Impacts of Variation in Climatic Extremes on Sugar Cane Production in the Sugar Complexes of Ferkessedougou (Northern Côte d'Ivoire)

Gla Blaise OUEDE, Affoué Berthe YAO Epse TOURE, Kouakou Valentin KOFFI, Kouakou Lazare KOUASSI

***Abstract**: The risks due to climate change heavily affect the Ivorian agriculture sector. This study aims to analyse the influence of extreme climatic parameters on sugar cane yield in the sugar complexes of Ferkessedougou. The methodological approach is based on redefining the agricultural season using the R-Instat software, and the correlation between extreme climatic parameters and sugar cane production is determined through statistical tests. The start date of the rainy season is on average May 28 in Ferkessedougou and June 4 in Korhogo, with standard deviations of 11 to 18 days. Early starts appear on May 15 for both stations, while late starts oscillate between June 30 and July 22 from 1989 to 2018. In the Ferke complexes, the rainy season lasts on average between 150 and 157 days. Late end dates are observed between November 19 and 21. The analysis of the correlation between the extreme climate indices and sugarcane yield shows coefficients of determination ranging from 46% to 67%. Also, the correlation matrix supports linear regression, confirming that the number of days of the year with precipitation ≥ 20 mm (R20 mm index) negatively influences sugar cane yield. Thus, it appears that any increase in one day of very intense rain systematically leads to a reduction in yield of 1.39 t/ha. Likewise, any increase in one consecutive dry day (CDD index) systematically leads to a decrease in 0.12 t/ha yield. Thus, this study has demonstrated that precipitation and different temperature forms can impact sugarcane yields in sugar fields. Knowledge from climatology can support informed decision-making at all levels of society.*

***Keywords**: Climatic Extremes, Côte d'Ivoire, Growing Season, Indice Climate, Yield of Sugar Cane.*

Abbreviations:
CDD: Consecutive Dry Day
AFD: Agency French Development
SUCAF-CI: Sucrerie of Afrique-Côte d'Ivoire
PCA: Principal Component Analysis

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I. INTRODUCTION

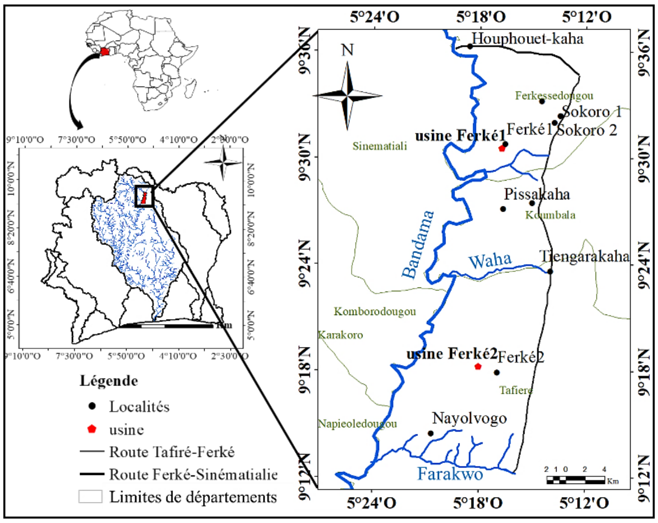
The depletion of water resources constitutes a potential major threat to the environment and economic activities [1]. The main factors responsible for this situation include the natural uncertainties observed in the climate [2] and the anthropogenic activities of a growing population [3]. Indeed, the successive periods of drought since the 1970s have led to waves of famine in West Africa, resulting in the loss of harvests and the decimation of livestock [4]. Like the countries of West Africa, the impacts of climate change have been strongly felt in Côte d'Ivoire, as its economy is primarily based on rainfed agriculture and has a strong dependence on river water resources used for agricultural and industrial production, as well as drinking water. This is the case of Sucrerie of Afrique-Côte d'Ivoire (SUCAF-CI), an agro-industrial company located in the departments of Ferkessedougou and Tafiré, in the north-east of Côte d'Ivoire. This company draws water from the Bandama River for the irrigation of sugarcane crops, the sugar manufacturing process, and domestic needs through two water reservoirs (Morrison and Lokpoho), which were built to support the water supply to the sugar farms of Ferkessedougou. In recent years, managers of sugar farms have experienced enormous difficulties in meeting their water needs due to the decline in the flow of the Bandama River and the drying up of water reservoirs [5]. This rapid drying up of water reservoirs and the deposits of silt observed at the bottom of the water reservoirs show signs of siltation and therefore a reduction in the capacity of the reservoirs [6]. However, sugar cane is one of the rare agricultural raw materials that can be produced in practically all climates. The variation in climatic factors is not without consequences on the production of sugar cane [7]. Thus, a pilot project, financed by the French Development Agency (AFD), is currently being implemented to assess the relevance of implementing climate information systems for the sugar cane sector in the Republic of Côte d'Ivoire. Furthermore, climate change scenarios indicate that climate variability will increase and intensify over the coming decades [8]. Recognising that water scarcity is a significant factor in reducing sugarcane productivity. This study aims to analyse the impact. of extreme climatic parameters on sugarcane yield to provide a database of climate information to improve sugarcane productivity [9].

II. MATERIALS AND METHODS

A. Presentation of the Study Area

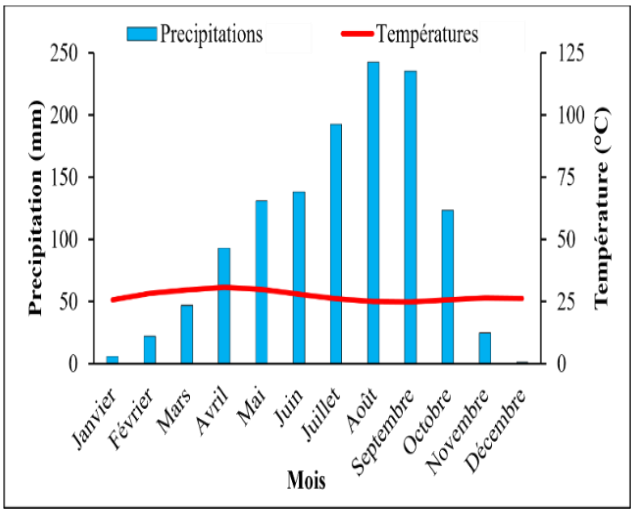
The Ferkessedougou sugar complexes are located in northern Côte d'Ivoire between longitudes 5°12' and 5°24

West and latitudes 9°12' and 9°36' North. They are limited in the Western part by the Bandama River; in the east by the departments of Koumbala and Tafiré; in the South by the Farakwo River; and in the South by the Farakwo River and in the North by the Ferkessedougou department, presented by (Figure 1):



[Fig.1: Location of the Ferkessédougou Sugar Complexes]

The climate at the two sugar complexes is the tropical transition regime characterised by two seasons [9]: a rainy season from April to October with average monthly precipitation between 127.6 and 248 mm, a dry season from November to March with average monthly rainfall ranging from 1.9 mm to 49 mm. The mean monthly temperature varies from 25°C in August to 29°C in April (Figure 2).



[Fig.2: Ombrothermal Diagram of the Ferke 2 Station Over the Period 1999-2019]

The Ferkessedougou sugar complexes, known as SUCAF-CI, were established in 1997 following the restructuring and privatisation program of the Ivorian sugar sector. SUCAF-CI comprises two sugar refineries (Ferke 1 and Ferke 2) located 40 km apart. Sugar is manufactured from sugar cane grown on industrial plantations (12,000 ha) and village plantations (2,500 ha).

B. Data

The data used are climate and sugar cane production data. The climatic data are daily rainfall and temperatures from SUCAF-CI and SODEXAM from 1989 to 2018. The production data are plots of non-irrigated sugar cane (rain cane) from the campaigns from 2006 to 2018.

C. Methods

C.1 Redefinition of the Sugar Cane Growing Season

The start and end dates of the rainy season were determined based on agronomic criteria defined in the R-INSTAT software. Three criteria are considered in defining the start of the rainy season [10]. The occurrence of a wet sequence of n days receiving:

- A quantity of rain of x mm without recording in a period of k following days,
- A dry sequence of k days is critical for the survival of seedlings.

The standardized criteria in Ivory Coast are [11].

- Wet sequence required for 2 days,
- Required rainfall threshold corresponds to 20 mm,
- Dry sequence less than or equal to 7 days followed,
- A control period (k) of 30 days.

Indeed, 20 mm of rain is the theoretical quantity of water necessary for the germination of an annual plant. Based on [12] A frequency study helps assess the growing season's start and end dates. Season start and end dates are ranked based on boundaries defined by the bottom quartile (20%), middle quartile (50%), and top quartile (80%). They are considered early if dates are less than or equal to the lower quartile cutoff value. On the other hand, when they are greater than or equal to 80%, they are late. Finally, when they are between 20% and 80%, they are called "normal".

• The difference between the end date and the start date of the rainy season expresses the length of the rainy season.

C2 Determination of the Correlation Between Variation in Climatic Extremes and Sugarcane Production

- *Characterisation of Climatic Extremes*

The characterisation of climatic extremes was done using the RClimDex program [13]. Fifteen (12) indices, including seven extreme temperature indices and eight extreme precipitation indices (Table I), were calculated over the period 1989-2018 [6].

Table I: Basic Equations of the RClimdex Software for the Indices to be Determined

Identification	Equations
Precipitation	
PRCPTOT	PRCPTOT = ∑annual RR
RX1Day	RX1Day = max (RR/1 day)
RX5Day	RX5Day = max (RR/5 day)
R95p	R95p = daily ∑RR with RR > 95th percentile
Fixed-term contract	CDD = max (consecutive days) or RR < 1mm
CWD	CWD = max (consecutive days) or RR > 1mm
R10	R10 = ∑days or RR ≥ 10 mm
R20	R20 = ∑days or RR ≥ 20 mm
Temperatures	
TXx	TX_X = monthly max (maximum daily temperatures)
TNx	TN_X = monthly max (minimum daily temperatures)
TXn	TX_N = monthly min (maximum daily temperatures)
TNn	TN_N = monthly min (minimum daily temperatures)
WSDI	WSDI =∑at least six consecutive days or TX > 90th percentile
CSDI	CSDI = ∑at least six consecutive days or TX < 10th percentile
DTR	DTR = annual average of ∑ (T_X -T_N)

With RR=daily precipitation;
TX = maximum temperature
and TN = minimum temperature.

- *Multiple Linear Regression*

The approach initially consisted of conducting a Principal Component Analysis (PCA) to identify the extreme climatic parameters that influence sugar cane yield. At the end of the PCA, the indices that strongly correlated with the yield were used to carry out a linear regression model, confirming the correlation between these indices and the sugarcane yield. To achieve this, we conducted a multiple linear regression analysis, a statistical method designed to highlight the influence of various rainfall and temperature indices on the production trend observed during the 2006-2018 campaigns. In other words, it statistically evaluates the sources of variation in sugarcane yield (ΔY) about the chosen predictors (ΔXi). The evolution of the sugarcane yield (ΔY) of the Ferke complexes is translated by the following equation:

$$\Delta Y = \sum mi * \Delta Xi + b\,I \qquad (1)$$

Where: $\mathbf{\Delta Y}$ represents the sugar cane yield, $\boldsymbol{mi}$: the sugarcane yield sensitivity (the regression weight) about the variables $\boldsymbol{\Delta Xi}$. $\boldsymbol{\Delta Xi}$ represents climatic indices, and b reflects potential nonlinear effects of variables $\boldsymbol{\Delta Xi}$, such as those resulting from interactions with other variables. To quantitatively estimate the rate of variance between sugarcane yield and extreme climatic indices, statistically significant trends for marginal significance levels (p-value) < 0.05, i.e. significance at threshold 95%, were defined [14].

III. RESULTS AND DISCUSSION

A. Start and end Dates of the Rainy Season

Analysis of the results shows that the start date of the rainy season is on average May 28 in Ferke and June 4 in Korhogo, with standard deviations of 11 to 18 days. Early starts appear on May 15 for both stations, while late dates oscillate between June 30 and July 22 from 1989 to 2018. Late end dates are observed between November 19 and 21. Regarding the end, it should be noted that the earliest ones appear on November 1 for both stations (Table II).

B. Length of the Rainy Season

The duration of the rainy season varies in time and space (Table III). It lasts on average 157 days, with a standard deviation of 22 days in Ferke, and 150 days in Korhogo, with a standard deviation of 26 days. In the sugar complexes of Ferke, we observe that the rainy season lasts approximately 5 months. In Korhogo, this duration is 150 days or 5 months. The minimum durations are between 111 days in Ferke and 102 days in Korhogo. The maximum duration of the rainy season is between 182 (Korhogo) and 189 days (Ferke).

Table II: Season Start Dates Over the Period 1989-2018

Station	Minimum	20%	Average	50%	80%	Maximum	Standard Deviation
Start of the Rainy Season							
Ferké	May 15th	May 20th	May 28th	May 25th	June 2nd	June 30th	11
Korhogo	May 15th	May 23rd	June 4th	May 31st	June 9th	Jul 22nd	18
End of the Rainy Season							
Ferké	1 Nov 1st	1 Nov 1st	9 Nov 9th	8 Nov 8th	1 Nov 15th	2 Nov 21st	7
Korhogo	1 Nov 1st	1 Nov 1st	7 Nov 7th	6 Nov 6th	1 Nov 12th	1 Nov 19th	7

Table III: Duration of Rainy Seasons (Days)

Station	Minimum	20%	Average	50%	80%	Maximum	Standard Deviation
Ferké	111	139	157	161	175	189	22
Korhogo	102	133	150	154	168	182	26

C. Relationship Between Extreme Climatic Parameters and Sugarcane Yield

The analysis was carried out on the first two dimensions. The 1-dim two-couple alone reflects most of the inertia of the data set (Figure 3). The graphs show that there is a correlation between the index of consecutive dry days (CDD) and the index of intense rainy days (R20 mm) and the yield of sugarcane (Figure 3A). Extreme temperature indices do not affect sugarcane yield (Figure 3B). In Figure 3C, the position on either side of the sugar cane yield and the R20 mm index shows they are inversely linked. In other words, precipitation greater than 20

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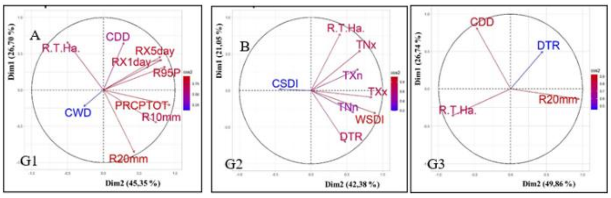
mm negatively impacts sugar cane yield.



[Fig.3: Correlation Circles of Groups of Variables]

The different models, as translated by the linear equations presented in Table IV, show the statistical relationships between yield and climatic indices. The results of Equations 3 to 6 express the quality of the regression because their p-value is < 0.05. The analysis of these regression equations highlights the following points:

The number of days of the year with precipitation ≥ 20 mm (R20 mm index) is negatively correlated (r = 0.71; p-value = 0.0039) with yield. This could explain a drop in yield during stormy days during the cane maturation phase.

The results have improved significantly for linear models with three variables. As a result, equations 4 and 5 explain nearly 67% (r = 0.82; p-value = 0.0016) and almost 46% (r = 0.69; p-value = 0.01) of the yield variance, respectively.

Equation 6 expresses 63% (r = 0.79; p-value = 0.0069) of the variance in yield.

Table IV: Correlation Between Performance and Indices Using the Regression Method

	Linear Equations	R2 -	P-Value
1	Yield=-0.0012*CDD+46.35 (2)	0.09	0.98
2	Yield=2.51*DTR+77.23 (3)	0.026	0.42
3	Yield=-1.39*R20mm+77.104 (4)	0.5	0.0039
4	Yield=-1.84*R20mm-0.12*CDD+97.69 (5)	0.67	0.0016
5	Yield=-1.36*R20mm-0.64*DTR+84.42 (6)	0.46	0.01
6	Yield=-2.51*DTR-0.0026*CDD+77.48 (7)	0.63	0.0069
7	Yield= = 1.83*R20 mm-0.11*DTR-0.12*CDD+98.93 (8)	0.129	0.74

D. Discussion

The analysis of the start and end dates of the rainy season at the Ferke sugar complexes reveals that there are early starts, which occur from May 20th onwards, at both stations. The latest starts appear between June 2nd and 9th. Regarding the end of the rainy season, the results showed that the rains stop in November. A late end can be observed between November 19th and 21st. The start dates of the season are more variable than the end dates of the rainy seasons. This corroborates findings of the authors [15] In the Bandama watershed. The variability of dates (start and end) has a significant influence on the length of the seasons.

In the Ferke complexes, the rainy season lasts on average between 150 and 157 days. These results are in opposition to those of [15] who found an average rainy season length of 175 to 197 days. We therefore observe a shortening of the seasons. Indeed, when the rainy season starts early, it tends to last longer. On the other hand, when the rain begins late, the rainy season is considerably shortened.

The analysis of the correlation between extreme climatic indices and sugarcane yield presents coefficients of determination varying from 46% to 67%. These coefficients are much more significant for two-variable models involving the indices (DTR and CDD) or (R20 mm and CDD). However, unlike the other indices, the index of very intense rainy days (R20 mm index) alone expresses 50% of the variation in yield. Indeed, this study reveals a negative correlation between the index of very intense rainy days and yield, demonstrating that the increase in R20 mm reduces efficiency. Indeed, during the pre-growth phase, too much precipitation can affect the development of the plant when drainage is ineffective [15]. These results align with those of the authors, who demonstrated that climatic factors influence the plant's biological processes and impact the yield of industrial plantations. Others [16] Specify that the lack of water is very harmful, particularly during the plant growth phases, but remains favourable to the accumulation of sucrose in sugarcane. They emphasise that a moderate water supply is recommended in pre-ripening, while the regular supply is in tillering field crops.

Temperature also appears in specific yield study models [17]. If the increase in this is often considered beneficial for sugarcane [7] Some consider that this relationship is quadratic: temperatures above 35°C can alter the growth of the plant [18]. However, in Ferke 2, the average temperature of the hottest month has consistently been above 35°C, reaching 38°C in certain years. Thus, this study demonstrated that precipitation and various forms of temperature are all factors that can impact the yield of sugar cane in sugarcane areas.

IV. CONCLUSION

This study aims to analyse the influence of the variability of climatic extremes on the production of sugar cane in the sugar complexes of Ferkessedougou (SUCAF-CI). Analysis of the results shows that the start date of the rainy season is on average May 28th in Ferke and June 4th in Korhogo, with standard deviations of 11 to 18 days. Early starts appear on May 15th for both stations, while late dates oscillate between June 30th and July 22nd from 1989 to 2018. Late end dates are observed between November 19th and 21st. Principal Component Analysis (PCA) in conjunction with multiple linear regression revealed the various indices that influence performance. At the end of this work, it should be noted that the number of days of the year with precipitation ≥ 20 mm (R20 mm index) alone expresses 50% of the yield variability. Thus, it appears that any increase in one day of very intense rain systematically leads to a reduction in yield of 1.39 t/ha. Likewise, any increase in one consecutive dry day (CDD index) systematically leads to a decrease in 0.12 t/ha yield. These results suggest that extreme climatic events have a significant impact on sugarcane yield.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** Each author contributed individually to the article. Gla Blaise OUEDE analyzed the data and wrote the manuscript; Affoué Berthe YAO Epse TOURE and Kouakou Valentin KOFFI assisted in preparing the manuscript and reviewing the document; and Kouakou Lazare KOUASSI supervised the study.

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