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Variability of bioclimatic determinants and their impacts on the productivity of cowpea and maize intercropping in three agro-ecologies areas of Côte d'Ivoire

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Abstract

In Côte d'Ivoire, the yield of cowpea and maize remains low due to climatic variations that are difficult to control. This study was initiated with the objective of evaluating the impact of climate variability on the productivity of cowpea and maize intercropping. To achieve this, experimental trials were conducted in the localities of Bédiala, Adzopé, and Dikodougou during the years 2020 and 2021. The experimental design was a completely randomized block with four replications. Each plot covered an area of 1088 m² (34 m × 32 m) and included 28 treatments. Cowpea and maize were sown simultaneously in single inter-row planting. Growth data for both crops were collected during the reproductive phase, while yield data were collected after the respective harvests. The results show that the year of planting and the cultivation area significantly influence the grain yields of cowpea and maize. The highest maize yields were recorded in 2020 in Bédiala and in 2021 in Dikodougou, while the best cowpea yield was observed in 2020 in Bédiala. This spatio-temporal analysis of agricultural yields is crucial for effective resource management and ensuring long-term food security.

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Introduction

Climate variability has become a major concern in agriculture due to its significant impact on crop yields and global food security. The effects of climate variability have been particularly pronounced in West Africa, with successive decades of deficient rainfall (Amoussou *et al.*, 2012). Côte d'Ivoire, as many West African countries, faces major food security challenges exacerbated by the increasing variability of bioclimatic determinants (Ahoussi *et al.*, 2013; Asseh *et al.*, 2019 ; Oga *et al.*, 2016; Sorokoby *et al.*, 2013). Agricultural production, particularly of cowpea (*Vigna unguiculata*) and maize (*Zea mays*), is essential for the subsistence and well-being of populations (Deffan *et al.*, 2015; Pasquet and Baudoin, 1997). However, the productivity of these crops is closely linked to local bioclimatic conditions such as precipitation, temperatures, and solar radiation. According to Ahoussi *et al.* (2013), the agricultural cropping systems in Côte d'Ivoire are significantly impacted by the unpredictable effects of climate change. Previous studies have shown that variations in these parameters can have significant effects on agricultural yields, sometimes leading to substantial losses (Kouakou *et al.*, 2012; Ouédraogo, 2014). Therefore, understanding the interactions between bioclimatic factors and agricultural productivity is essential for developing more effective management strategies and mitigating the adverse effects of climate change. However, few studies have specifically focused on the association between the variability of bioclimatic determinants and the simultaneous productivity of cowpea and maize in the northern, central-western, and southern regions of Côte d'Ivoire. To address this gap, this study was initiated to evaluate the variability of bioclimatic determinants and their impacts on the joint productivity of cowpea and maize in these three regions of Côte d'Ivoire.

Materials and methods

Study site

This study was conducted in rural areas across three localities in Côte d'Ivoire : Adzopé, Bédiala, and Dikodougou. These localities were chosen based on the agro-ecological gradient of Côte d'Ivoire. The department of Adzopé is located in the southeast of Côte d'Ivoire, in the Mé region, 105 km from the city of Abidjan. Its geographical coordinates are : latitude 6.10° North, longitude 3.87° West. Adzopé is situated in a humid ombrophile forest zone with an Attiéen-type climate (Amba *et al.*, 2022). Bédiala is located at 7°10' North latitude and 6°18' West longitude, in the central-western part of Côte d'Ivoire, within the Daloa department, the capital of the Haut Sassandra region. It is situated approximately 400 km from Abidjan. The Haut-Sassandra region has a humid tropical climate with annual rainfall ranging between 1200 and 1600 millimeters (Koffie-Bipko and Kra, 2013). The department of Dikodougou is located in the Sub-Sudanese savanna in northern Côte d'Ivoire, specifically between 8.63° and 9.35° North latitude and 6° and 6.50° East longitude. It is situated 50 km south of the city of Korhogo. In the Dikodougou area, the climate is tropical humid with monomodal rainfall patterns (Stessens *et al.*, 1996).

Biological material

The plant material consisted of two improved varieties of cowpea (KVX 745-11P and Tiligré) sourced from the National Institute of Environment and Agricultural Research (INERA) in Burkina Faso, and one improved variety of maize (GMRP 18) from the National Agronomic Research Center (CNRA) in Côte d'Ivoire. The KVX 745-11P and Tiligré varieties of cowpea are erect and semi-erect types, respectively, with a 70-day growth cycle, exhibiting good seedling vigor, resistance to striga, and drought tolerance. The GMRP 18 maize variety has a 100-day growth cycle and is characterized by resistance to lodging, rust, and streak.

Cultural practices

The study involved setting up experimental trials in the localities of Bédiala, Adzopé, and Dikodougou over two consecutive seasons, 2020 and 2021. For each trial, a completely randomized block design with four replications was used. Each plot covered an area of 1088 m² (34 m × 32 m) and included 28 treatments. The treatments were spaced 1 m apart and consisted of intercropping cowpea and maize. Each treatment plot measured 8 m × 4 m and contained 12 rows of eight planting holes with spacings of 50 cm x 60 cm. Cowpea and maize were sown simultaneously in single inter-row planting. The trials in Adzopé were conducted from September to December for both consecutive seasons. In Bédiala, the trials were set up from August to November. In Dikodougou, the trials were conducted from July to October. Growth data for both crops were collected during the reproductive phase, while yield data were collected after the various harvests.

Data collection

The data used in this study are divided into agronomic and climatic data. The agronomic data pertain to the growth and yield parameters of cowpea and maize. The climatic data relate to the climatic characteristics of the study sites for the two consecutive years (Table 1 and 2).

Table 1. Climatic characteristics of the study sites for the year 2020

Parameters	2020		
	Bédiala	Dikodougou	Adzopé
Air T(°C)	26.45	25.38	28.11
RH (%)	77.5	78.65	73.32
Rainfall (mm)	419.66	217.2	510.79
SRad (MJ/m²)	1725.12	1635.67	1362.36
ETP (mm)	366.11	351.34	296.16

Air T : air température ; RH : relative humidity ; SRad : solar radiation ; ETP : potential evapotranspiration

Table 2. Climatic characteristics of the study sites for the year 2021

Parameters	2021		
	Bédiala	Dikodougou	Adzopé
Air T(°C)	26.6	26.14	28.22
RH (%)	78.99	74.45	73.38
Rainfall (mm)	631.8	708.4	554.23
SRad (MJ/m²)	1808.78	1755.25	1351.6
ETP (mm)	385	377.65	299.35

Air T : air température ; RH : relative humidity ; SRad : solar radiation ; ETP : potential evapotranspiration

The climatic data were provided by the weather stations of the Cotton and Cashew Council located in these regions. The growth data for cowpea included diameter of stem (DSt) and the number of branches (NBr). For maize, the growth data included diameter of stem (DSt) and plant height (PH). Concerning yield parameters, for cowpea, they included the number of pods (NPo), the pods weight per plant (PWP), the average weight of a pod (AWP), the weight of 100 seeds (W100s), and the seeds weight per plant (SWP). For maize, these data included the weight of the ear (WE), the length of the ear (LE), the number of rows per ear (NRE), the number of seeds per row (NSR), the weight of 100 seeds (W100s), and the seeds weight per ear (SWE). The grain yields per hectare of cowpea and maize were determined using the following formula :

$$\text{Grain yield (kg. ha} - 1) = \left(\frac{\text{M}}{\text{Sp}}\right) \times 10000$$

M : dry mass of cowpea or maize seeds per elementary plot ;

Sp : area of the elementary plot for cowpea or maize.

Statistical analysis

The statistical analysis of the data was performed with R software, Version 4.2.1. A two-way analysis of variance (ANOVA 2) was conducted to compare the effect of experimental site and trial year on crop productivity. When a significant difference ($P < 0.05$) at the $\alpha = 0.05$ level was observed among traits, ANOVA was supplemented by the Least Significant Difference (LSD) multiple range-test. This test identified the cultivation zone and trial year that maximized the various parameters studied.

Results

Effect of trial year and cultivation zone on cowpea production parameters

The performed ANOVA 2 showed variation in the different studied parameters based on year and cultivation zone (Table 3). Concerning growth parameters, stem diameter at ground level (DSt) recorded maximum values in 2020 in Adzopé and Bédiala. In 2021, the highest value was observed solely in Bédiala. As for the number of branches (NBr), the maximum value was observed in 2020 in Bédiala. Regarding yield data, the highest number of pods (NPo) was observed in Bédiala for both consecutive seasons. Pod weight per plant (PWP) and grain weight per plant (SWP) recorded their highest values in Bédiala during the 2020 season. As for average pod weight (AWP), in 2020 the maximum values were recorded in Adzopé and Bédiala, while in 2021 the highest values were observed in Adzopé and Dikodougou. The highest 100-seed weight (W100s) was observed exclusively in Adzopé for both consecutive seasons.

Effect of trial year and cultivation zone on maize production parameters

The effect of trial year and cultivation zone on maize production parameters was evaluated. The results are summarized in Table 4. The two-way ANOVA performed showed variation in the different parameters based on the year and cultivation zone. Plant height (PH) was highest in Adzopé for both consecutive years. Regarding stem diameter (DSt), the largest diameter was recorded in Adzopé in 2020 and 2021, and in Bédiala during the 2020 season. The highest ear weight (WE) and the greatest number of grains per row (NSR) were observed in Adzopé and Bédiala in 2020 and in Dikodougou in 2021. As for parameters such as ear length (LE) and the number of rows per ear (NRE), the highest values were observed in the 2020 season in Bédiala and in the 2021 season in Dikodougou. Regarding the weight of 100 seeds (W100s), the maximum values were recorded during the 2021 season in Bédiala and Dikodougou. For seed weight per ear (SWE), the highest value was recorded in Bédiala for the 2020 season, while the Dikodougou site had the highest seed weight in the 2021 season.

Table 3. Average values of agronomic parameters of cowpea based on trial year and cultivation zone

Traits	2020			2021			*P*
	Adzopé	Bédiala	Dikodougou	Adzopé	Bédiala	Dikodougou	
NBr	3.12 ± 0.51a	3.32 ± 1.60a	1.26 ± 1.22c	3.55 ± 0.87a	2.58 ± 1.23b	2.27 ± 1.30b	< 0.001
DSt	9.61 ± 2.12b	10.56 ± 2.36a	8.19 ± 1.63c	9.49 ± 2.05b	9.29 ± 2.34b	9.27 ± 1.71b	< 0.001
NPo	13.27 ± 6.37cd	29.86 ± 21.29a	11.16 ± 5.72d	15.45 ± 7.12bcd	18.77 ± 7.08b	16.86 ± 7.63bc	< 0.001
PWP	25.16 ± 13.57b	49.39 ± 30.76a	15.16 ± 8.26c	26.76 ± 14.98b	26.86 ± 10.93b	26.57 ± 12.27b	< 0.001
AWP	1.99 ± 0.47a	1.93 ± 0.50a	1.55 ± 0.35b	1.91 ± 0.58a	1.55 ± 0.50b	1.84 ± 0.43a	< 0.001
W100s	16.41 ± 3.50a	14.04 ± 4.35b	13.69 ± 4.29b	15.07 ± 4.87ab	14.13 ± 5.83b	14.24 ± 4.01b	< 0.001
SWP	18.24 ± 10.94b	36.70 ± 23.05a	11.63 ± 6.52c	19.78 ± 10.77b	18.71 ± 8.24b	20.50 ± 9.54b	< 0.001

NBr : number of branches ; DSt : diameter of stem ; NPo : number of pods per plant ; PWP : pod weight per plant ; AWP : average pod weight ; W100s : weight of 100 seeds ; SWP : seed weight per plant

Means within a row followed by the same letter are statistically equal at the 5% significance level

Table 4. Average values of agronomic parameters of maize based on the trial year and cultivation zone

Traits	2020			2021			*P*
	Adzopé	Bédiala	Dikodougou	Adzopé	Bédiala	Dikodougou	
PH	262.05 ± 59.19a	116.37 ± 41.52e	161.28 ± 34.76c	211.10 ± 95.17b	126.85 ± 17.90e	148.04 ± 23.35d	< 0.001
DSt	14.35 ± 2.48a	13.82 ± 2.53a	11.36 ± 2.18c	13.86 ± 1.77a	12.58 ± 2.24b	12.57 ± 1.85b	< 0.001
WE	93.01 ± 35.63ab	101.23 ± 40.17a	55.36 ± 26.66d	72.61 ± 23.87c	87.72 ± 29.30b	98.19 ± 32.23a	< 0.001
LE	13.17 ± 2.89bc	15.34 ± 3.05a	12.72 ± 2.92c	11.41 ± 2.16d	12.31 ± 2.36cd	13.92 ± 2.25b	< 0.001
NRE	12.63 ± 1.74bc	13.18 ± 1.79ab	12.47 ± 2.03c	12.50 ± 2.10c	12.11 ± 1.67c	13.33 ± 1.77a	< 0.001
NSR	27.51 ± 5.89a	25.96 ± 7.28a	22.61 ± 6.98b	22.50 ± 4.89b	22.67 ± 5.25b	25.30 ± 6.19a	< 0.001
W100s	21.11 ± 4.15d	22.46 ± 4.72cd	16.48 ± 6.08e	25.41 ± 24.71bc	28.38 ± 4.91a	25.51 ± 4.98b	< 0.001
SWE	70.81 ± 28.53b	82.25 ± 32.17a	44.12 ± 21.72d	58.97 ± 20.22c	69.95 ± 24.34b	81.44 ± 26.85a	< 0.001

PH : plant height ; DSt : diameter of stem ; WE : ear weight ; LE : ear length ; NRE : number of rows per ear ; NSR : number of seeds per row ; W100s : weight of 100 seeds ; SWE : seed weight per ear

Means within a row followed by the same letter are statistically equal at the 5% significance level.

Table 5. Average yield values of cowpea and maize based on trial year and cultivation zone

Years	Site	Maize Yields (Kg/ha)	Cowpea Yield (Kg/ha)
2020	Adzopé	1062.16 ± 428.07b	273.74 ± 164.10b
	Bédiala	1233.80 ± 482.57a	550.58 ± 345.76a
	Dikodougou	661.86 ± 325.80d	174.48 ± 97.89c
2021	Adzopé	884.61 ± 303.38c	296.80 ± 161.63b
	Bédiala	1049.32 ± 365.17b	280.75 ± 123.65b
	Dikodougou	1221.62 ± 402.79a	307.54 ± 143.17b
	P	< 0.001	< 0.001

Effect of year and cultivation zone on grain yield of cowpea and maize

The year and study zone allowed for differentiation of grain yields of cowpea and maize (Table 5). For maize, the highest yields per hectare were obtained in 2020 at Bédiala and in 2021 at Dikodougou. Regarding cowpea, the highest yield was observed in 2020 at the Bédiala site.

Effect of rainfall on cowpea yield based on study sites

Fig. 1 and 2 depict the evolution of cowpea yields and rainfall during the 2020 and 2021 seasons across three sites. Generally, yields follow the same trend as local rainfall. In 2020, Bédiala experienced higher rainfall than Dikodougou, and correspondingly, cowpea grain yield in Bédiala was higher than in Dikodougou. Decreases in rainfall correlated with decreases in cowpea yield. In 2021, except for Bédiala, cowpea yield increased with higher rainfall levels.

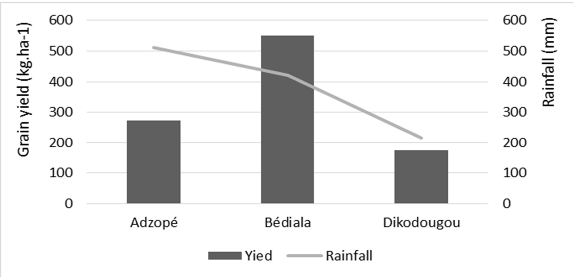

Fig. 1. Evolution of rainfall and cowpea yield according to study sites for the year 2020

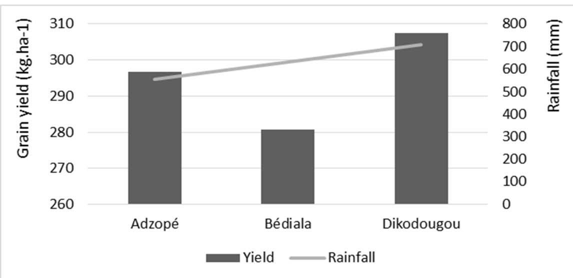

Fig. 2. Evolution of rainfall and cowpea yield according to study sites for the year 2021

Effect of solar radiation on cowpea yield based on study sites

Fig. 3 and 4 demonstrate that cowpea yield and solar radiation varied across different sites. Cowpea yield increases with higher solar radiation and decreases with lower solar radiation. In 2020, the peak solar radiation was observed at Bédiala, coinciding with the highest yield recorded there. However, in 2021, the maximum yield was recorded at Dikodougou, where solar radiation was significant.

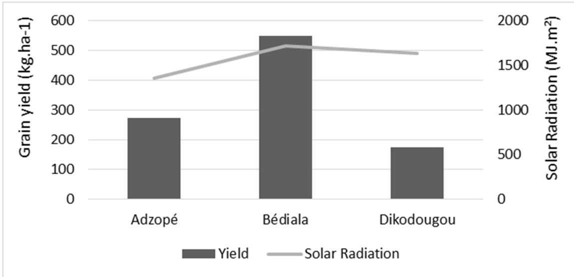

Fig. 3. Evolution of cowpea yield based on solar radiation in 2020

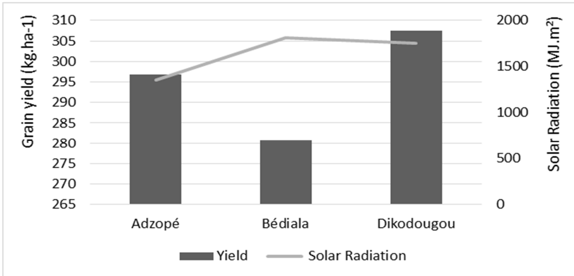

Fig. 4. Evolution of cowpea yield based on solar radiation in 2021

Effect of rainfall on maize yield according to study sites

Analysis of Fig. 5 reveals decreasing rainfall from Adzopé to Dikodougou during the 2020 season, with the highest yield observed at Bédiala. Dikodougou recorded the lowest maize yield during the 2020 season. However, Fig. 6 shows increasing rainfall from Adzopé to Dikodougou, with maize yields following a similar trend.

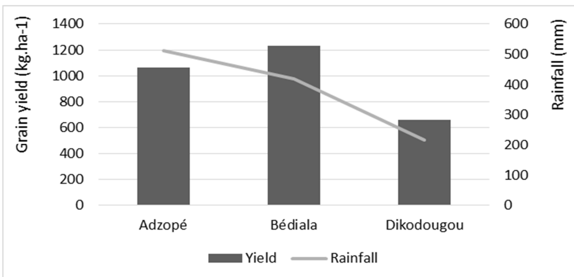

Fig. 5. Evolution of maize yield based on rainfall in 2020

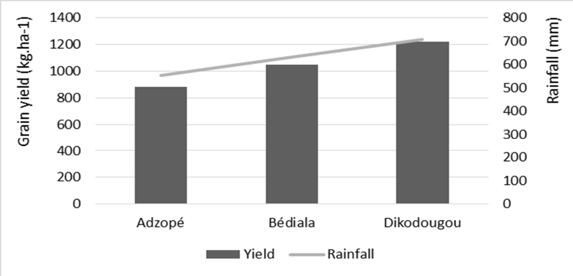

Fig. 6. Evolution of maize yield based on rainfall in 2021

Effect of solar radiation on maize yield according to study sites

Fig. 7 shows that solar radiation increased from Adzopé to Bédiala before declining at Dikodougou. Analysis of this figure indicates that maize yield varies with solar radiation. Adzopé and Bédiala recorded the highest yields. However, Fig. 8 demonstrates an increasing trend in maize yield across the sites. Additionally, maize yield increases with solar radiation.

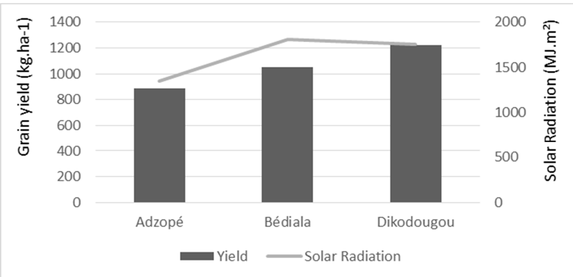

Fig. 7. Evolution of maize yield based on solar radiation in 2020

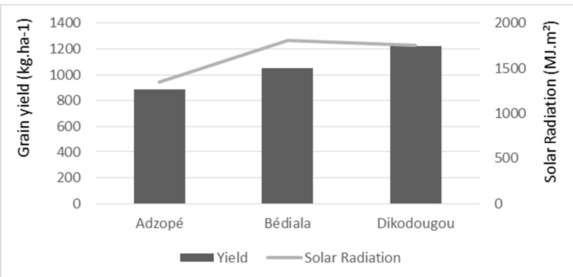

Fig. 8. Evolution of maize yield based on solar radiation in 2021

Discussion

This study highlighted the effect of climatic variability on the production parameters of cowpea and maize in three agroecological zones of Côte d'Ivoire. Generally, we observed significant variation in production parameters depending on the study zones and the year of cultivation. Growth and yield parameters reached their maximum values primarily in Adzopé and Bédiala during two consecutive seasons. These high performances are likely due to highly favorable environmental conditions in these zones. According to (Karikari and Tabona, 2004), environmental factors play a crucial role in plant physiology. During the 2020 season, rainfall, which is the most essential climatic factor for cowpea and maize production, was maximal in these two zones. This led to higher yields of cowpea and maize in Adzopé and Bédiala. In the 2021 season, both rainfall and solar radiation in Bédiala and Dikodougou were higher than those in Adzopé. It is also observed that cowpea and maize yields were highest in these zones. These significant yields could be attributed to the favorable weather conditions in these study areas. Adequate rainfall provides the necessary soil moisture, promoting good plant growth and fruiting. Therefore, an increase in rainfall generally tends to favor higher yields, while a decrease can lead to lower production. In 2020, despite lower relative humidity and solar radiation in Adzopé, taller plant heights and larger stem diameters were achieved there. This underscores the importance of rainfall in agricultural productivity. The work of (Colet *et al.*, 2023) on soybeans supports our hypotheses. Indeed, these authors asserted that the high soybean yield for the last two planting dates was due to weather conditions, particularly precipitation.

Rainfall is crucial for good agricultural production. For instance, due to dry conditions, (Hankinson *et al.*, 2015) observed no yield response of soybeans to planting date in 2014 at the Northwest Agricultural Research Station in the United States. The maximum weight of 100 maize seeds observed in Bédiala could be attributed to the high rainfall and solar radiation recorded in that area. Maize requires ample water and sunlight, and these favorable conditions likely promoted efficient photosynthetic activity, thereby leading to a good maize grain production. The influence of rainfall and solar radiation on cowpea and maize grain yield was effectively illustrated in this study. The trends in yield and climatic parameters across different cultivation zones exhibited similar patterns. The relationship between cowpea and maize yields and climatic factors demonstrates an interconnection between environmental factors and agricultural production. These findings highlight that climatic parameters such as rainfall and solar radiation significantly influence the growth and yield outcomes of cowpea and maize. However, it is interesting to note that this relationship is not always linear or consistent over time. In 2021, despite increases in rainfall and solar radiation at most sites, cowpea and maize yields decreased in Adzopé and Bédiala. This observation suggests that other factors such as soil fertility, diseases, and pests may also influence the response of cowpea and maize to climatic conditions.

Conclusion

This study was conducted to assess the influence of climatic variability on cowpea and maize productivity, considering spatio-temporal factors. The study results indicate that the year and cultivation zone significantly impacted cowpea and maize grain yields. For maize, the highest yields per hectare were recorded in 2020 at Bédiala and in 2021 at Dikodougou. Regarding cowpea, the highest yield was observed in 2020 at the Bédiala site. These observations underscore the influence of climatic variables in determining agricultural yields. In 2020, where rainfall in Bédiala was higher than in Dikodougou, grain yields were also higher in Bédiala compared to Dikodougou. Furthermore, decreases in rainfall were accompanied by decreases in crop yields. However, in 2021, except for the Bédiala site, an increase in rainfall was associated with an increase in cowpea yield in the other study sites. This nuanced understanding of the spatio-temporal dynamics of agricultural yields is essential for effective resource management and sustainable food security.

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