivoire cover the regions of high Sassandra (30.6%), low Sassandra (13.8%), Mean Comoé (7.66%) and Mean Cavally (7.15%). In addition, eight other regions in the south of the country whose production varies from 3% to 7% contribute to filling the rest of the national production [16]. Thus, the East, the Center-West and the South-West are therefore clearly identified as being the main cocoa production areas of Côte d'Ivoire. The Center-West and South-West zones recorded strong growth in terms of production, while the East zone remained almost constant in its production over the same period. As part of this study, this

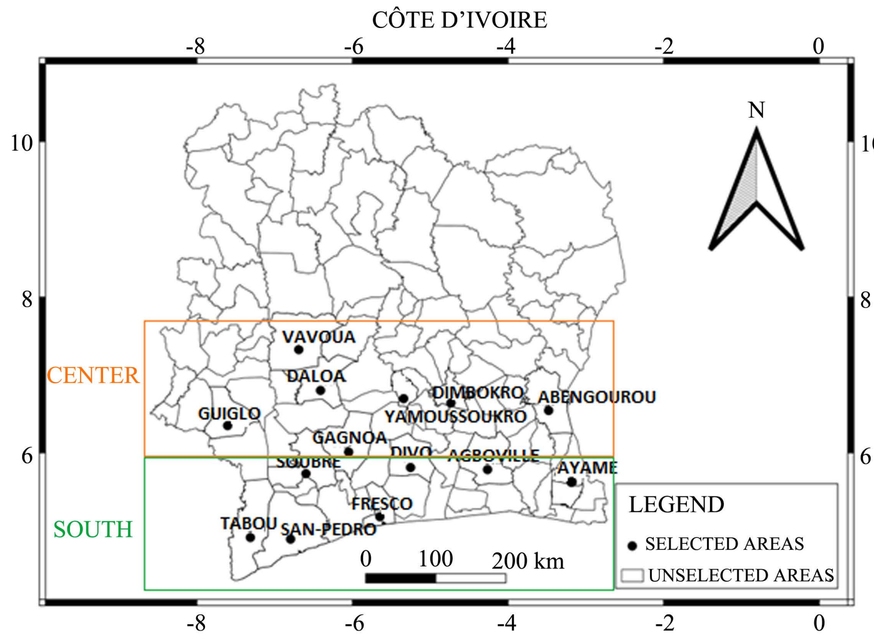


Figure 1. Cocoa growing areas and selected regions of Cote d'Ivoire.

cocoa production area was subdivided into two regions, the central region (6˚N - 8˚N) and the southern region (4.5˚N - 6˚N), where eleven regional capitals where cocoa are produced were selected in particular the towns of Ayamé, Agboville, Divo, Soubré, Gagnoa, Abengourou, Guiglo, Daloa, Dimbokro, Tabou et Vavoua (**Figure 1**).

2.2. Data

2.2.1. Observational Data

The observational data used are global monthly precipitation and temperature data from the Climatic Research Unit (CRU) at a resolution of 0.5˚ × 0.5˚ over the period from 1901 to 2013 (http://catalogue.ceda.ac.uk/uuid/3f8944800cc48e1cbc29a5ee12d8542d). These data were extracted and analyzed in central and southern areas of Côte d'Ivoire over the period from 1951 to 2005. They were used for validation and the choice of simulations for the study.

2.2.2. CORDEX Simulations

Six simulations from the CORDEX-Africa database were used in this study (**Table 1**). CORDEX-Africa is a set of multi-model simulations at 50 km spatial resolution, from regional climate models (RCM) forced by global models from CMIP5 [17]. They are carried out according to four greenhouse gas emission trajectories represented by the RCP2.6, RCP6, RCP4.5 and RCP8.5 scenarios. However, in the context of this study, we refer to the two scenarios RCP4.5 (so-called optimistic scenario) and RCP8.5 (so-called pessimistic scenario) which are well good for impact studies. It has been shown that CORDEX-Afrique reproduces the seasonal averages and the annual cycles of temperature and precipitation

Table 1. List of CORDEX simulations involved RCM and GCM used in the study.

Simulation Name	RCM	GCM	Simulation code
CLMcom-CCLM4_CNRM-CERFACS-CNRM-CM5	CLMcom-CCLM4	CNRM-CERFACS-CNRM-CM5	S1
CLMcom-CCLM4_ICHEC-EC-EARTH	CLMcom-CCLM4	ICHEC-EC-EARTH	S2
CLMcom-CCLM4_MPI-M-MPI-ESM-LR	CLMcom-CCLM4	MPI-M-MPI-ESM-LR	S3
SMHI-RCA4_CNRM-CERFACS-CNRM-CM5	SMHI-RCA4	CNRM-CERFACS-CNRM-CM5	S4
SMHI-RCA4_ICHEC-EC-EARTH	SMHI-RCA4	ICHEC-EC-EARTH	S5
SMHI-RCA4_MPI-M-MPI-ESM-LR	SMHI-RCA4	MPI-M-MPI-ESM-LR	S6

of several climatic regions of Africa quite well [18] [19], however with some bias [20]. Thus, the simulated rainfall and temperature from CORDEX-Africa used here has been subdivided into historical (1951 to 2005) and projection (2006 to 2100) periods.

2.3. Methods

2.3.1. Statistical Analysis

Statistical analysis based on calculations of the mean, standard deviation (STD), minimum and maximum of the time series of both CORDEX simulations and CRU observations was used for comparative studies between these two datasets. The details are shown in Table 2 and Table 3.

2.3.2. Calculation of Climatic Indices

In order to study the sensitivity of the cocoa tree to extremes of rain and temperature, the climatic indices impacting this crop were calculated. Thus, within the framework of this study, four climatic indices from the team of experts on the detection and indices of climate change (ETCCDI) and identified as being relevant for cocoa-culture were considered. Those are:

The CDD index which corresponds to the number of consecutive days without rain. When within the rainy season, dry spells occur; they have a negative effect on agricultural production. Indeed, the dry spells create water stress at the level of the plant when they occur at the beginning or in the middle of the growing season. Given a time series of daily precipitation amount (RR), then the largest number of consecutive days where RR is less than R is counted. R is an optional parameter with default R = 1 mm. Another output variable is the number of dry spells longer than N days. Here, taking into account the specificities and needs of the cocoa tree, the following thresholds have been set for the CDD index, for the cumulative amount of rain we have 70 mm and the period of for the number of days we have 90 days have been fixed for the CDD calculation. A period is considered dry if during a period of 30 days the precipitation received is less than 70 mm.

The number of rainy days (CWD) is defined as the number of 5 consecutive days where at least a given amount 5 mm of rain has occurred. The CWD

Table 2. Comparison between the statistical parameters of the annual average temperature of the models and observations.

		S1	S2	S3	S4	S5	S6	Ensemble mean	Observation
Central zone	STD (˚C)	0.41	0.34	0.37	0.26	0.31	0.35	0.34	0.36
	Mean (˚C)	25.96	24.15	24.89	24.94	24.30	25.21	24.90	26.33
	Maximum (˚C)	32.77	29.30	30.41	32.27	30.69	32.23	31.28	32.36
	Minimum (˚C)	21.07	20.14	20.83	18.65	18.91	19.79	19.90	20.47
Southern Zone	STD (˚C)	0.28	0.26	0.30	0.23	0.27	0.32	0.27	0.34
	Mean (˚C)	25.88	24.27	25.04	25.90	24.95	25.77	25.30	26.28
	Maximum (˚C)	31.02	27.82	28.93	31.24	29.67	30.74	29.90	31.03
	Minimum (˚C)	22.35	21.59	22.28	21.13	21.02	21.99	21.73	21.66

Table 3. Validation of annual precipitation (models and observations) over the 1971-2002 period.

		S1	S2	S3	S4	S5	S6	Ensemble mean	Observation
Central zone	STD (mm)	148.57	145.86	150.34	108.4	133.19	106.5	132.14	129.94
	Mean (mm)	46.45	76.93	81.48	130.45	146.66	156.83	106.46	108.73
	Maximum (mm)	948.70	1426.8	1240.5	1814.3	2089.5	2101.1	1603.4	1488.9
Southern zone	STD (mm)	214.21	290.69	221.79	122.71	165.99	187.23	200.43	171.73
	Mean (mm)	71.30	160.34	152.58	99.58	126.32	137.62	124.62	129.57
	Maximum (mm)	1451.3	2830.6	2363.7	1522.9	1975.6	1993.3	2022.9	2014.9

determines the length of the rainy-agricultural seasons and helps guide farmers in the choice of varieties to grow. The increase in drought linked to rainfall variability not only reduces production, but increases harvesting difficulties. Faced with this vulnerability, agricultural households are adopting resilient strategies [21]. For the calculation of the CWD index, the thresholds of 5 mm for the amount of rain and 5 days for the number of days have been set.

For the cultivated cocoa tree to have regular growth, well-distributed leaf flushes throughout the year, abundant flowering and fruiting, annual rainfall between 1200 mm/year and 1500 mm/year is required [15];

The duration of the great dry season less than 3 months with a total of more than 70 mm [22].

A maximum temperature (T_{max}) is the maximum daily temperature reached. Given that the ideal conditions for the cultivation of cocoa trees are maximum daily temperatures between 30˚C and 32˚C, a threshold of T_{max} at 33˚C was fixed in the present study. This index was calculated over the reference period (1971 to 2000) and the future period (2021 to 2050) and makes it possible to estimate the number of days per year when the maximum temperature is above 33˚C in the central areas and southern Côte d'Ivoire.

The total amount of rain during the main rainy season (April-May-June-July) is defined as the accumulation of precipitation received during this main rainy season. The threshold of 700 mm being specific to the cocoa tree, since quantities of rain lower than 700 mm are not favorable to the good development and production of the cocoa tree (Mian, 2007).

This climatic index was determined for the reference (1951 to 2005) and future (2006 to 2100) periods.

3. Results and Discussions

3.1. Results

3.1.1. Model Validation

1) Temperature

Comparison of CORDEX-Africa simulations with CRU observational data reveals that the models reproduce the seasonal temperature profile quite well with maximums in February, March and April and minimums in July and August. However, compared to that of CRU, the models underestimate the temperature in both the southern and central zones. The ensemble mean of the models reproduces the temperature profile with some bias. From January to but these differences are smaller than those observed between May and December. This is the same in the south as well as in the center. In general, the overall mean is closer than CRU values in the south (not shown in this study).

The comparison with the observations was deepened with a statistical study based on parameters such as standard deviations; the averages, minimums and maximums of the annual temperature in the central and southern zones, over the 1971-2000 period. These results are recorded in **Table 2**.

In the central zone, the standard deviation varies from 0.39˚C to 0.41˚C, reflecting a great variability in the average annual temperatures simulated by the models. Simulations S1 and S3 have a higher standard deviation than that of the observation while that of simulations S2, S4, S5 and S6 is lower. The overall mean of the models is lower than that of the observation, explained by the fact that the average, maximum and minimum values simulated in the models are all lower than those of the observation. These underestimates of simulated temperatures (average, maximum and minimum) could be explained by the conditions of the simulations, the various hypotheses put forward.

Concerning the southern zone of Côte d'Ivoire, the comparison of the simulated average and maximum temperatures with those of CRU, reveals an underestimation of the CORDEX Africa models considered in this study, although the minimum simulated temperature is similar to that observed. Moreover, in this southern zone, the dispersion of temperatures around the average varies between 0.23˚C and 0.30˚C, implying a low dispersion of temperatures around the average.

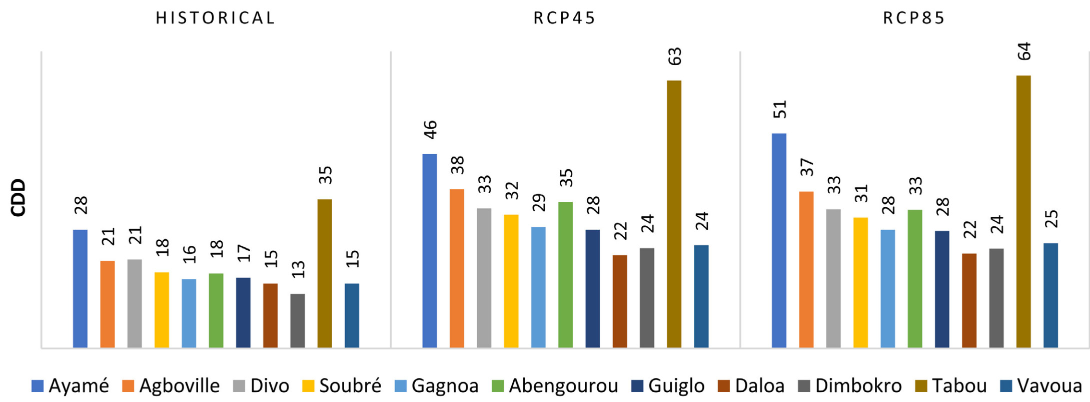
2) Precipitation

The comparisons of the simulated annual rainfall cycles and those of the CRU observation for each of the southern and central zones are presented. These comparisons reveal the bimodal nature of the rainfall distributed over the long and short rainy seasons in these two zones. From the country, this bimodal characteristic of precipitation is more or less fairly well reproduced by the different individual models, although the peaks do not occur at the same time. This non-coincidence of the peaks in the different models impacts the overall mean of the models, where the break point in the precipitation tends to disappear for a long unimodal rainy season, moreover, in the southern zone, there is a lag between the simulated peak (July) and that observed (June) of the long rainy season. Thus, the break in the precipitation is less marked at the level of the models although the overall mean retains its bimodal character.

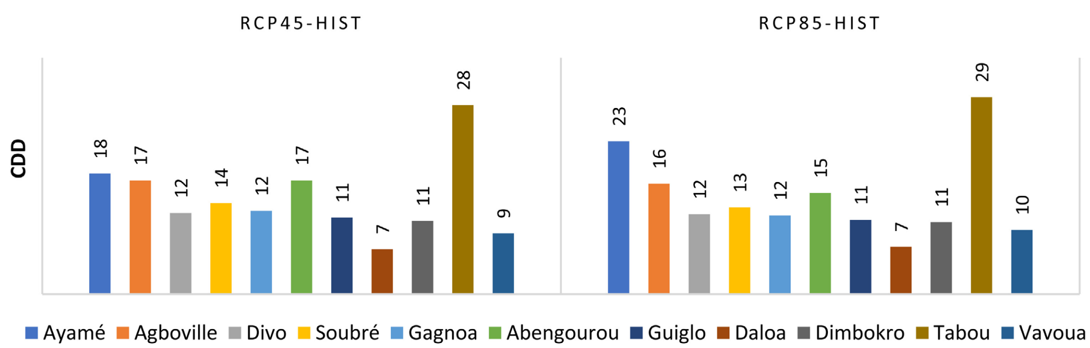
Table 3 presents the comparison of annual precipitation between models and observation over the historical period from 1971 to 2000. The average annual precipitation simulated in the two areas (south and center) are overestimated compared to observation. However, the overall mean is underestimated compared to the observation in the two zones considered. There is a great variability in precipitation illustrated by high values of standard deviations between 107 mm and 160 mm for the models considered and 129.94 mm for the observation. This high variability between the models influences the overall mean and would explain the overestimation of precipitation by the models.

3.1.2. Evolution of the Number of Consecutive Dry Days (CDD)

The CDD index determines the maximum number of consecutive dry days. Figure 2(a) and Figure 2(b) represent the number of consecutive days for the



(a)



(b)

Figure 2. (a) Difference in the number of consecutive dry days (CDD) between the scenarios and the models and (b) Number of consecutive dry days (CDD) in the localities studied, calculated over the 1971-2000 and 2021-2050 periods.

historical period, the RCP4.5 and RCP8.5 scenarios and the difference historical period and scenarios respectively. In general, we note that the CDD index is more important in the scenarios. This index varies from area to area. Thus, for Ayamé and Tabou, compared to the historical period, we have a surplus of 18 and 28 times for RCP4.5 and 23 and 29 times for RCP8.5 where the threshold set for CDD is exceeded.

Ayamé and Tabou are experiencing an increase in the number of consecutive dry days. Increasing the number of consecutive dry days within a rainy season can have a strong impact on cocoa production. This increase in the CDD index creates an increase in dry seasons and a shortening of rainy seasons in cities. The dry sequences create a lack of water at the level of the plant, but for good production, cocoa needs an annual rainfall of 1200 mm/year [15]. **Figure 2(b)** shows the difference in the number of consecutive dry days between the scenarios and the models. Note that this difference is positive.

3.1.3. Number of Consecutive Wet Days (CWD)

The number of wet days (CWD) determines the length of the rainy-agricultural seasons in a given place. **Figure 3(a)** shows us the evolution of the number of

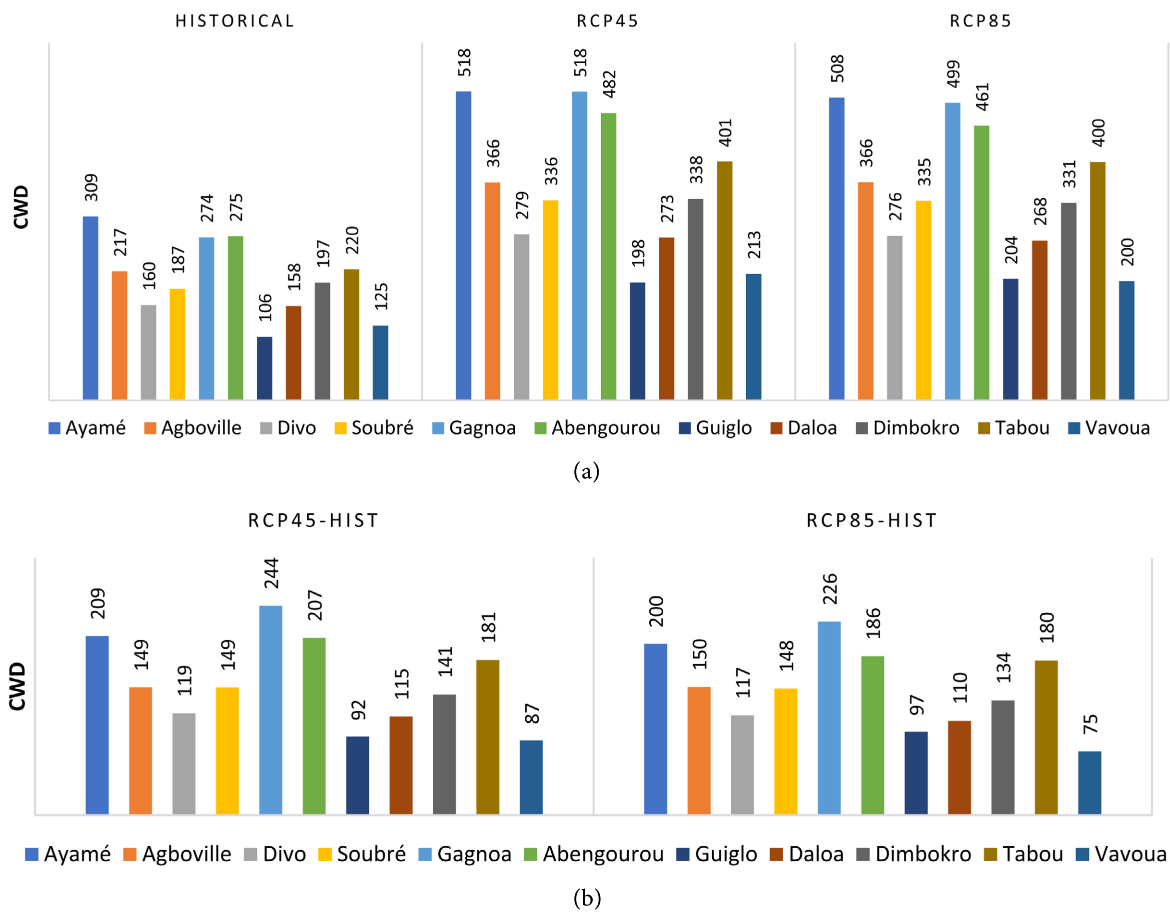


Figure 3. (a) Number of rainy days (CWD) in the studied localities and (b) Difference in the number of rainy days between the scenarios and the models over the periods from 1971 to 2000 and 2021 to 2050.

wet days, the evolution of the index (CWD) increases faster at the level of the scenarios than at the level of the historical data in the cities. The longest wet days observed in Ayamé, Gagnoa and Abengourou with 309, 274 and 275 days respectively in the historical data; 518, 518 and 482 days in the RCP4.5 scenario; 508, 499 and 461 days in the RCP8.5 scenario. The increase in the number of wet days can have an impact on cocoa production. This increase leads to an increase in rainy seasons and a restriction of dry seasons in cities. The rainy sequences create an abundance of water at the level of the plant which will be favorable for good production. Indeed, the length of crop cycles is a very determining factor in cocoa production. It guides farmers in the choice of varieties to cultivate because a variety whose cycle length is clearly longer than the duration of the rainy-agricultural season will eventually experience serious adaptation problems [23]. **Figure 3(b)** shows the difference in the number of rainy days between the scenarios and the models. Note that this difference is positive.

3.1.4. Total Amount of Rain in the Long Rainy Season

Figure 4(a) and **Figure 4(b)** shows the interannual variations in cumulative rainfall during the rainy season in the central and southern zones. In general, the accumulation of precipitation is greater in the south than in the center during the rainy season. Also, apart from the historical period, where the total precipitation fluctuates around 700 mm (minimum threshold required for cocoa cultivation) for the central zone, the total precipitation is well above this threshold of

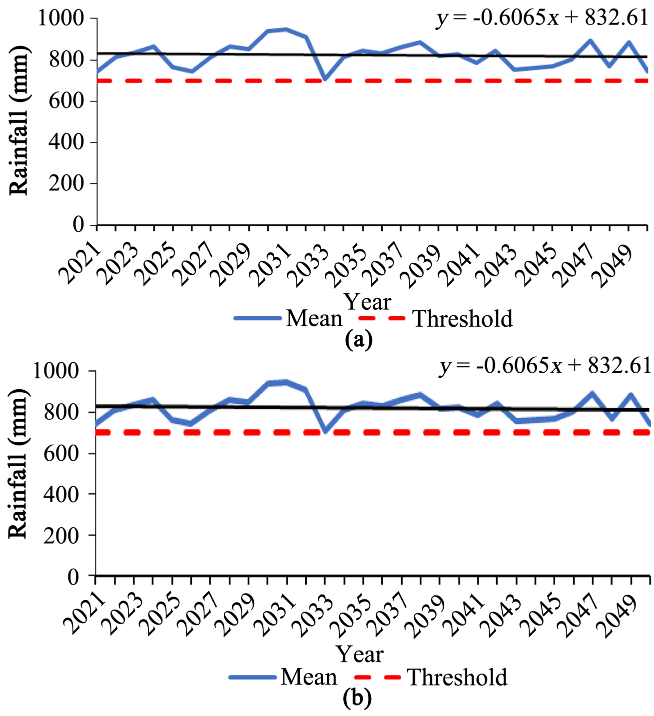


Figure 4. (a) April-May-June-July interannual variations in rainfall in the central zone of Côte d'Ivoire and (b) April-May-June-July interannual variations in rainfall in the southern zone of Côte d'Ivoire from 2021 to 2050 for the RCP4.5 scenario.

700 mm in the central zone. south. Indeed, this southern zone under the influence of the West African monsoon is characterized by high annual rainfall that can reach 1200 mm. In addition, the rains are almost continuous during the monsoon period where previous studies have shown that more than 80% of rainfall in West Africa occurs during this monsoon period. In addition, the analysis of the time series of annual rainfall data during the reference periods (1971 to 2000) and future (2021 to 2050) in the central zone, show great interannual variability (**Figure 4(a)**). This significant inter-annual variability in the central zone reveals years of both favorable (above 700 mm) and unfavorable (below 700 mm) rainfall for cocoa cultivation. In addition, the linear regression of the annual rainfall totals for the historical period and the projections (2021 to 2050 under the RCP4.5 and RCP8.5 scenarios), on the central zone, shows a regular increase in rainfall. Thus, the cumulative rainfall during the long rainy season, although variable over the period from 2021 to 2050 under the RCP4.5 and RCP8.5 scenarios, remains above the 700 mm threshold in the central zone, making it favorable for cocoa production.

The chronological series of rainfall accumulations during the rainy season in the southern zone reveals a large interannual variability associated with an increase in rainfall accumulations (**Figure 4(b)**). The linear regression of rainfall accumulations during the main rainy season, over the historical period (1971 to 2000), shows a drop in rainfall accumulations which were all greater than 700 mm in the southern zone, therefore favorable to the cultivation of cocoa. While the linear regression reveals an increase in rainfall over the entire period 2021 to 2050 under the RCP4.5 and RCP8.5 scenarios, maintaining the southern zone still favorable for cocoa production.

3.1.5. Days per Year When the Maximum Temperature Is Above 33˚C

The spatial distribution of the number of days per year during which the maximum daily temperature is above 33˚C during the historical (1971-2000) and projected (2021-2050) periods is presented in **Figure 5**. It emerges that for all the periods considered (historical and projections under RCP4.5 and RCP8.5), the number of days per year when the maximum temperature is above 33˚C increases throughout the two periods. This increase in temperature due to radiative

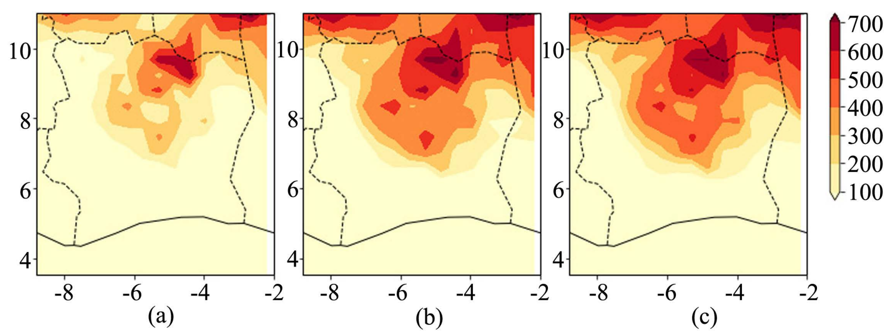


Figure 5. Simulations of the maximum temperature above 33˚C by the models over the (a) historical period and under the scenarios (b) RCP4.5 and (c) RCP8.5 in Côte d'Ivoire.

forcings in the two scenarios RCP4.5 and RCP8.5, is greater in the north of Côte d'Ivoire with maximums of the order of 700 days, against maximums of 200 and 100 days on the central and southern zones respectively. Thus, according to the RCP4.5 and RCP8.5 scenarios, the central and southern areas of Côte d'Ivoire could experience fewer days with temperatures above 33˚C compared to the north of the country. This implies that the central and southern areas could experience small variations in maximum temperatures and remained with regard to maximum temperatures, favorable to cocoa production. Maintaining these southern and central areas favorable to the cultivation and production of cocoa is justified by previous studies which have shown for good cocoa production, average annual temperatures of 25˚C are needed [10], temperatures average maximums between 30˚C and 32˚C and minimum temperatures of 18˚C to 21˚C, with an absolute minimum of 10˚C.

3.2. Discussion

The water consumption of the cocoa tree varies according to the environmental conditions. Thus, during the rainy season, water consumption depends on potential evapotranspiration; while during the dry season it depends on the usable reserve. Studies show that in non-irrigated conditions, the cocoa tree's water requirement is low and varies between 0.5 mm/decade and 1.5 mm/decade which correspond to 15 to 45 mm/month depending on the soil water reserve [24]. The minimum annual rainfall threshold bearable by the cocoa tree is 1200 mm/year.

The cocoa sector will also be impacted by climate change. Indeed, the expected warming of temperatures should harm cocoa plantations, especially those located in the Lagunes and Sud-Comoé regions [25]. The optimum altitude for cocoa cultivation is currently 100 - 250 meters above sea level. With climate warming, this will increase to 450 - 500 meters by 2050 to compensate for the increase in temperature [26]. An increase in temperature should dry out the land more quickly and reduce its fertility. The logical answer would then be to move the plantations to the southwest, which being at a higher altitude, would become more suitable for growing cocoa. Such a move will cause even more deforestation. Moreover, it would take place in a context where many trees, old and diseased, will have to be replaced in the coming years, putting much more pressure on new cultivable areas. Finally, this exodus is likely to generate land conflicts in the new regions, especially since they are now home to many protected areas, including the Taï National Park which is part of the UNESCO World Heritage List.

Through this study we see that in general, the dry sequences of 90 days with an accumulation of precipitation less than 70 mm (CDD) increases over the entire studied area. However, this increase is not the same everywhere. Thus, among all the cities selected in the central and southern areas of Côte d'Ivoire, Ayamé and Tabou are the most affected with an increasing rate of the number of consecutive dry days (CDD) respectively of 16 days and 19 days compare to the reference period. On the other hand, for the future period, as the RCP4.5 and

RCP8.5 scenarios, these areas show an upward rate of the CDD index respectively 14 days and 20 days for the RCP4.5, 17 days and 22 days for RCP8.5. These different trends indicate that the regions could be hit by a rainfall recession. These results are similar to those of [27] and [28]. Indeed, [27], in their study on the evolution of rainfall extremes in the Goh region (central-west of Côte d'Ivoire), showed that the CDD index increased and that in general, the Goh region is experiencing a drop in rainfall and therefore an increase in dry sequences during the rainy seasons. [28], in their study on the evolution of rainfall and temperature extremes in the Davo river basin (south-west of Côte d'Ivoire) from certain indices of the RCLIMDEX software, showed that consecutive dry days (CDD) have increased in Daloa region and that in general, the Davo watershed is experiencing a drop in rainfall and therefore an increase in dry spells during the rainy seasons.

However, the number of consecutive wet days (CWD) in the case of this study is the number of days where there is in 5 days an accumulation of precipitation greater than 5 mm which deals with the cocoa physiology. This index has increased in all localities. But more particularly in Ayamé, Gagnoa and Abengourou with respectively 162 days, 158 days and 147 days compare to the reference period, 179 days, 161 days and 149 days for the RCP4.5; and 156 days, 154 days and 145 days for RCP8.5. These different trends show that these regions could be hit by an increase in rainfall which could lead to an increase in the amount of rain favorable to cocoa cultivation. The similar results are found by [28] over Daloa and Gagnoa regions.

Cumulative rainfall above 700 mm during the rainy season is responsible for the good growth and maturity of the cocoa tree. According to our results, for all the scenarios (RCP4.5 and RCP8.5), the accumulations are greater than 700 mm, which implies that the conditions would always be met for a good cocoa-growing practice in the center and in the south in the years to come. Years with a rainfall deficit during the long rainy season compared to the cocoa tree's water requirement estimated at 700 mm. In this context, the water needs of the cocoa tree are less and less satisfied during the crucial phases of the annual cocoa cycle which corresponds to the flowering which normally takes place during the long rainy season (April to June) for the harvest, main from September to January and in November-December for the second harvest. [15] showed that the rainfall deficits recorded during this period lead to a reduction in the size and weight of fresh beans, which considerably reduces the quantity of beans produced, resulting in a poor quality of the cocoa harvested. Moreover, [9] showed that the amount of rainfall and its seasonal distribution are the most influential factors for cocoa production. In this study, the RCP8.5 and RCP4.5 scenarios showed that the central and southern areas of Côte d'Ivoire could be favorable for cocoa cultivation by 2050. Many authors such as [29] [30] [31] showed that the amount of precipitation in the major rainy season is essential for cocoa cultivation. Indeed, cocoa production is conditioned by exogenous factors such as land sown area, soil moisture, soil types, etc., as related by [9], but which have not been taken into account in this work cause to not available.

The number of days where the maximum temperature is above 33˚C varies between 100 - 700 days. For example, the central zone records an average of 200 days, while the southern zone records less than 100 days. We notice that the very hot season lasts 78 days with a daily maximum temperature above 33˚C, the hottest day of the year with a maximum temperature of 35˚C and minimum of 23˚C. In addition, the cool season lasts 84 days with a maximum daily temperature below 29˚C (not shown in this study). The coldest day of the year with a minimum temperature of 21˚C and maximum of 33˚C. [32] in their study on the agro-climatic analysis of the cocoa zone in Côte d'Ivoire, showed that the Dimbokro, Gagnoa and Daloa stations have a high temperature value of 33.5˚C which is negative for cocoa so may cause a displacement of farmers. The average changes in temperatures will also result in changes in various types of climatic events, the probability of which is more or less well known. Therefore, it seems very likely that we will observe events over the next few decades. The scenarios show an increase in the number of days when the temperature is above 33˚C by 2050 over most part of the country from north to south. Also, an increase in temperature leads to a decrease in cocoa production [9]. A study found that although the impact of climate change is global, tropical equatorial regions with low annual temperature variability will be hardly hit. A 2011 report from the International Center for Tropical Agriculture predicted that the suitability of cocoa in West Africa particularly in Côte d'Ivoire could begin to decline as early as 2030. Indeed, temperature plays a vital role and well known in evapotranspiration and water demand. It therefore significantly affects growing seasons, water requirements and strategies to ensure water availability to meet demand. [33] [30] pointed out that temperature-related uncertainties accounted for a greater contribution to the uncertainty of climate change impact than those related to the rainfall system for most crops and the regions. The cocoa environment needs ecological and soil conditions, which are beyond the scope of this study, and none of them could be considered independently.

4. Conclusion

This work concerns how climate scenarios as RCP4.5 and RCP8.5 could contribute to improve cocoa cultivation in most central and southern areas of Côte d'Ivoire. It made it possible to understand the evolution of climatic parameters and indices likely to affect cocoa production. This study was carried out using CORDEX data. The validation of the models from the observation data showed a good reproduction of the seasonal temperature with however an underestimation, unlike precipitation where the seasonal cycle is not faithfully reproduced. High variability between the models is also observed. An analysis of rainfall shows that for cumulative rainfall above 700 mm in the main rainy season, production will increase by 2050 in most central and southern areas of Côte d'Ivoire. The temperature study shows that the central and southern areas of

Cote d'Ivoire could be areas with a low number of days with temperatures above 33˚C. The climatic indices and parameters used for this work to estimate cocoa production cannot be limited to two independent parameters such as rainfall and temperature. Consideration of other explanatory variables could lead to a good estimate of cocoa production yields. We could have used other climatic indices related to soil, humidity to arrive at a more realistic estimate of cocoa production. Scientists are still figuring out what this means for cocoa trees growing as temperatures rise. To stabilize the climate while improving agricultural production, it would be necessary to preserve the forest ecosystem and then fight against drought. It should be noted that cocoa still remains a solid pillar of the economy in the UEMOA space, particularly in Côte d'Ivoire. However, the deterioration of yield and production growth indicators, combined with the difficulties experienced by the industry in recent years, is making it less and less of a growth sector. Thus, this work aims to inform decision-makers on the impact of climate change on cocoa in order to adopt more appropriate farming practices for good cocoa production in Côte d'Ivoire in the years to come. Finally, note that several ecological factors of the cocoa tree could be important, none of them could be considered independently of all the other factors.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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