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Research Article

Evaluation of Rainfall and Temperature Conditions for a Perennial Crop in Tropical Wetland: A Case Study of Cocoa in Côte d'Ivoire

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The rainfall and temperature conditions are evaluated for the first time during the 1989–2006 period, in six main cocoa production areas (Abengourou, Agboville, Daloa, Dimbokro, Guiglo, and Soubre) of Côte d'Ivoire using data from SODEXAM (ground-based observation) and the ex-CAISTAB. Statistical analysis shows an important sensitivity of cocoa production to rainfall conditions in all regions. It is worth noting that only the major rainy season from April to July and the rainfall amount of the little dry season from August to September affect the cocoa production for an 80% confidence level. This influence varies from one cacao production area to another. Moreover, the effects related to temperature on the cocoa yield seem to represent a smaller contribution of climate impact than those related to precipitation during the studied period. The temperature change remains in the acceptable range of values, between 25°C and 29°C, which is a favorable condition for cocoa growing. These findings are obtained despite the significant contributions from nonclimatic factors, to year-to-year variability in cocoa production.

1. Introduction

Across Côte d'Ivoire, cocoa farms have expanded considerably since 1980s thanks to a strong agricultural policy and favorable agronomic and climatic conditions in many regions. Another favorable condition, in addition to propitious agroclimatic conditions, to cocoa growing is the cheap labor availability [1]. Thus, the economy of Côte d'Ivoire is mainly based on the pair coffee-cocoa. For example, in 1997, the coffee-cocoa pair provided about 17% of the Gross Domestic Product (GDP) and 38.6% of export earnings [2]. In addition, according to the International CoCoa Organization (ICCO) statistics, Côte d'Ivoire produced 1,395,000 Tons of cocoa for the 2009-2010 seasons that represented 46.5% of world production.

Cocoa is a perennial tropical plant, which contributes to the economy and development of many countries like Ghana and Côte d'Ivoire. However, its production undergoes a strong interannual variability mainly related to climate variations [3] and the ignorance of many physical, biological, and socioeconomic processes. Cocoa growing requires relatively more rigorous pedological and climatic conditions than other tropical crops like a palm tree, coffee, and rubber tree [4, 5]. For example, cocoa needs wetter conditions of about a minimum of 1200 mm to 1500 mm annual rainfall amount per year with a limited number of dry days (<90 days) [6] for its development.

On the other hand, West African countries, especially Côte d'Ivoire have experienced strong climate variability characterized by a deficit on rainfall amount [7, 8]. Furthermore, Freud et al. [9] showed that the rainfall trend in the last few decades has led to a decrease in ecologically favorable conditions for cocoa in many parts of the country. In the same vein, several works as Nicholson [10], Lamb [11], Folland et al. [12], Lamb and Peppler [13], Fontaine and Janicot [14], and Nicholson and Grist [15] evaluate possible mechanisms associated with these deficits in rain amount. For example, these drought episodes are sequences of continuous rainfall deficit periods from 1960 to 1990, which were not only limited to the Sahel area but spread to the coastal regions of West Africa [14, 16], especially in Côte d'Ivoire [17, 18]. The dry conditions led to a serious disturbance in water resources and then a disaster for the populations and cause a loss in livestock and a gradual disappearance of certain export crops.

In agriculture, the consequences are significant and result in changes in the growing seasons: an occurrence of late or early rains and, particularly, long dry spells. The effects of the changes are really important on the economy of West African countries especially for a country like Côte d'Ivoire, 40% of whose resources are based on cocoa [19]. Amani [20] pointed out that farmers who have been most affected by this climate variability have used biotechnology methods that involve selecting cloned or hybrid cocoa species. These biotechnology methods were expected to improve with the agrobiochemical supports (e.g., fertilizers, herbicides, and insecticides) the cocoa production. However, the methods did not show subsequent improvement in the production per hectare [21].

Moreover, in the centre of Côte d'Ivoire, especially around Daoukro, considered as the old "main production zone"; Koukou-Tchamba et al. [22] and Kanohin et al. [23] underlined a decrease in cocoa production, and they attributed it to a decline of the rainfall in the region. Thus, a new cocoa production "hot spot" has emerged towards the southeast and southwest regions, which have not been exploited before. Furthermore, a strong link between the main cocoa production areas and the recorded seasonal precipitation amount has been underlined [24]. The cocoa growing has been also linked to other parameters like the temperature, during the flowering period, the type of the soil, humidity, and insolation [25, 26]. Thus, precipitation and temperature are suggested to play an important role in the significant interannual variability of cocoa production experienced in Côte d'Ivoire during the past recent years. However, Agoh and Augustin [27] show that these two climatic factors drive differently the interannual variability of cocoa production in a given area. For example, in the Daloa region, cocoa yield is affected by the duration of sunshine and rainfall, while in the Gagnoa region, it depends on the duration of sunshine and temperature.

Therewith, some studies like [28] projected a decrease in rainfall associated with a reduction in the number and length of consecutive dry days under 1.5°C and 2°C global warming based on Representative Concentration Pathways (RCP 8.5). This study assesses the influence of precipitation and temperature on the development and cocoa yield, in six departments (Abengourou, Agboville, Daloa, Dimbokro, Guiglo, and Soubre) across Côte d'Ivoire. It tries to also improve our understanding of the relative and individual contributions of the two factors in estimating of climate change impacts on cocoa yields. These departments are considered as the main cocoa production areas of the country. The study is conducted over the period spreading from 1989 to 2006. The work is structured as follows; Section 2 is dedicated to the description of the study area, the material, and the method used. Section 3 shows the results and, the discussion is given in Section 4. Finally, conclusion and perspectives are given at the end.

2. Materials and Methods

2.1. Study Area. The area of interest is an extensive zone composed of dense evergreen and semideciduous wet forests covering an area of 170,320 km^2 [29]. It represents about 53% of the Ivorian territory and is located between 2.5°W and 8.5°W and, between 4°N and 9°N, in the southern half of the country (Figure 1). The region is bounded at its northern part by the preforest Savannah zone commonly known as "V Baoulé" and by the Atlantic Ocean in the south [24]. Three types of soils characterize this region: hydromorphic, ferralitic, and ferruginous soils [30]. These soils are mostly favorable to agriculture and cocoa cultivation particularly. This region is characterized by a bimodal rainy season: the major and first rainy season is between April and early-to-mid July with a peak in June and, the little rainy season extends from the mid-September to November with a peak in October. Kouadio et al. [31] showed that the rainfall regime in the north of Gulf of Guinea is influenced by the Intertropical Convergence Zone (ITCZ) and Sea Surface Temperature (SST) anomalies at the equator and West Africa coast.

2.2. Materials. This study used ground-based observations (rainfall and temperature) from the National Meteorology of Côte d'Ivoire (SODEXAM) and cocoa production data from the ex-Caisse de Stabilisation du Café et du Cacao (ex-CAISTAB) over the 1989–2010 period. These parameters are recorded across six stations (five rain gauge stations and one synoptic station). The selected and available stations (Abengourou, Agboville, Dimbokro, Guiglo, Soubre, and Daloa) cover the study area and provide acceptable and uniform meteorological information about the considered regions (Figure 2).

2.3. Method. The work is based on statistical analysis of cocoa yield in regard to the weather conditions. The analyses assess the relationships between the climate and the cocoa yield. The significance of any trend or signal is also analysed. The water requirements for the cocoa production are calculated based on values provided by Dian [30] and Mian [29]. The main rainy season from April to July must record an amount of rain above 700 mm [29] and the little dry season (August to September) must record at least 70 mm [30] to ensure a good cocoa growing and production. The considered temperature, and thereafter, is obtained by averaging the daily temperatures over March-April (first flowering period) and September-October (second flowering period) for each year.

3. Results

3.1. Interannual Variability of Cocoa Production. The interannual variability of cocoa production is studied through

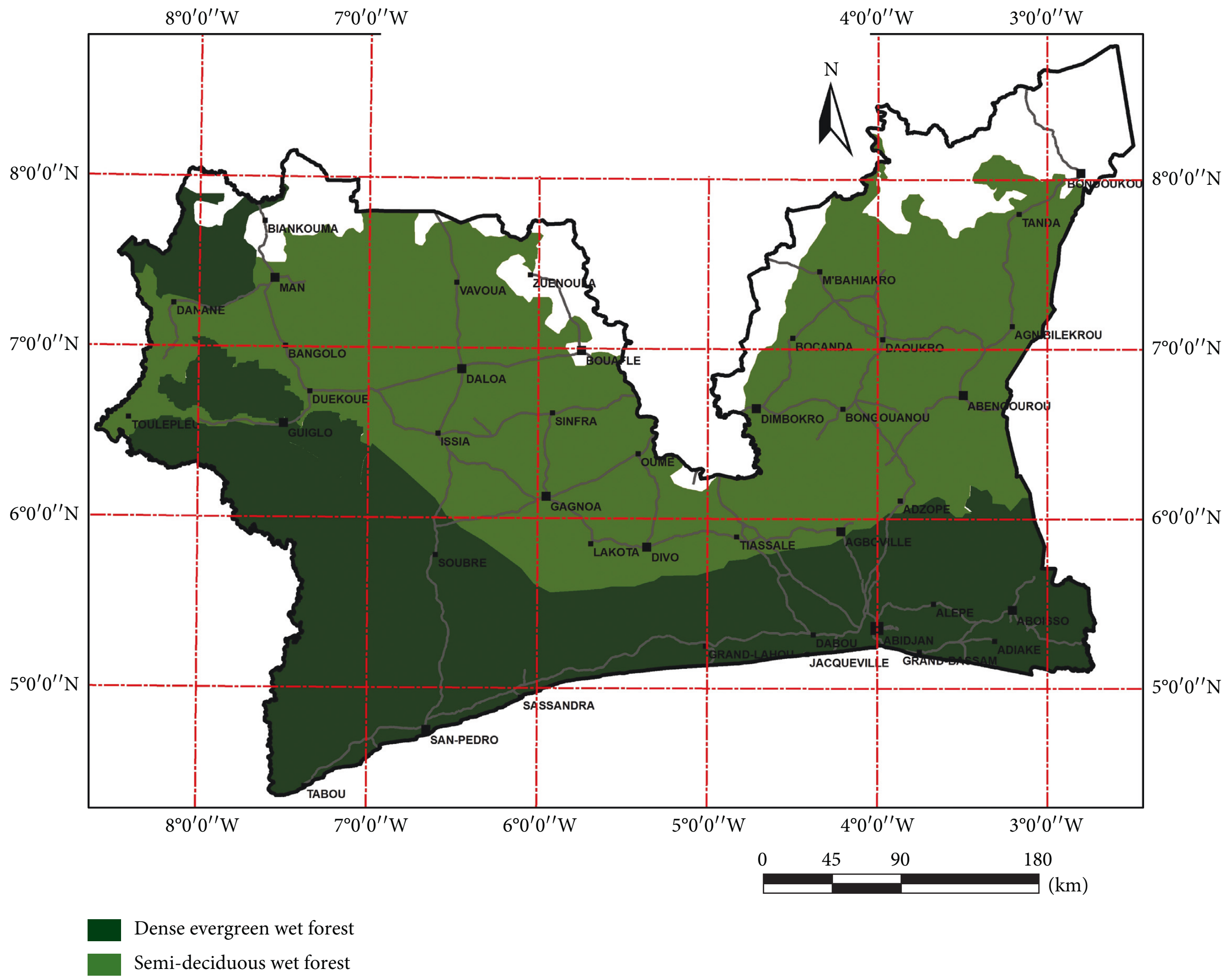

Figure 1: Vegetation types of the study area (adapted to Koné et al. [26]).

the standardized anomalies calculated over the 1989–2006 period (Figure 3) in the six departments. These standardized anomalies vary from −3 to 3 and then suggest periods of deficit and abundance in cocoa production across all regions. For Abengourou, Guiglo, and Daloa, there is an alternate of deficit (before 1995 and from 2003) and abundance (from 1995 to 2002). A similar pattern is observed in Dimbokro with a deficit before 1993 followed by a scatter period where there are successive multiple deficits and abundances. The other departments (i.e., Agboville and Soubre) show a long period of deficit in the cocoa production before 2001 followed by a period of abundance. The displayed tendency (Figure 3), as it is expected from the standardized anomalies, shows a succession of decrease and increase in cocoa production. For example, there is a decrease in cocoa production from 1989 to 1995 followed by an increase, from 1995 to 2003 in Guiglo and from 1995 to 1999 around Daloa and Abengourou. The similarity in the variability of the cocoa production of Daloa and Abengourou may be due to their climate type and latitudinal location (Figure 2). These departments belong to the same climate type (climate of center) proposed by Kouadio et al. [32]. The meteorological conditions in these two areas could similarly influence the cocoa yield and thus impact the variability of the cocoa production.

3.2. Cocoa Production Band Meteorological Parameters. Figures 4 and 5 show the variations of cocoa production in regard to the amount of rainfall during the main rainy season (April to July) and little dry season (August to September), and the temperature in the six regions, respectively. A relative important correlation coefficient (0.43) is noticed between cocoa production and precipitation amount during the main rainy season around Guiglo than that over the rest of departments (Figure 4). The values of 0.31 and 0.32 are, respectively, obtained in Abengourou and Daloa. The lowest correlations are found in Agboville (−0.16), Dimbokro (0.02), and Soubre (0.14). In these latest regions, it seems that there is no noticeable influence of rainfall on cocoa production, whereas, in Abengourou, Daloa, and Guiglo, the rainfall amount of the main rainy season has no negligible impact on the variability of the cocoa production even if the correlation coefficients are below 0.5. These values

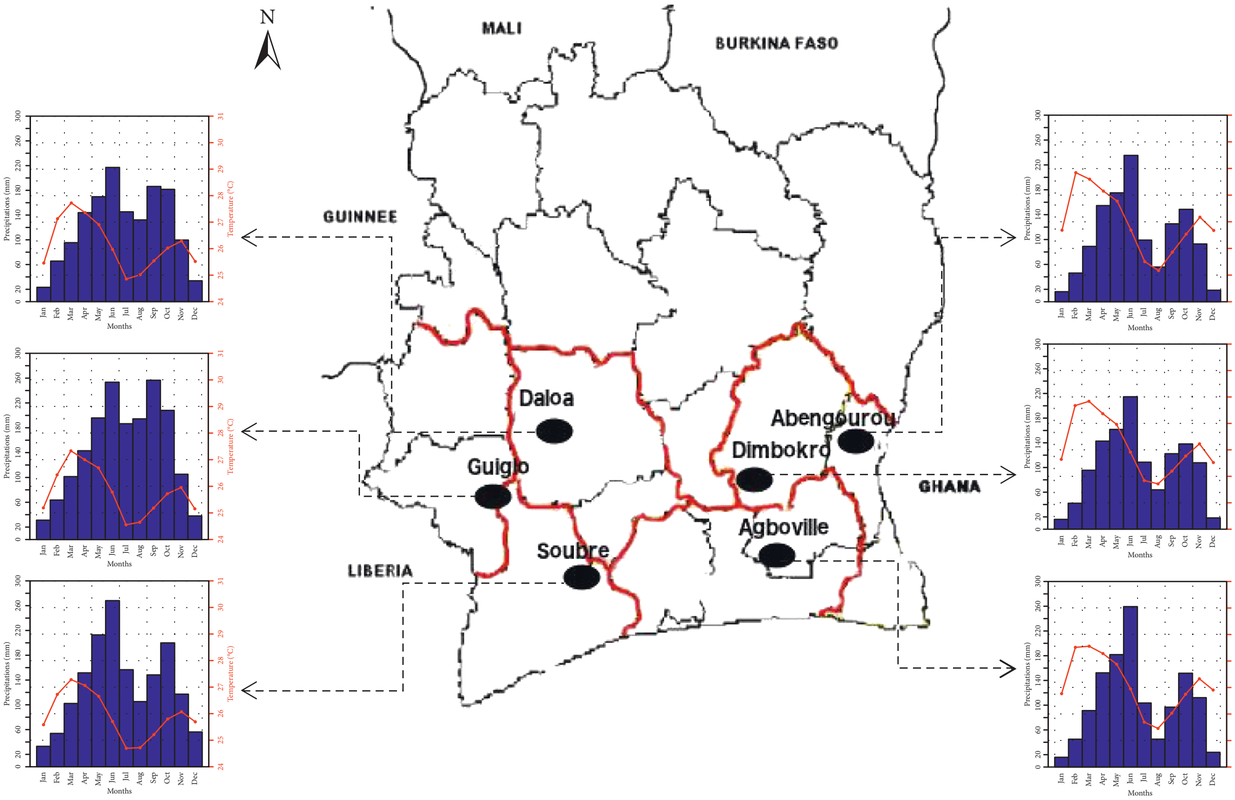

FIGURE 2: Study area with the six reference departments and their mean ombrothermal diagram over the 1989–2006 period. Red contours delimit the important areas of cocoa production.

of the correlation coefficients suggest an increase in the cocoa production with the rainfall. Figure 5 shows correlation values, between cocoa production and little dry season, below 0.23 across all the departments, except in Agboville (0.32). Thus, the assumed link may be marginal between the cocoa production variability and the rainfall amounts during the little dry season from August to September. The mean temperature values are between 25°C and 29°C (figure not shown) and offer favorable temperature conditions to the cocoa culture in the departments. There is a decrease in cocoa production with the mean temperature for some department like Daloa (−0.06), Abengourou (−0.32), and Dimbokro (−0.42) while for the remaining, the production increases with the mean temperature.

3.3. Cocoa Production Response to Rainfall and Temperature as the Predictors in a Multiple Linear Regression. In this section, multiple regressions are used to evaluate sources of variations in the cocoa production (ΔY) in regard to both rainfall amounts of the main rainy season (ΔP_{rs}), the little dry season (ΔP_{ds}), and the growing season average temperature (ΔT). The change in cocoa production (ΔY) for a given department is obtained by the following equation:

$$\Delta Y = m_1 \Delta P_{\text{rs}} + m_2 \Delta P_{\text{ds}} + m_3 \Delta T + b, \quad (1)$$

where m_1, m_2, and m_3 represent the sensitivity of cocoa production to both rainfall amounts of the main rainy season, the little dry season and the temperature, respectively, and b represents the potential nonlinear effects of precipitation or temperature, such as those that arise from interactions with other variables. This equation ignores other aspects of meteorological conditions, such as relative humidity, wind speed, sunshine, and nonclimatic factors, such as soils types, soil humidity, planted area, and number of the vegetative cycle. It represents a useful first-order estimate of year-to-year variability in cocoa yield for a considered department over the studied period. All calculated coefficient values of equation (1) are given in Table 1. This table shows that the increase in cocoa production is mainly due to the rainfall amounts of the major rainy season and the little dry season in Abengourou and Daloa. In Guiglo and Soubre, this increase is related to all the considered three parameters, while in Agboville, only the rainfall amount of the little dry season has remarkable impact on the cocoa production. In Dimbokro, the negative correlation coefficients suggest a decrease in cocoa production with both temperature and rainfall. The significance of the correlation coefficients between the cocoa production and the three defined parameters (i.e., ΔP_{rs}, ΔP_{ds}, and ΔT) is assessed using indexes from the Fisher–Snedecor and Student t-tests (see Tables 2 and 3). Table 2 shows a high p value in Dimbokro (0.843) and Soubre (0.815), while it displays a low value in Abengourou (0.426), Agboville (0.442), Daloa (0.409), and Guiglo (0.219). These p values are associated with high values of coefficient of determination (R^2) in Abengourou (0.175), Agboville (0.169), Daloa (0.181), and Guiglo (0.263), while the values are marginal in Dimbokro (0.055) and Soubre (0.063). In

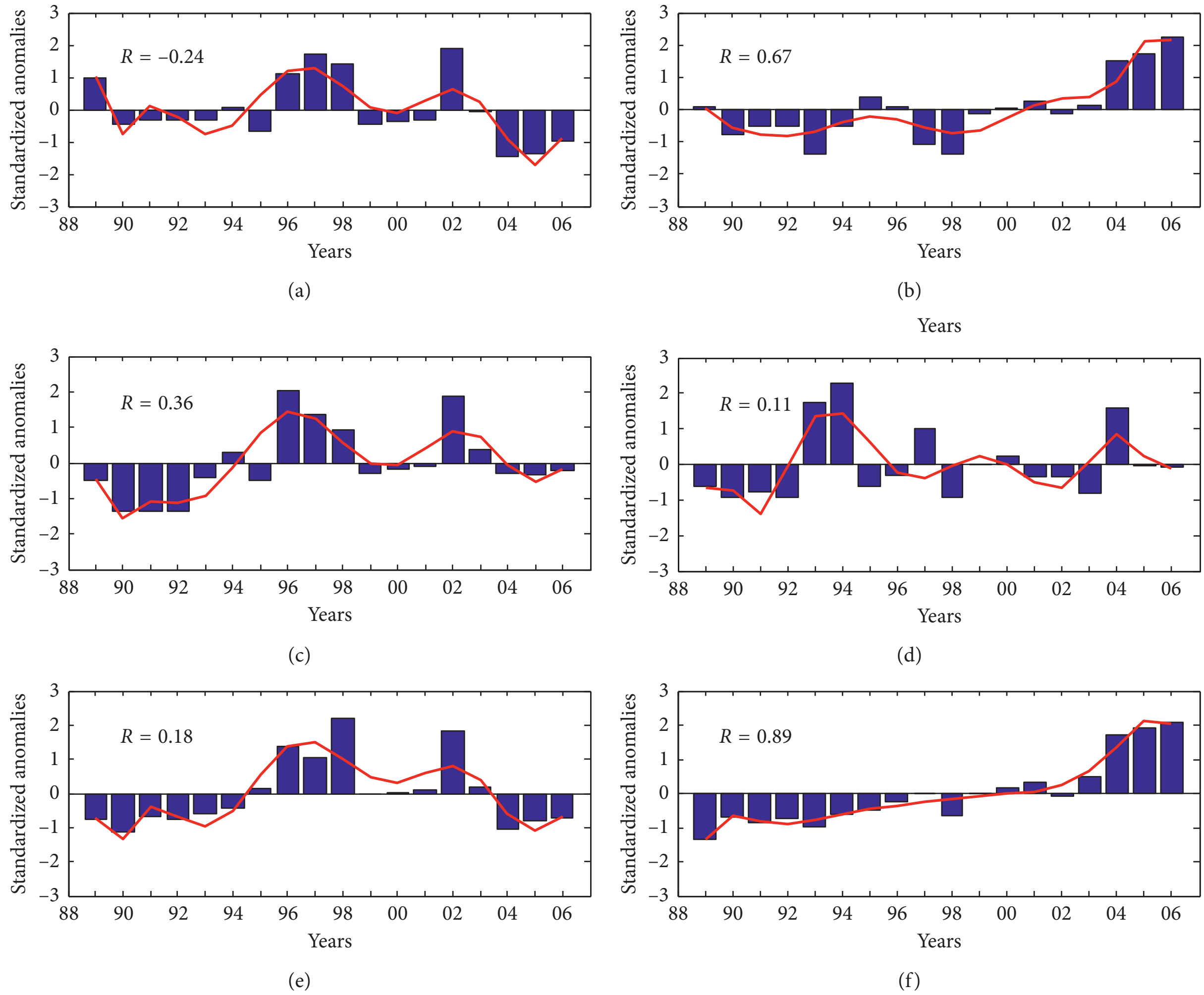

Figure 3: Standardized anomalies of cocoa production in the six reference departments of the study area during the 1989–2006 period. Red line indicates the trend curve. (a) Abengourou. (b) Agboville. (c) Daloa. (d) Dimbokro. (e) Guiglo. (f) Soubré.

these four departments where coefficient of determination is noticeable, the equation of multiple regressions is relevant to explain the cocoa production. Then, the temperature and the rainfall during the main rainy season and the little dry season are crucial to explain the variation in cocoa production. Thus, in Abengourou and Daloa, an increasing temperature induces a decrease in cocoa production while in the department of Agboville, the increase in rainfall amount during the main rainy season tends to reduce the cocoa yield. The opposite evolution of cocoa production in regard to the increased precipitation may be related to the influence of some other factors like the type of the soil and soil fertility, which are not considered in this study. The increase of runoff, erosion, and relative humidity can damage the cocoa trees if the soil conditions do not manage to inhibit their negative effects. In addition, it is possible that the increase in the average growing season rainfall has a lower impact on cocoa yield than the increase in rainfall during the critical stages of cocoa trees growth. In this case, the intraseasonal temporal distribution of rainfall is a significant component for crops. In Guiglo, the decrease in cocoa production due to one of the three parameters could be inhibited by the increase of the two others. On the over hand, in Table 3, the t-values evaluate the importance of each variable ΔP_{rs}, ΔP_{ds}, and ΔT in the estimating cocoa production (ΔY) with an 80% confidence level ($t_c = 1.34$). The rainfall amounts (either main rainy season or little dry season) are suggested to be the key parameters that influence the annual cocoa production in three departments: Agboville with ΔP_{ds} ($t = 1.5$) and Daloa and Guiglo with ΔP_{rs} ($t = 1.48$ and $t = 1.75$, respectively). But the mean temperature (ΔT) (t-values < 1.34 in all departments) seems to have negligible impacts on cocoa production in all departments.

4. Discussion

The impact of the rainfall and the temperature conditions in cocoa yield across six departments (Agboville, Daloa, Guiglo, Abengourou, Dimbokro, and Soubre) of Côte d'Ivoire has been highlighted. Cocoa production shows a strong annual variation from one department to another. Its variation is characterized by a succession of periods of

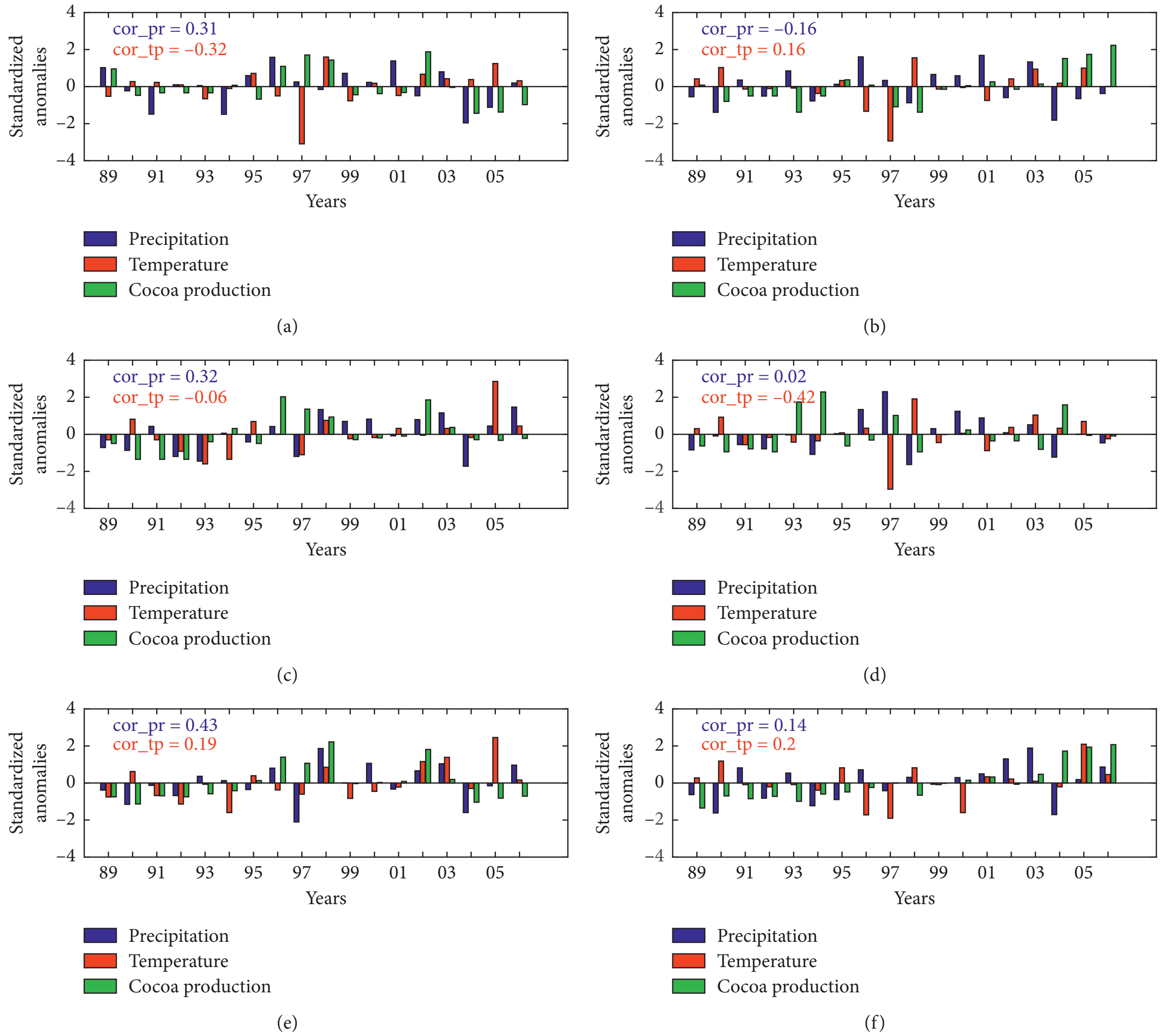

Figure 4: Standardized anomalies of rainfall of the main rainy season, temperature, and cocoa production in the six departments from 1989 to 2006. The correlation coefficients between cocoa production and rainfall (blue) and temperature (red). (a) Abengourou. (b) Agboville. (c) Daloa. (d) Dimbokro. (e) Guiglo. (f) Soubré.

abundance and deficit during the 1989–2006 period. The deficit phase, before 1994 (Figure 3), has affected all the departments and extended until the year 2000 in Agboville and Soubre (Figure 1). This phase in cocoa production coincided with the period of rainfall deficit across West Africa spreading from the Sahel [7, 17, 33–35] to the Guinean coast areas, especially in Côte d'Ivoire [17]. Thus, the low cocoa production during this period could be related to the drought that occurred from 1960 to 1990. This dry condition affected the whole West Africa from the Sahel to the Guinean coast [14, 16–18]. It may imply a hydric stress on the cocoa plants and then reduce the cocoa yield. In addition, these regional effects have been amplified by seasonal and local signals of precipitation variations. For example, correlation coefficients (Figure 4) show that the cocoa production in Abengourou, Daloa, Guiglo, and Soubre is more sensitive to rainfall amounts of the major rainy season. Meanwhile, in the department of Agboville and Dimbokro, the cocoa yield is mostly related to the rainfall amount of the little dry season (August to September). Moreover, Brou et al. [6] showed that the rainfall deficit recorded during this period inhibited cocoa trees development, and considerably reduced the cocoa production and the quality of the beans. Many authors [36, 37] have shown that precipitation amount of the main rainy season (P_{rs}), the little dry season (P_{ds}) and the temperature (T) are essential for cocoa growing even if these parameters have different impacts depending on the region. Indeed, the cocoa production is conditioned by many factors, which some of them are related to climate (i.e., precipitation amounts of the major rainy season and the little dry season, and the temperature, etc.) and other exogenous factors such as land area,

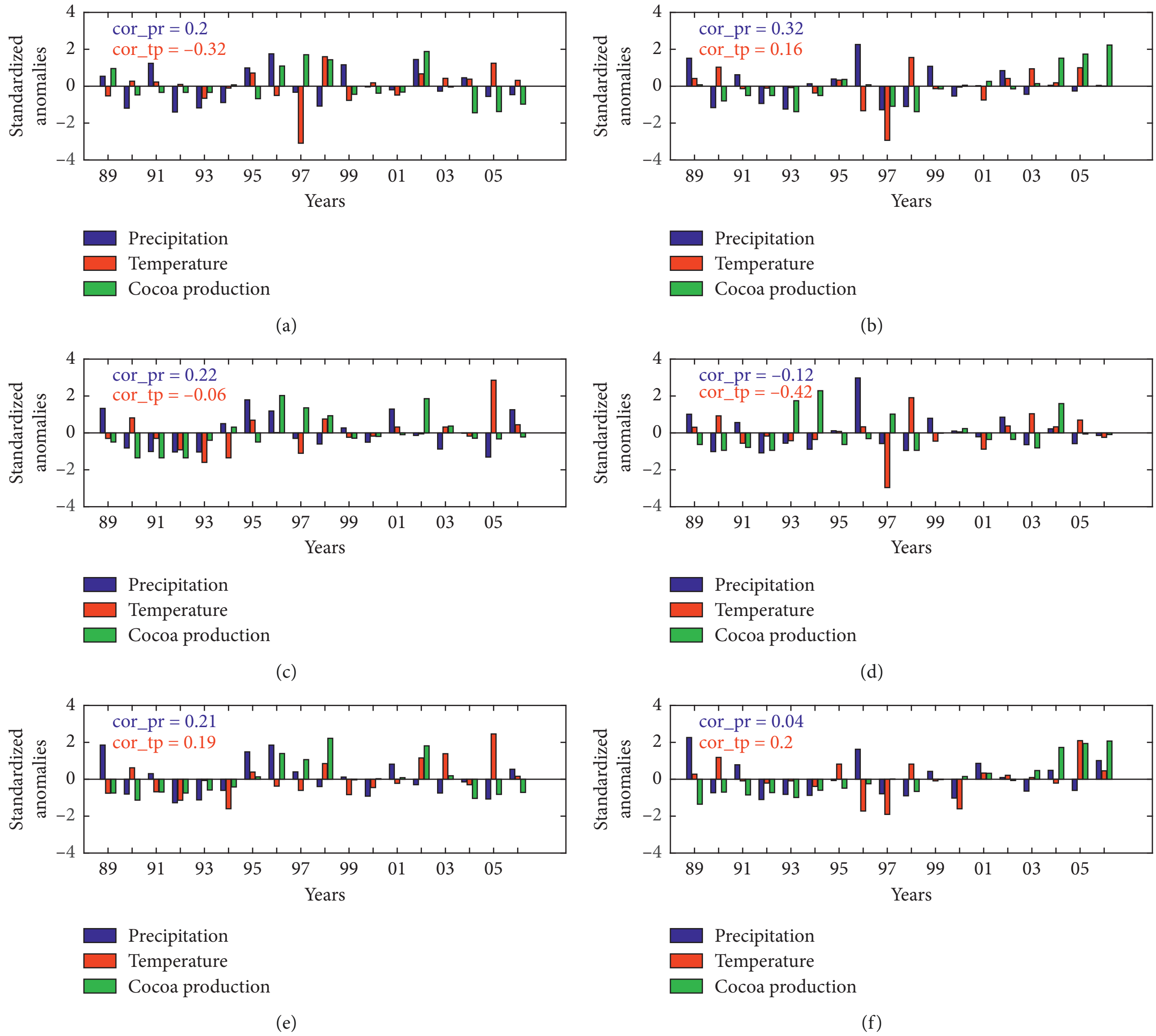

Figure 5: Standardized anomalies of rainfall of the little dry season, temperature, and cocoa production in the six departments from 1989 to 2006. The correlation coefficients between cocoa production and rainfall (blue) and temperature (red). (a) Abengourou. (b) Agboville. (c) Daloa. (d) Dimbokro. (e) Guiglo. (f) Soubré.

soil moisture, soil types, etc., which are beyond the scope of this work. The statistical analysis by Fisher–Snedecor and Student's t-test (Tables 2 and 3) show that only ΔP_{rs} and ΔP_{ds} variables have significant impacts in the estimated cocoa productions in Agboville, Daloa, and Guiglo for an 80% confidence level. The influence of precipitation on cocoa production was shown in the East Central region of Côte d'Ivoire in several studies [23, 36, 38]. These works noticed an important interannual variability of cocoa production due to a decreasing and an irregular spatial distribution of the rain. Thus, they concluded that the seasonal rainfall distributions remain one of the key factors influencing the cocoa production. On the other hand, the low values of the correlation coefficient between the cocoa yield and the rainfall of the little dry season imply that this seasonal rainfall cannot accurately describe the year-to-year variability of the cocoa production.

The Student t-values of the temperature are less than 1.34 in all departments, so this parameter seems to have negligible impacts on cocoa production during the 1989–2006 period. In addition to the different impacts of the rainfall, temperature has comparative influence on cocoa production, which changes from one location to another. For instance, in Guiglo, Agboville, and Soubre, the cocoa production increases with the temperature while in the other departments, a rise of the temperature tends to inhibit the cocoa yield. The relative lower values of the correlation coefficients between the temperature and the cocoa production suggest negligible impact of the temperature. This is mainly attributed to the range of values of the temperature, which fluctuates between 25 and 29°C. This range of values is a favorable condition for a good yield of cocoa and its growth [29]. Moreover, temperature is identified to have a more significant impact on crops [39].

Table 1: Multiple regression coefficients applied to the explanatory variables (i.e., precipitation and temperature) and the explained variable (i.e., cocoa production) for each studied department over the 1989–2006 period.

Areas	Correlation coefficients and degree of freedom			Coefficients of the explanatory variables of the constant b			
	r^2	F	df	b	m_1	m_2	m_3
Aben	**0.175**	0.989	14	$2.5E+5$	29.79	32.53	$-7.9E+3$
Agbo	**0.169**	0.951	14	$-0.15E+5$	−7.09	16.13	$1.1E+3$
Daloa	**0.181**	1.030	14	$7.7E+5$	106.8	64.05	$-28.5E+3$
Dimb	**0.055**	0.273	14	$30.8E+5$	−86.31	−321.9	$-10.5E+4$
Guigl	**0.263**	1.665	14	$-5.3E+5$	86.28	56.92	$19.2E+3$
Soub	**0.063**	0.314	14	$-25.8E+5$	116.3	26.01	$100.7E+3$

Table 2: Statistic of the Fisher–Snedecor test.

Areas	R^2	F	V_1	V_2	P value
Abengourou	**0.175**	**0.989**	3	14	**0.426**
Agboville	**0.169**	**0.951**	3	14	**0.442**
Daloa	**0.181**	**1.030**	3	14	**0.409**
Dimbokro	0.055	0.273	3	14	0.843
Guiglo	**0.263**	**1.665**	3	14	**0.219**
Soubre	0.063	0.314	3	14	0.815

$F = r^2V_1/V_2\ (1-r^2)$; $V_1 = n - \mathrm{df} - 1$; $V_2 = \mathrm{df}$. n is the observation number ($n = 18$), df is the number of degree of freedom (df = 14), P is the probability for which the R^2 values will be an artifact with a 95% confidence interval, and F is the Fisher coefficient.

Table 3: Statistic results of the Student's t-test.

Areas	ΔP_{rs}	ΔP_{ds}	ΔT
Abengourou	0.81	0.62	0.94
Agboville	0.72	**1.50**	0.40
Daloa	**1.48**	0.76	0.82
Dimbokro	0.19	0.49	0.64
Guiglo	**1.75**	1.15	0.56
Soubre	0.56	0.12	0.80

ΔP_{rs} is the rainfall amount of the main rainy season, ΔP_{ds} is the rainfall amount of the dry season, and ΔT is the growing season average temperature. The bold numbers are the $t > t_c = 1.34$ values with an 80% confidence level.

An exposure to important heat especially during the growing season may considerably damage crop production. The rise of the temperature leads to an increasing evapotranspiration, which produces a considerable reduction in water available for crop even with an associated augmentation in rainfall amount. Besides, Lobell and Burke [40] showed that the most critical need for agriculture in terms of climate change impact assessments and adaptation efforts is the strengthening of knowledge about crop respond temperature and the magnitude of regional temperature change.

5. Conclusions

This study assessed the meteorological constraints for cocoa production in Côte d'Ivoire and, more specifically, in six cocoa production departments. The statistical analysis helped to determine the key meteorological parameters impacting the cocoa production in each of the department of interest. The results show that rainfall amount and its seasonal distribution are the most influencing factors for cocoa production. Temperature impacts on cocoa production are not negligible although they were not significant during the 1989–2006 period. This is mainly due to the narrow range of variation in the temperature (25°C–29°C) in between favorable conditions for cocoa production. For example, in Abengourou, Daloa, and Dimbokro, an increase of the temperature results on a decrease in the cocoa production. In addition, temperature plays a vital and well-known role in evapotranspiration and water demand. It thus significantly affects growing seasons, water requirements, and strategies to assure the availability of water to fulfill the demand. Lobell and Burke [40] and Ochieng et al. [37] underlined that uncertainties related to temperature represented a greater contribution to climate change impact uncertainty than those related to rainfall system for most crops and regions. The cocoa environment needs ecological and pedological conditions, which are beyond the scope of the current study, and none of them could be considered independently. The linear model represented by equation (1) describes the relationship between meteorological conditions and cocoa production. Thus, the calculated determination coefficient values indicate that this linear model using growing season temperature, seasonal rainfall, and the nonlinear terms related to precipitation and/or temperature explains only a part of the cocoa yield variation (less than a third of variations) in a given region. However, this present result also show that the cocoa culture could be subject to combinations of stress factors that affect its yield or could respond nonlinearly to changes in its development conditions and/or exhibit threshold responses. Taking into account other climate variables, such as the relative humidity, wind speed, and sunshine, and nonclimatic factors, such as planted area, number of the vegetative cycle, soil moisture and soil types, is useful to predict majority change in cocoa production in the context of the climate variability and changes.

Data Availability

The cocoa, rainfall, and temperature data used to support the findings of this study were supplied by SODEXAM and ex-CAISTAB under license and so cannot be made freely available. Requests for access to these data should be made to Laboratory of Atmosphere Physic and Fluids Mechanic (LAPA-MF) of the University Felix Houphouet-Boigny of Abidjan, 22 BP 582 Abidjan 22.

Conflicts of Interest

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

Acknowledgments

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