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Influence of Climate on Sugarcane Yield in Côte d'Ivoire: Case of the Ferkessédougou Region

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Abstract

This study aims to understand the current climatic trends and explain the possible losses of agricultural yields. To achieve this objective, this work characterized the evolution of extreme temperature indices in the sugar complexes of Ferké 1 and Ferké 2, two stations located in the northern part of Côte d'Ivoire. The onset and cessation dates of the rainy season and the length of the rainy season were investigated. The agricultural and climatic data were obtained from each sugar complex. The period of study ranges from 2002 to 2019 in Ferké 1 and Ferké 2. The results show significant upward trends in extreme temperature indices. The analysis of sugarcane yield associated with the different climatic parameters shows no significant results in general. However, on the Ferkessédougou sugar complexes, the results highlight that maximum and minimum temperatures could be the variables that influence most yield production. The maximum temperature with coefficients of 1.60 and 0.77 at Ferké 1 and Ferké 2 respectively seems to contribute to an increase in yield while the minimum temperature with coefficients of −0.98 and −0.22 at Ferké 1 and Ferké 2 respectively could lead to a loss in yield. The results obtained with the Single Linear Regression (SLR) and the Multiple Linear Regression (MLR) models also highlight the strong influence of minimum and maximum temperatures.

Keywords

Onset and Cessation Dates, Duration, Rainfall, Temperature, Climatic Indices, Sugarcane Yield, Ferké 1, Ferké 2

1. Introduction

The climate change observed in recent decades is one of the major challenges for the scientific community both regionally and globally. While several studies have addressed the climate change issue in Côte d'Ivoire, few studies have focused on the region of Ferkessédougou preciously on the sugar complex. However, improving sugarcane yields requires a good understanding of the climate change impacts. Many complex processes and interactions determine crop responses to climate anomalies [1]. Climate extremes, such as droughts or heat waves, can lead to harvest failures and threaten the livelihoods of agricultural producers and the food security of communities worldwide [2]. Moreover, climate change is likely to have drastic effects agriculture sector, particularly in terms of managing the increase in frequency and intensity of extreme weather events [3]. Facing such situations, African countries whose economies generally depend on agriculture are strongly impacted. According to [4], sustainable agricultural development depends on human capability to manage the risks associated with extreme climate events. For this purpose, understanding climatic trends and assessing their possible impacts on crops is a major challenge for population resilience and the adaptation of agricultural practices [5]. [4] highlighted that different types of climate extremes are projected to intensify and become more frequent in several regions worldwide due to climate change.

In addition, knowledge of variation of rainfall onset, cessation and length of the growing season at both a national and international level is paramount, as many agricultural activities and planting for sustainable food yield depend on rainfall for land preparation, seed/ crop planting and harvesting [6]. For example, in Nigeria, [7] indicated that the irregularity of onset and cessation of the rainy season across many regions over the years had made it difficult for farmers to optimize the seed planting period and adjust to the length of the growing season. The resultant effect is the decrease of agricultural yield and increase in the risk of hunger. Another study [8] observed that a delay of 1 or 2 weeks in the onset is sufficient to destroy the hopes of a normal harvest while a false start of planting, encouraged by a false start of rainfall may be followed by prolonged dry spells which can last for two weeks or more, thus may be critical to plant germination and growth.

Despite all these risks and climatic forecasts, real studies on the evolution of climatic extremes and their impacts on the sugarcane on sugar complexes of Ferké have not been carried out.

This study is a contribution of the CLIMSUCAF project (2019-2021) on the provision of climate services to sugarcane cultivation in the Ferkessédougou sugar perimeters of SUCAF-CI (SUCrerie d'AFrique en Côte d'Ivoire). This project is intended to promote adaptation strategies to fight the adverse effects of climate change on sugarcane cultivation in Côte d'Ivoire.

This paper is organized in two sections as follows. The first section consists of analyzing climate extremes using the indices defined by the Expert Team on

Climate Change Detection and Indices (ETCCDI) in the sugarcane complex of Ferkessédougou. The use of climate extremes indices is identified as guidance in the assessments of weather extremes [9]. In the second section, this study evaluates the impact of onset date, cessation date and length of growing season on sugarcane and examines how these climate extremes impact the sugarcane yield as underlined by [2]. The authors indicated that the understanding of climate extremes impacts on crop yield in the past and present climate is crucial in order to secure and optimize yields in a changing climate.

2. Materiel and Methods

2.1. Study Area

The sugar complex of SUCAF-CI is located, at 15 Km from the town of Ferkessédougou and 42 Km from Korhogo city. They are located from 9˚20' to 9˚60' North latitude and between 5˚22' and 5˚40' West longitude. The altitude varies between 280 and 380 m above sea level and the amplitude of the individual topographic sequences is less than 70 m. The armor plateaus are the highest element of the sequence. The area is drained by Bandama riverbank tributaries (Lokpoho, Monongo, Waha, Farakwo) in a dendritic fashion [10] [11] [12] [13]. The rainfall regime is unimodal and centered on the months of August-September. In term of climate, it is tropical with two seasons: One dry, from November to April and the other humid, from May to October. The soils are predominantly ferralitic, and secondarily alluvial hydromorphic at the terraces of the Bandama River; they are derived essentially from igneous or metamorphic rocks of the base complex that have undergone periods of deep weathering, followed by erosion and dissection in past geological times [13]. The topsoil is shallow (40 to 60 cm) due to the presence of shells [14]. The average annual rainfall is 1200 ± 80 mm. The rainfall deficit to be met by irrigation to satisfy sugarcane water needs is on average close to 700 mm [15] (**Figure 1**).

2.2. Data

The daily climate data used in this work are collected from the climatological station of Ferké 1 and Ferké 2 sugar estate. Each station has approximately thirty (30) rain gauges for rain collection. The daily rainfall is obtained by averaging the quantity of rain recorded on all the rain gauges. As for the values of maximum and minimum temperatures, they are measured by maximum and minimum thermometers every five (5) hours. These data span over a period of 2002-2019 at daily timescale.

2.3. Methods

Statistical methods such as arithmetic mean, mean deviation, standard deviation and coefficient of variation were applied to establish the trends.

2.3.1. Arithmetic Mean

It is the mean of a set of n-numbers. It noted $\bar{x}$ and given as follows:

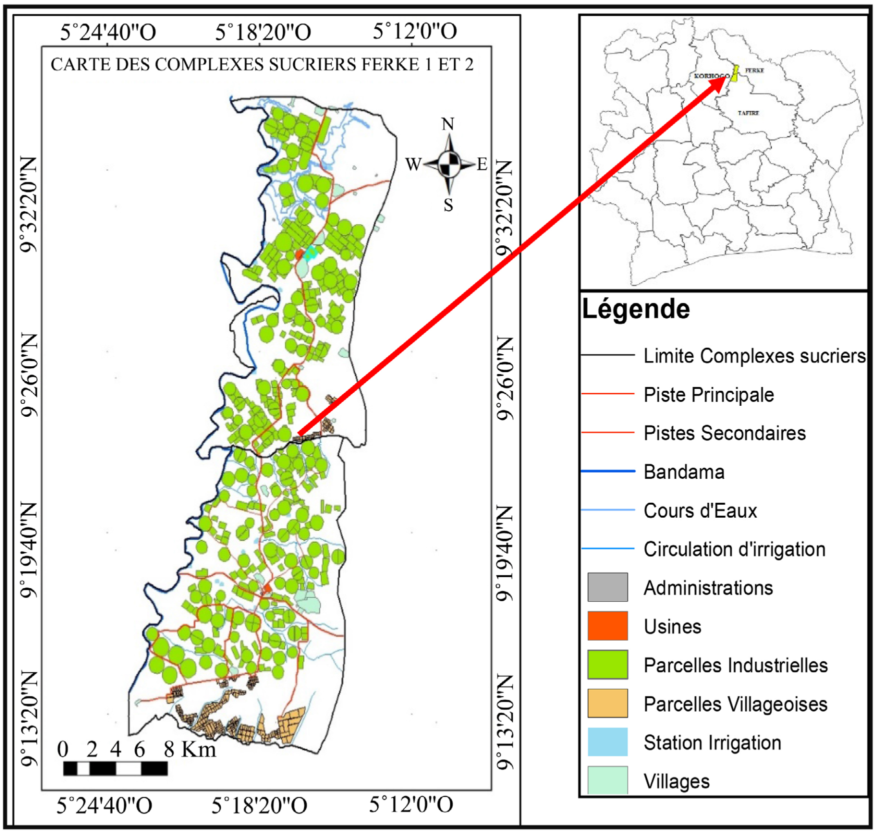

Figure 1. Study domain of sugarcane complexes in Ferkessédougou.

$$\overline{x} = \frac{\sum x}{n}$$

2.3.2. Mean Deviation

It used to measure the extent variability in the data set and given as follows:

$$\text{Mean deviation} = \frac{\sum(x - \overline{x})}{n}$$

where x = the element under study in day/month;

$\overline{x}$ = mean of the element.

n = set of elements.

2.3.3. Standard Deviation

Standard deviation is a measure of dispersion of a set of sample variables from the mean this, being a basis for measure of variability, served to collate information on the annual variation of rainfall in the study area

$$S = \sqrt{\frac{n\sum x^2 - \left(\sum x\right)^2}{n(n-1)}}$$

where S is the standard deviation;

x = the element under study in a day, in a month or a year;

n = number of days in a month or year for which element was measured.

2.3.4. Coefficient of Variation (C. V)

$$\mathrm{C.V} = \frac{S}{\overline{x}} \times 100$$

where C. V = Coefficient of Variation;

S = Standard deviation;

$\overline{x}$ = mean.

R Software version 3.4.3 was used for regression calculations based on observed climate variables. The new program associated with this software called RClimDex, version 1.0 was used for climate index calculations [16]. The latter software also allows detecting possible recording errors in daily data [17] [18]. The principle of this detection is as follows: any daily maximum temperature lower than the daily minimum temperature is replaced by −99.9. Additionally, any negative or missing precipitation values are replaced by −99.9 and daily data for a year cannot exceed 365 or 366 observations.

For each climate variable and index, the annual trend was identified using the linear regression method [19], while statistical significance was based on the Kendall criterion [20] [21]. This is a non-parametric test for detecting a trend over a long term climate time series. The smoothing curve is used to reduce irregularities and singularities. A trend is said to be significant when the p-value (probability) due to the error is less than or equal to 5% (0.05). The present study is based on 14 of 27 indices used by the software (**Table 1**).

Table 1. List of climatic indices for extreme daily temperatures used for the localities of Ferké 2.

Climate indices	Definition	Units
1. TXx	Highest maximum temperature	˚C
2. TX90P	Percentage of days when TX > 90th percentile	days
3. TX10P	Percentage of days when TX < 10th percentile	days
4. TXn	Lowest maximum temperature	˚C
5. TMAXmean	Mean maximum temperature	˚C
6. TNn	Lowest minimum temperature	˚C
7. TN90P	Percentage of days when TN > 90th percentile	days
8. TN10P	Percentage of days when TN < 10th percentile	days
9. TNx	Highest minimum temperature	˚C
10. TMINmean	Mean minimum temperature	˚C
11. WSDI	Annual count of days with at least 6 consecutive days when TX > 90th percentile	days
12. CCD	Maximum number of consecutive dry days	days
13. CWD	Maximum number of consecutive wet days	days
14. Prcptot	Annual total wet-day precipitation	mm

The coefficient of determination (r^2) measures the accuracy of the fit of the regression line to the observed data. Several climate indices used in the study of extreme events have been reported by the Expert Team on Climate Change Detection, monitoring indices to better characterize and understand climate change [22].

2.3.5. Identification of Rainfall Onset, Cessation and Length of the Growing Season

The timing of the onset of rains is an important issue in planning agricultural operations in West Africa. Several studies [23] [24] [25] [26] have shown that earlier crop establishment results in higher yields.

Assessment of the length of the growing season depends on knowledge of the onset of the rains. Various definitions of rain onset exist in the literature [27] [28] [29] [30]. To calculate the probabilities of a growing season of different durations for a given rainfall onset date, the Kolmogorov-Smirnov test for fitting a specified distribution the method of [31] was used. In our study, we used the agronomic criterion. The agronomic start must not be followed by dry spells of more than seven days. At least 20 mm of rainfall over 3 days must be recorded, with no dry episode exceeding 7 days in the following 30 days (to avoid false starts) and as an end of season date after 20 consecutive days without rain.

2.3.6. Relationship between Climatic Parameters and Sugarcane Yield in the Single Linear Regression Model

In this section, with Single Linear Regression, each climate parameter will be related to the yield in order to know its impact, and to establish a relationship between sugarcane yield and climatic parameters.

3. Results and Discussions

3.1. Results

The first results of the study consisted in analysis of trends of the climatic extreme parameters (rainfall and temperature trends). The second results consisted to analysis sugarcane yield trend. Then, the following relationships between different parameters are studied as follows: sugarcane yield and rainfall; sugarcane yield and maximum temperature; sugarcane yield and minimum temperature; sugarcane yield and length of growing season; sugarcane and onset; and sugarcane and cessation. Finally, multiple linear regression model involving sugarcane yield and the climatic parameters is assessed.

3.1.1. Analysis of Trends

Figures 2-4 show trends in climate parameters and p-values. The p-values and trends values are summarized in **Table 2**.

Analysis of TX90p and TN90 shows an increase in hot days and nights respectively of 1.290 days/year and 1.318 days/year in Ferké 1 and 1.349 days/year and 1.342 days/year in Ferké 2. However, analysis of TX10p and TN10p revealed a decrease in cold days and nights with trends of −0.587 days/year and −0.650

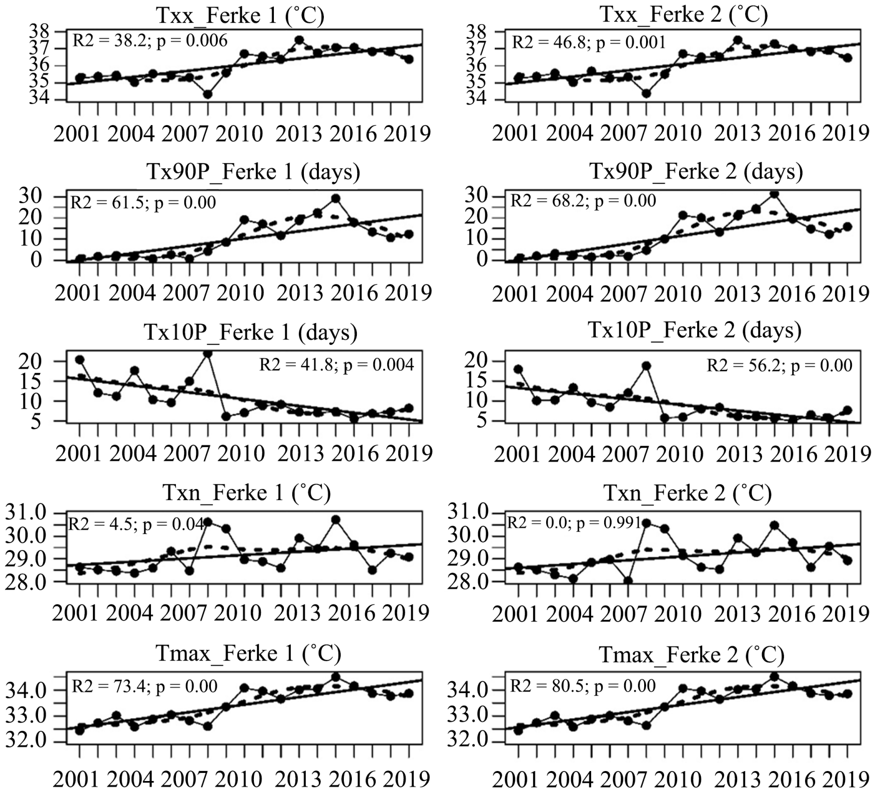

Figure 2. Time series of TXx, TX90P, TX10P, TXn and TMAXmean indices of Ferké 1 and Ferké 2.

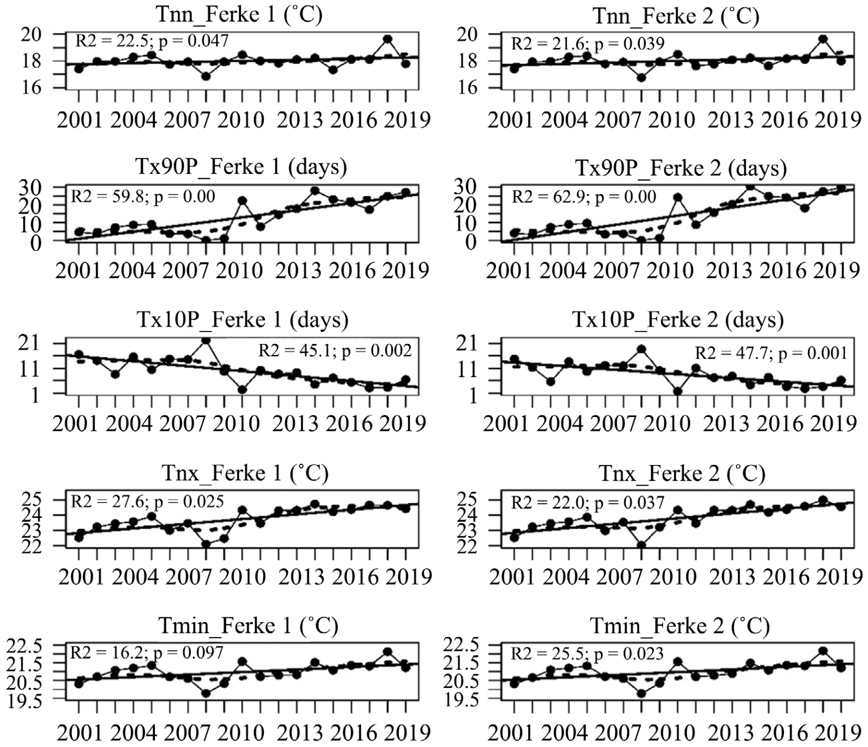

Figure 3. Time series of TNn, TN90P, TN10P, TNx and TMINmean indices of Ferké 1 and Ferké 2.

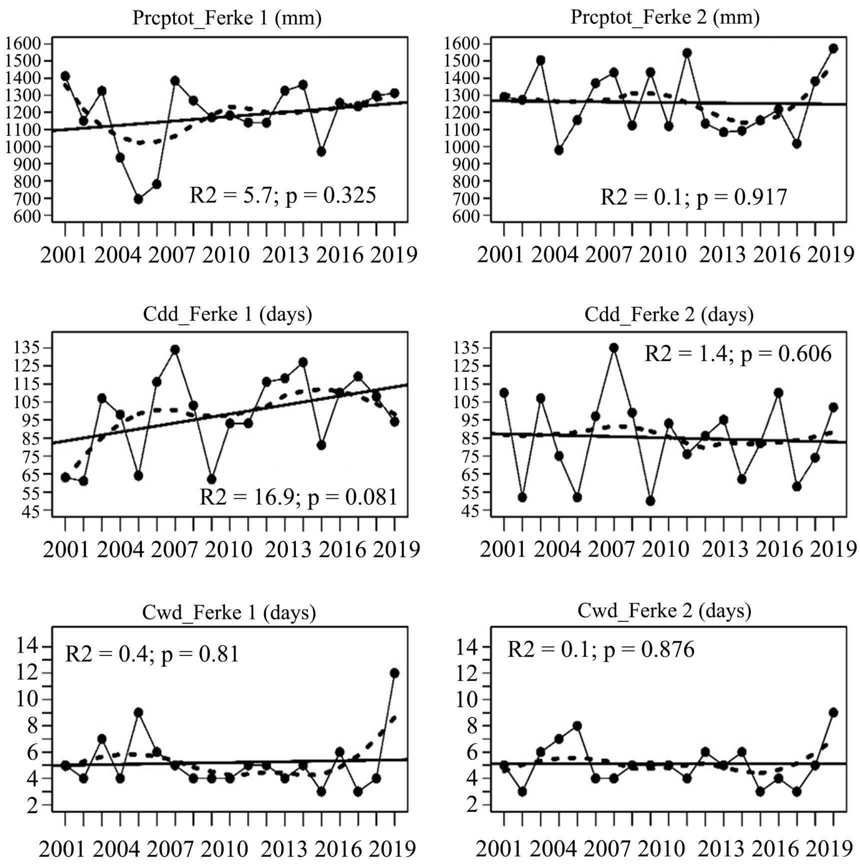

Figure 4. Time series of CDD, CWD and Prcptot indices for Ferké 1 and Ferké 2.

Table 2. Trend values and p-values of the climatic indices.

Climate indices	Ferké 1		Ferké 2	
	trend	p-value	trend	p-value
1) TXx	0.106	**0.01**	0.108	**0.00**
2) TX90P	1.29	**0.00**	1.349	**0.00**
3) TX10P	−0.587	**0.00**	−0.693	**0.00**
4) TXn	−0.064	**0.40**	−0.001	0.99
5) TMAXmean	0.104	**0.00**	0.111	**0.00**
6) TNn	−0.127	**0.04**	−0.109	**0.04**
7) TN90P	1.318	**0.00**	1.342	**0.00**
8) TN10P	−0.650	**0.00**	−0.650	**0.00**
9) TNx	0.117	**0.02**	0.094	**0.03**
10) TMINmean	0.035	0.09	0.040	**0.02**
11) CDD	1.665	0.08	0.486	0.60
12) CWD	0.023	0.81	0.009	0.87
13) Prcptot	8.499	0.32	−0.692	0.91

days/year respectively in Ferké 1 and −0.639 days/year and −0.650 days/year respectively in Ferké 2. It is worth noting that all these trends are significant with more of 95 % confidence level.

Number of consecutive of dry days (CDD) showed a not statistically significant increase of 1.665 days/year and 0.486 day/year in Ferké 1 and Ferké 2 respectively.

An increase of consecutive wet days (CWD) and annual total wet day precipitation (Prcptot) observed in Ferké 1 with respective values of 0.023 day/year and 8.499 mm/year. These trends are not statistically significant with p-values respective of 0.81 and 0.33. However, in Ferké 2, trends of consecutive wet days and annual total wet day precipitation are decreasing respectively of −0.009 day/year not statistically significant (p = 0.87) and −0.692 mm/year not statistically significant also (p = 0.92).

3.1.2. Sugarcane Yield Trend over Ferké 1 and Ferké 2

The curves of evolution and of trend of sugarcane yield over Ferké 1 and Ferké 2 for the period 2002-2019 is presented in **Figure 5**. The latter revealed that sugarcane yield over both complexes shows a slight upward trend. These trends were no significant with values 0.68 and 0.53 respectively in Ferké 1 and Ferké 2.

In Ferké 1, with a mean of 70.71 t/ha, a Coefficient of variation of 9.89%, a standard deviation of 6.99 t/ha, the lowest and highest values were observed in 2003 (48.48 t/ha) and 2014 (80.24 t/ha) respectively. With the exception of the year 2003 which recorded 48.48 t/ha, the yields for other years were between 65 and 81 t/ha.

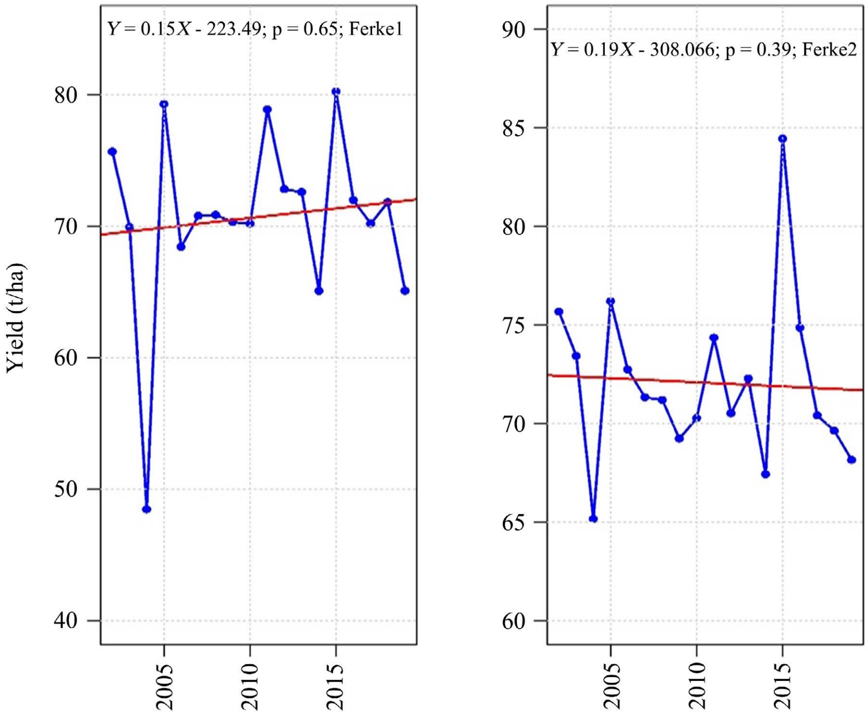

Figure 5. Yearly rainfall trend in Ferké 1 and Ferké 2 (2002-2019).

In Ferké 2, the mean of the yields observed was 71.86 t/ha. The Coefficient of variation was 5.96%, the standard deviation was 4.28 t/ha, the lowest value was 67.43 t/ha in 2019 and the highest value was 84.44 t/ha in 2014.

3.1.3. Relationship between Onset/Cessation Dates and Length of Growing on Sugarcane Yield

Figure 6 depicts the sugarcane yield as function of yearly variation rainfall onset on the period 2002-2019. Onset dates were early in some years while other years were late. On one hand, the mean onset date in Ferké 1 was 29th March with a coefficient of variation of 26% and a standard deviation of ±23 days. On the other hand, in Ferké 2, the mean onset date was 20th March with a coefficient of variation and standard deviation respectively of 29% and ±23 days. The 4th and 24th February were the earliest onset dates respectively in Ferké 2 and Ferké 1. The 24th and 29th April were the last onset date respectively in Ferké 1 and Ferké 2 on the period of study.

Some years showed early onset dates with low yields such as February 2004 in the both complex but other years had early onset dates with good yields such as February 2011 in Ferké 1 and February 2005 in Ferké 2. Similarly, some years presented late onset with good yields and sometimes low yields.

The sugarcane yield as function of yearly variation rainfall cessation on the period 2002-2019 is shown in **Figure 7**. The mean cessation date for the period of study was 23th and 26th October, with a coefficient of variation of 4% and 5% and a standard deviation of 10 and 13 days respectively in Ferké 1 and Ferké 2. **Figure 7** indicated that in Ferké 1, the earliest cessation date was 9th October 2017, and the last was 21st November 2014. In 2004 and 2014, the cessation dates

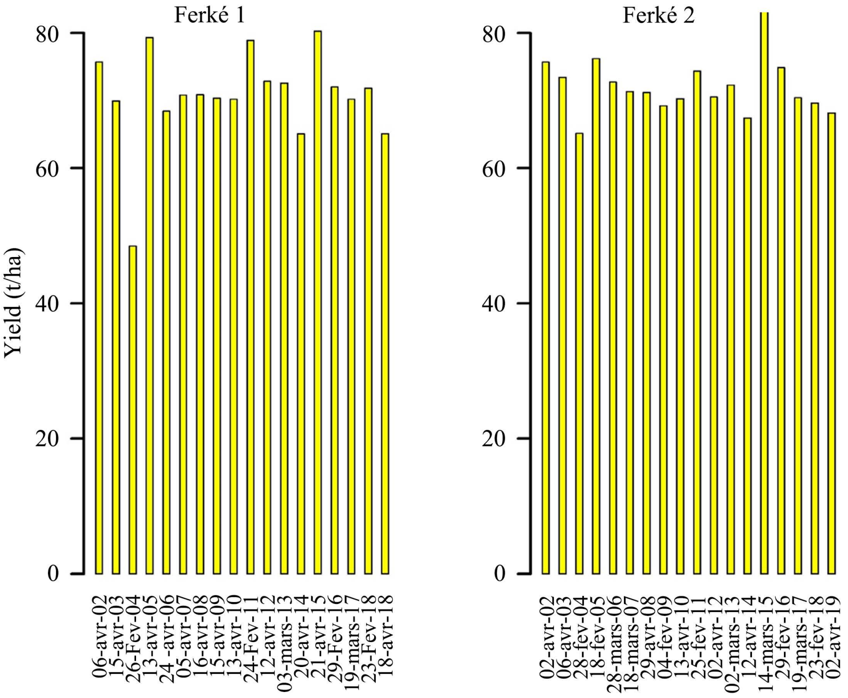

Figure 6. Yearly onset dates and yield of sugarcane in Ferké 1 and Ferké 2 (2002-2019).

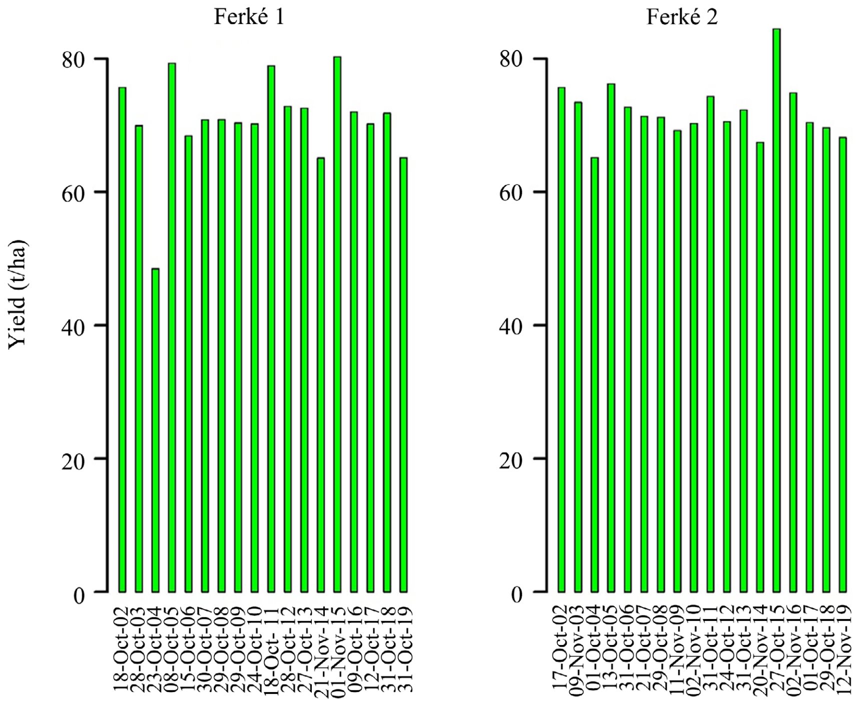

Figure 7. Yearly cessation dates and yield of sugarcane in Ferké 1 and Ferké 2 (2002-2019).

were respectively 23rd October and 21st November but both year registered low sugarcane yield. On the Meanwhile, in 2005 and 2015, the cessation dates were 08th October and 01st November and the sugarcane yield was high. In Ferké 2, the earliest cessation dates were 1st October 2004 and 2017, and the last was 20th November 2014 and both year had low yields.

Figure 8 presents the relationship between sugarcane yields and length of growing season in Ferké 1 and Ferké 2. It shows that the length of the growing season ranges from 175 to 251 days and 184 to 281 days respectively in Ferké 1 and Ferké 2. Out of 19 years of study, only 7 (2006, 2007, 2011, 2014, 2017, 2018 and 2019) showed a positive correlation between the yield and the length of growing season in Ferké1 and 10 years (2004 to 2008 and 2011 to 2017) showed a positive correlation in Ferké 2.

In general, a negative correlation ($r = -0.29$) between sugarcane yield and length of growing season is highlighted respectively in Ferké 1 and a positive correlation ($r = 0.13$) in Ferké 2 over the study period. The p-values are respectively 0.23 and 0.62 in Ferké 1 and Ferké 2.

Table 3 and Table 4 present a summary of onset/cessation dates and length of rainfall season respectively in Ferké 1 and Ferké 2.

3.1.4. Relationship between Climatic Parameters and Sugarcane Yield by the Single Linear Regression (SLR) Model

In the section, a statistical approach by Single Linear Regression (SLR) model was carried out involving sugarcane yield as the dependent variable and climatic parameters as the independent variables. The reason behind is to find the relationship between yield and climatic parameters.

Table 3. Rainfall onset dates, cessation and length of rainfall season in Ferké 1 (2002-2019).

Years	Onset	Cessation	Length of rainfall season (days)
2002	06-April	18-October	196
2003	15-April	28-October	197
2004	26-February	23-October	241
2005	13-April	08-October	179
2006	24-April	15-October	175
2007	05-April	30-October	209
2008	16-April	29-October	199
2009	15-April	29-October	198
2010	13-April	24-October	195
2011	24-February	18-October	233
2012	12-April	28-October	200
2013	03-March	27-October	239
2014	20-April	21-November	216
2015	21-April	01-November	195
2016	29-February	09-October	224
2017	19-March	12-October	208
2018	23-February	31-October	251
2019	18-April	31-October	197

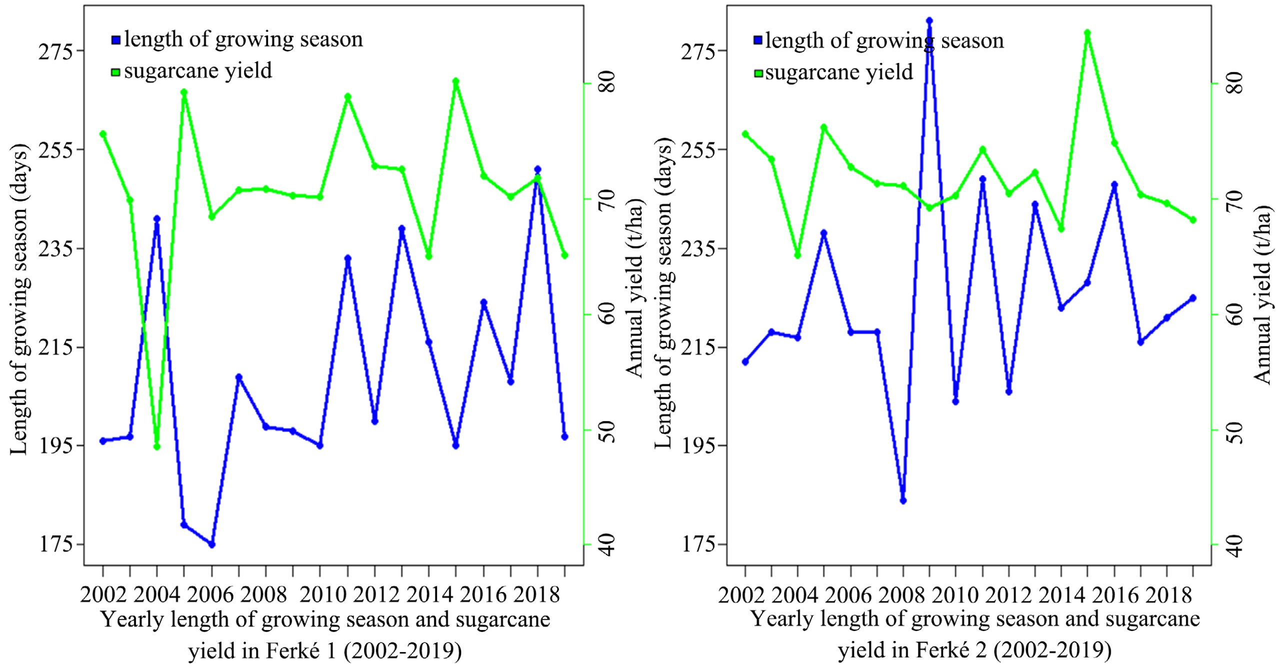

Figure 8. Relationship between sugarcane yield and length of growing season in Ferké 1 and 2.

Table 4. Rainfall onset dates, cessation and length of rainfall season in Ferké 2 (2002-2019).

Years	Onset	Cessation	Length of rainfall season (days)
2002	02-April	17-October	212
2003	05-April	09-November	218
2004	28-February	01-October	217
2005	18-February	13-October	238
2006	28-March	31-October	218
2007	18-March	21-October	218
2008	29-April	29-October	184
2009	04-February	11-November	281
2010	13-April	02-November	204
2011	25-February	31-October	249
2012	02-April	24-October	206
2013	02-March	31-October	244
2014	12-April	20-November	223
2015	14-March	27-October	228
2016	29-February	02-November	248
2017	19-March	01-October	216
2018	23-February	29-October	221
2019	02-April	12-November	225

Figure 9 intercompares the relationship between surgarcane yield and rainfall in Ferké 1 and Ferké 2. The latter shows a positive correlation between sugarcane yield and rainfall in both cases. For instance, in Ferké 1, with the p = 0.78, this result is not statistically significant and the coefficient of correlation is 6.81. In Ferké 2, the p = 0.67, the coefficient of correlation is 10.66%. The relationship between sugarcane yield and minimum temperature is presented in Figure 10. A negative correlation $r = -16.60$ and -1.87, between sugarcane yield and minimum temperature respectively in Ferké 1 and Ferké 2 is obtained. The calculated p value was 0.67 in Ferké 1 and 0.94 in Ferké 2. This indicates that it is not statistically significant.

The relationship between sugarcane and maximum temperature is assessed in Figure 11. The results revealed a weak positive correlation (16.18 and 11.16 respectively in Ferké 1 and Ferké 2). The p-value obtained were 0.52 (Ferké 1) and 0.65 (Ferké 2).

Table 5 and Table 6 summary the different values of the coefficients (a), constants (b), correlation (r) and p-value (p) between the yield and the extreme climate indices according to the following equation:

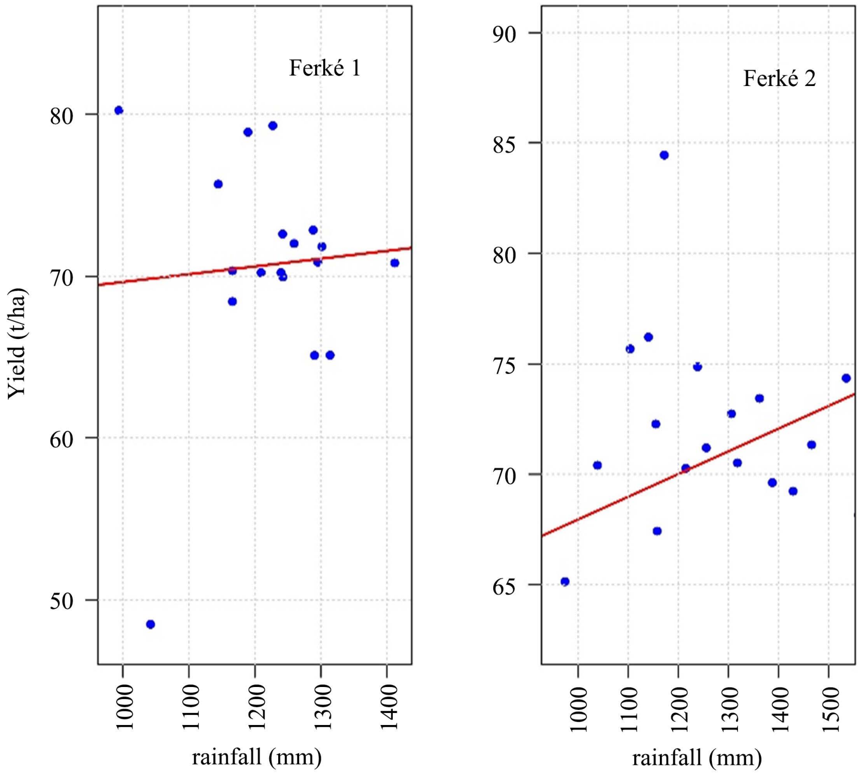

Figure 9. Relationship between sugarcane yield and rainfall in Ferké 1 and Ferké 2 (2002-2019).

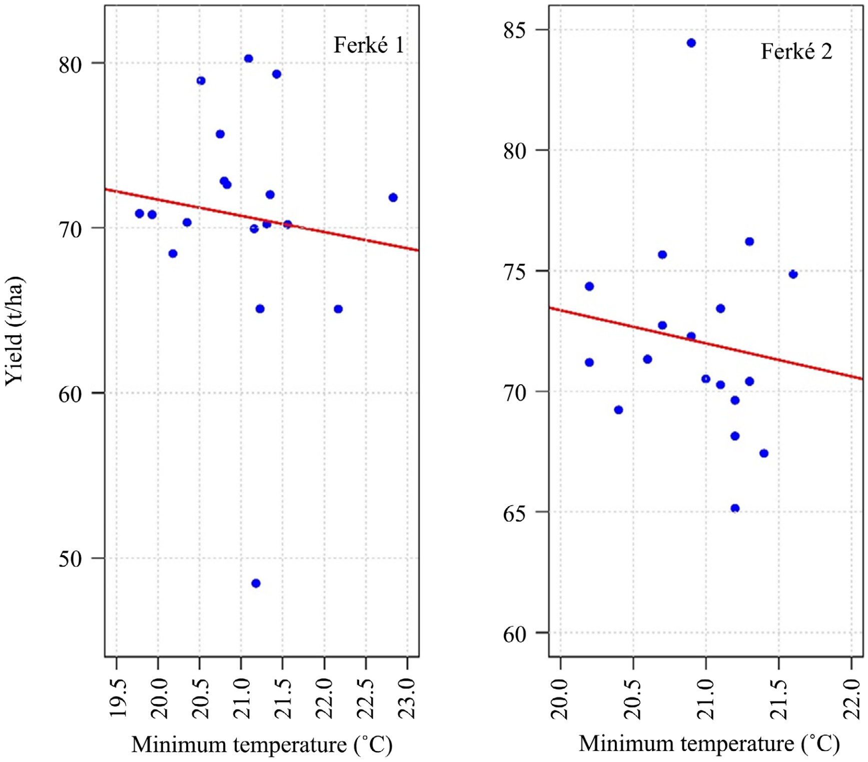

Figure 10. Relationship between sugarcane yield and minimum temperature in Ferké 1 and Ferké 2 (2002-2019).

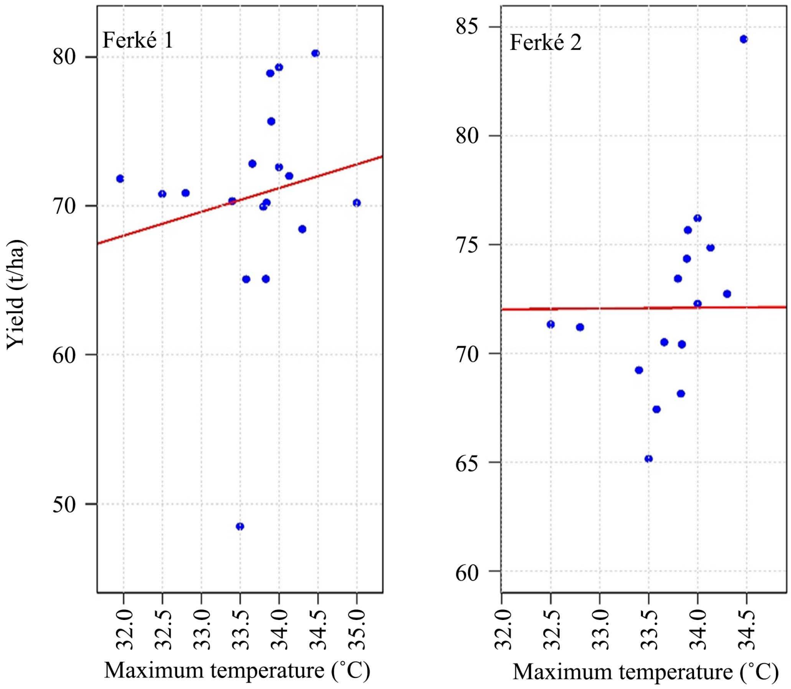

Figure 11. Relationship between sugarcane yield and maximum temperature in Ferké 1 and Ferké 2 (2002-2019).

Table 5. Coefficients of SLR model between yield and climate indices in Ferké 1 (2002-2019).

Indices	a	b	r	p-value
TXx	0.83	37.75	0.13	0.60
TX90P	0.21	68.47	0.25	0.30
TX10P	−0.54	76.09	−0.34	0.16
TNn	−0.47	76.35	−0.16	0.51
TN90P	−0.03	71.09	−0.04	0.88
TN10P	−0.20	72.58	−0.15	0.55
Sdii	−0.29	75.02	−0.11	0.65

Table 6. Coefficients of SLR model between yield and climate indices in Ferké 2 (2002-2019).

Indices	a	b	r	p-value
TXx	0.97	33.04	0.23	0.36
TX90P	0.04	71.10	0.23	0.35
TX10P	−0.03	71.27	−0.15	0.54
TNn	−0.03	71.19	−0.16	0.51
TN90P	−0.04	71.07	−0.22	0.37
TN10P	0.16	71.27	0.16	0.53
Sdii	−1.07	87.56	−0.04	0.87

$$Y = aX + b \tag{1}$$

where Y is the yield of sugarcane and X the concerned climate index.

3.1.5. Relationship between Climatic Parameters and Sugarcane Yield by the Multiple Linear Regression (MLR) Model

Another approach by Multiple Linear Regression (MLR) was used to highlight relationships between sugarcane yields (explained variable) and different climate parameters (*i.e.* minimum and maximum temperatures, rainfall and length of growing season). The coefficients of determination are 30% and 15% respectively in Ferké 1 and Ferké 2, the p-values are 0.23 and 0.62 respectively in Ferké 1 and Ferké 2. The followings equations are obtained:

$$Y_1 = -42.99 + 0.01Rain_1 + 5.88T_{\max 1} - 3.36T_{\min 1} - 0.11Lgs_1 \tag{2}$$

$$Y_2 = 46.94 - 0.01Rain_2 + 2.71T_{\max 2} - 2.98T_{\min 2} + 0.11Lgs_2 \tag{3}$$

where $Rain$, $T_{\max}$, $T_{\min}$ et Lgs are the rainfall, maximum temperature, minimum temperature and length of growing season respectively.

Equations (4) and (5) translate the relationship between sugarcane yield (Y_1 and Y_2) and extremes climate indices in Ferké 1 and Ferké 2. They are presented as follows:

$$\begin{aligned} Y_1 = 60.79 + 0.50T_{Xx} + 0.52T_{X90P} - 0.55T_{X10P} - 0.42T_{Nn} \\ - 0.55T_{N90P} - 0.10T_{N10P} - 0.45Sd_{ii} \end{aligned} \tag{4}$$

$$\begin{aligned} Y_2 = 79.57 + 0.30T_{Xx} + 0.09T_{X90P} - 0.60T_{X10P} - 0.25T_{Nn} \\ - 0.10T_{N90P} + 0.37T_{N10P} - 1.35Sd_{ii} \end{aligned} \tag{5}$$

3.2. Discussion

The results of this study show an increase in extreme temperature indices in both locations (Ferké 1 and Ferké 2). Previous work done by [32] in the Ferké 2 area has shown similar results these results are consistent with the findings of [33]. In fact, their work on climate change trends and indices in Northern Italy revealed a gradual increase in temperatures along with a decrease in cumulative precipitation. In addition, [34] showed a global warming that has been underway since the 1970s, followed by a decrease in snowfall. [35] reported drier climate trends in East Asia, Australia, South Africa and parts of South America. Also, the work reported by [36] emphasized a generalization of savannah in Ferkessédougou Department at a rapid rate since 1986. The results of our study are consistent with increasing hot temperatures trend in the regions in the tropics. Other works have shown that the Sahelian countries of West and Central Africa have been subjected to severe drought for more than 20 years [37] [38]. This phenomenon can be explained by climate deregulation linked to the unfavorable influence of certain synoptic and/or environmental factors on the migration mechanism of the Inter Tropical Front (ITF) which determines the climate in West Africa [39] [40]. The increase hot temperature indices and the accentuation of heat waves could negatively impact agricultural yields. This is corroborated by the work of [41] who highlighted the negative impact of sequences of consecutively dry days by pointing out that dry sequences create a lack of water in the plant. Their work also indicated that dry sequences could cause a false start to the seasons or even mortgage an entire crop year. The values of the standard deviation show a great variability of the onset of the rainy season as underlined by the authors [6] [42] in their works. On both complexes, from one year to the next, onset of rainfall for growing season is likely to commence 23 days before or later than the normally expected onset date. [42] specified that this yearly variation makes the planning of selection and sowing of crop types and varieties difficult. Over the study period, some years had high sugarcane yield but did not fall within the mean date of rainy season, which suggest that other factors may be responsible for the sugarcane yield. The equations of the SLR on **Figures 9-11** allow to estimate the climatic parameters in contributing to sugarcane yield. These equations showed that the yield is weakly influenced by rainfall with slopes de 0.004 and 0.003 respectively in Ferké 1 and Ferké 2. This low dependence on rainfall could be explained by the irrigation effect. In industrial plantations, the water deficit is made up by water supplied by irrigation. The SLR showed that the increase of the maximum temperature contributes to the improvement of the quality of the sugarcane yield on the two sugar complexes of Ferkessédougou. These results are not statistically significant in Ferké 1 with a p-value of 0.80 but significant in Ferké 2 with a p-value of 0.07. This would be an advantage for the sugarcane crop since the study showed a tendency of increasing temperature. Several studies confirmed the positive effect of the temperature increase on the sugarcane crop. For example, [43] estimated that sugarcane yields should increase by 15% to 30% in Brazil. Also, [44] projected sugarcane yield increase of 4% in Australia, 9% in Brazil and 20% in South Africa. In another study, a literature review on the subject was conducted and compared numerous articles from different geographic locations [45]. The latter showed that climate change could have a positive effect on irrigated sugarcane yields, particularly in South Africa and Brazil, but water requirements for irrigation and the risk of plant contamination are projected to increase.

However, this study showed negative correlation values between yield and minimum temperature. In their study, [46] found a negative correlation at the 90% confidence level between sugarcane yield and temperature minimum. The yield of the sugarcane would therefore be negatively influenced by the low temperature. Furthermore, study conducted in Nigeria by [42] on maize yield showed the negative impact of increasing minimum temperature on maize yield. Therefore, temperature effects are particularly noticeable in germination amount as well as very cold are not conducive to germination of sugarcane [46] [47].

The analysis of yield variation according to climatic extremes showed that yield would be influenced positively by TXx with respective slope values of 0.83 and 0.97 at Ferké 1 and Ferké 2. This is in agreement with the correlation values between yield and maximum temperature. The negative values of the slopes between yield and TNn showed that the TNn would contribute to a decrease in yield on the sugar plantations of Ferkessédougou as shown by the relation between yield and minimum temperature. The variation in yield was also studied as a function of the drought index. With negative slope values (−0.29 at Ferké 1 and −1.07 at Ferké 2), this study shows a decrease in yield caused by the drought index. Actually, drought could be a detrimental factor for sugarcane cultivation as it contributes to the increase of the plant's water stress. Studies of [48] [49] highlighted that the hydric deficit is very harmful, particularly during the growth phases of the agricultural plants but remains favorable to the accumulation of sucrose in the sugarcane. [50] gave coefficients of determination in the order of 0.64 to 0.94 for the Ferkessédougou sugar complex. In the same vein, [51] showed that irrigation rationing leads to a significant reduction in yields and its components.

Finally, the multiple linear regression relationship (MLR) between sugarcane yield and climatic parameters was realized. From the obtained equations, we can estimate that the maximum and minimum temperatures could be the two factors that most influenced the yield of the sugarcane. The Equations (2) and (3) show that the highest and lowest coefficients are obtained with the maximum and minimum temperature, respectively. This result confirmed those obtained in the SLR. Thus, the findings of the work are robust.

4. Conclusion

This study allows us to analyse the relationship between climatic factors and extremes on the sugar complex of Ferkessédougou and evaluate their impacts on the sugarcane yield. It showed a significant increase and decrease of extreme temperatures respectively TXx and TNn at 95% confidence level. The analysis of rainfall indices did not show significant results. The average sugarcane yields obtained over the period 2002-2019 are around 70.71 and 71.86 t/ha in Ferké 1 and Ferké 2 respectively. The standard deviation values are 6.9 and 4.28 t/ha. The evaluation of rainfall, temperatures, onset and cessation of rainfall in sugar complex of Ferkessédougou showed that temperatures (maximum and minimum) are the major climatic variables contributing to sugarcane yield. The study of the impacts of climate extremes has also shown a great dependence between sugarcane yield and the highest maximum and lowest minimum temperatures. The results of these analyses are not statistically significant, and it could mean that the sugarcane yield does not depend solely on climatic parameters. It would be important to investigate further by combining climatic and soil variables with the sugarcane yield study.

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Conflicts of Interest

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

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