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Response of Wheat to Agro-climatic and Soil Morphopedological Factors in the Forest-savanna Transition Zone of the Ivory Coast

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Authors' contributions

This work was carried out in collaboration among all authors. Authors KBC and BK designed the study. Author KBC drafted the protocol and the first version of the manuscript. Authors SNC, KA and KBC performed the statistical analyses. Authors KKF and SNC corrected the first draft of the manuscript. Authors KBC, BK, KKF, SNC, KA. and YKE revised and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To characterize thermal and rainfall trends, identify the main soil types along a topographic sequence and assess the agronomic response of wheat on these soils according to the seasons.
Study Design: To analyze rainfall and temperature trends and conduct a field experiment on soils located within a toposequence according to the seasons.
Study Location and Duration: The study was conducted in the forest-savanna transition zone in central Ivory Coast. Climate data were collected over 42 years, from January 1981 to December 2022. The agronomic study was carried out from September 2021, to September 2023.
Methodology: (i) Collect climate data to highlight climate evolution, (ii) conduct a morphopedological study on a toposequence to identify soil types, (iii) conduct an agronomic study through experiments carried out in microplots during different seasons to identify the moste sutable soil type and the ideal season for wheat cultivation.
Results: The study shows a significant increase in average temperature of approximately over 1°C, as well as a decrease and high variability in rainfall, indicating a notable tendency towards drought in this area. Furthermore, morphopedological analysis reveals the presence of a Regolic Ferralsol at the summit, a Plinthic Duric Petrosol on the upper slopes, an Arenic Duric Petrosol on the middle slopes and an Arenic Fluvisol on the lower slopes. Finally, agronomic trials indicate that wheat performs best when its vegetative phase lapes with the dry season and its reproductive phase with the rainy season, with grain yields ranging from 1 t ha^{-1} to 4.6 t ha^{-1}.
Conclusion: The most sutable soils were the Plinthic Petrosol duric and Arenic Fluvisol and whend the best seasons were the great interseason or the great dry season.

Keywords: Climate factors; climatic seasons; soil wheat; forest-savanna zone of Ivory Coast.

ABBREVIATIONS

ICARDA	*: International Center for Agricultural Research in the Dry Areas*
GR	*: Germination Rate*
GY	*: Grain Yield*
SY	*: Straw Yield*
TDM	*: Total Dry Matter*
HI	*: Harvest Index*
FMR	*: Flowering Mortality Rate*
GRS	*: Great Rainy Season*
GDS	*: Great Dry Season*
SRS	*: Small Rainy Season*
SDS	*: Small Dry Season*
GRS-GDS	*: Great Interseason*

1. INTRODUCTION

Climate change has accelerated in recent decades, causing major impacts on human activities (Puget *et al.,* 2010). At this rate, it risks exceeding the adaptive capacity of many species and causing profound disruptions to their ecosystems. Indeed, climate variability is considerably weakening African agricultural systems, which are now struggling to respond to new environmental constraints. This situation is leading to a general decline in agricultural yields (Lobell & Gourdji, 2012) and, in turn, to higher food prices. Ivory Coast, like many West African countries, is not immune to these impacts and is already suffering the consequences. However, the country has significant agricultural potential that could ensure national food security and strengthen its position on international markets. To cope with climate change, the adoption of resilience and adaptation strategies is essential (Nicolas, 2013). Among these measures, the relocation or shifting of crop areas appears to be a promising way to maintain or improve agricultural production under new climatic conditions. This approach is particularly relevant for wheat cultivation as local production is virtually no-existent while the country imports considerable volumes: approximately 690 000 tons of wheat between 2019 and 2023

(Agenceecofin, 2025). The lack of domestic wheat production is largely due to the perception that this crop is unsuitable for Ivorian climatic conditions. However, it is successfully grown in Mali and Burkina Faso, countries with climatic characteristics similar to those of Ivory Coast. Furthermore, Traoré *et al.,* (2016) demonstrated the possibility of producing durum wheat in Ivory Coast through pot trials. Boli, (2025) also conducted successful field trials. These findings highlight the need to assess the yield potential of wheat under real field conditions in the Ivorian climate. The objective of this study is therefore to examine the combined effect of soil types and climatic seasons on wheat cultivation in the transitional agroclimatic zone of Ivory Coast. This will involve characterising climate trends over the last 42 years, identifying the soils cultivated along a toposequence and assessing the behaviour of wheat on these soils through experiments conducted in different climatic seasons.

2. MATERIALS AND METHODS

2.1 Study Area and Plant Material

The study was conducted in the forest-savanna transition zone of Ivory Coast located at coordinates 6º 21' 44.1" N; 5º 02' 32.6" W at an altitude of approximately 150 m. The soils encountered are dominated by Ferralsols, frequently associated with outcrops of slabs or blocks of ferruginous laterite. The spontaneous vegetation is mainly composed of *Imperata cylindrica* (Poaceae), characteristic of the herbaceous formations of this ecological area.

The plant material used in this study is the *NORMAN* variety, a durum wheat (Triticum *durum*) cultivar developed by the International Center for Agricultural Research in the Dry Areas (ICARDA). This light grey, oval-shaped variety is known for its relative tolerance to major diseases and insect pests, making it a genotype adapted to challenging agroclimatic conditions.

2.2 Climate Data Collection

Historical climate data covering the period from January 1981 to December 2022 were extracted from the NASA POWER (Prediction of Worldwide Energy Resources) database. In addition, climate parameters recorded during the planting periods were collected daily using the "METEO" weather application, allowing for detailed monitoring of atmospheric conditions in situ.

2.3 Soil Characterization

Along a 200 m long topographic sequence, soil pits spaced 50 m apart were opened for detailed morphopedological description. Soil profiles were characterized using the tactile method and classified according to the IUSS Working Group WRB nomenclature (2022). For this agronomic study, the soil observation depth was intentionally limited to 50 cm.

2.4 Plot Lay Out

Subsequently, on each topographic level, a 4 m² experimental microplot was established. After clearing and manually tilling the plots, wheat was sown at a rate of three seeds per hill, with a spacing of 20 cm × 20 cm. At physiological maturity, the harvest was carried out manually. The harvested ears were then air-dried for two weeks before threshing and weighing.

2.5 Agronomic Data Collection

Three weeks after emergence, the Germination Rate (GR) was determined by counting seedlings per microplot. Subsequently, plant height and tiller count were collected at a weekly interval until harvest. At maturity, several agronomic parameters were evaluated: Grain Yield (GY), Straw Yield (SY), Total Dry Matter (TDM), Harvest Index (HI) and 1000-grain weight. The various parameters were calculated using the following equations:

$$GY\ (t\ ha^{-1}) = (\text{dry grain weight (kg)} / 4(m^2)) \times (10000/1000) \times ((100-H)/86) \quad (1)$$

$$\text{With } H\ (\%\ \text{moisture}) = [\text{Initial M} - \text{Final M} / \text{Initial M}] \times 100 \quad (2)$$

with M= mass of a quantity of wheat taken from each microplot.

$$SY\ (t\ ha^{-1}) = (\text{dry straw weight (kg)} / 4(m^2)) \times (10000/1000) \quad (3)$$

$$TDM\ (t\ ha^{-1}) = GY + SY \quad (4)$$

$$HI\ (\%) = (GY / TDM) \times 100 \quad (5)$$

2.6 Statistical Analyses

The measured parameters, namely Germination Rate (GR), plant height, number of tillers, Flowering Mortality Rate (FMR), grain yield (GY), straw yield (SY), total dry matter (TDM), harvest index (HI) and 1000-grain weight, were subjected to analysis of variance (ANOVA) to determine the significant effect of season and soil type on each of these traits. Statistical analyses were performed using SAS software, for a significance level set at α = .05.

3. RESULTS

3.1 Climate Data

The Fig 1-A shows three climate parameters aggregated in five-year intervals over the period 1981–2020, namely: annual averages of rainfall, maximum temperatures and minimum temperatures. Analysis of these data reveals a gradual decrease in rainfall between 1981–1985 and 2016–2020, accompanied by an increase in temperatures. Fig 1-B illustrates the average monthly rainfall recorded from January 1981 to December 2022. The results indicate that June is the rainiest month, with an average of 208 mm/month, while January has the lowest rainfall in the study area. From this diagram (Fig 1-B), four distinct seasons can be identified.

- •The Great Rainy Season (GRS), which runs from late March to early July.
- •The Great Dry Season (GDS), which begins in November and ends in early March.
- •The Small Rainy Season (SRS), which extends from September to October.
- •The Small Dry Season (SDS), which covers the period from July to August.

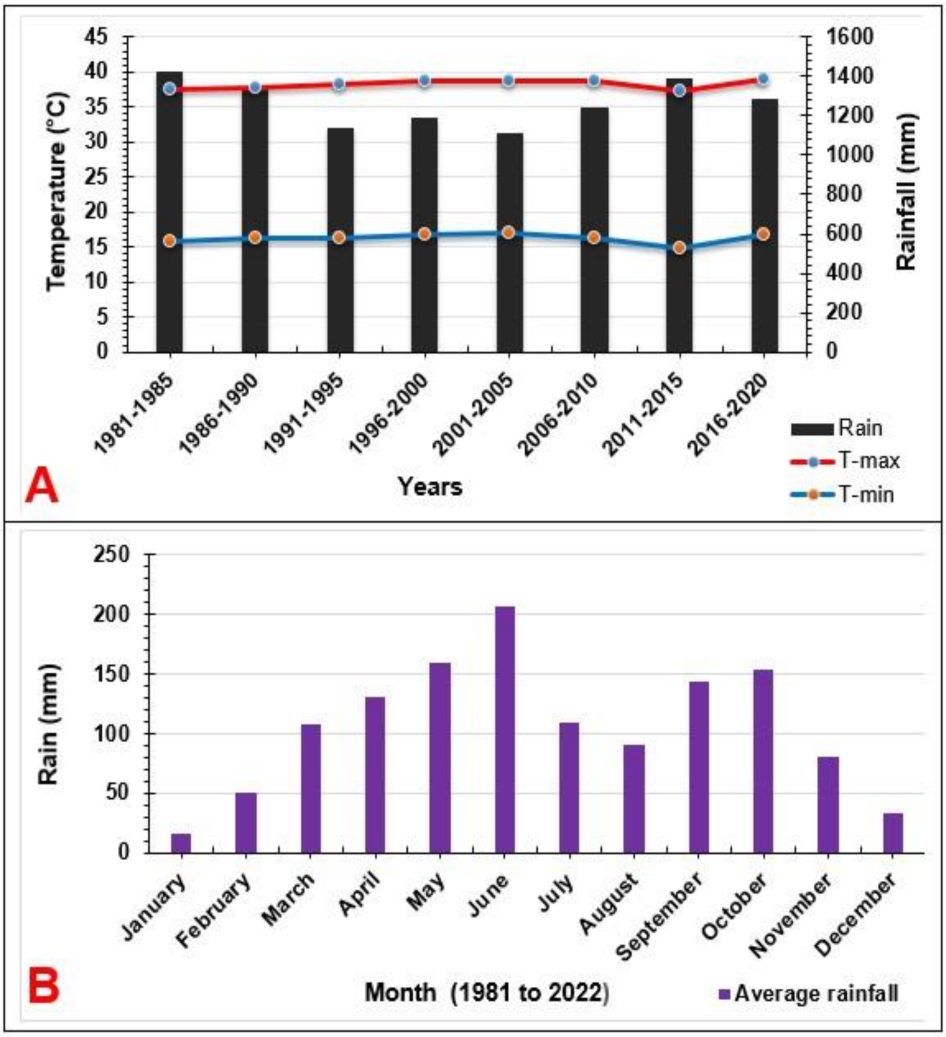

Fig. 1. Average annual (A) and monthly (B) climate data

3.2 Characteristics of Cultivated Soils

Morphopedological prospecting along the toposequence revealed the presence of a Regolic Ferralsol at the top (Fig 2-A), a Plinthic Petrosol duric at the top of the slope (Fig 2-B), an Arenic Petrosol duric in the middle of the slope (Fig 2-C) and an Arenic Fluvisol at the bottom of the slope (Fig 2-D). The Ferralsol Regolic soil type surveyed at the summit (Fig 2-A) is characterised by three main horizons. Horizon A0 (0–20 cm) is humic, very dark gray (7.5YR 3/1), sandy in texture and lumpy in structure. It is macroporeous, contains numerous roots and has a low coarse element content (<30%). The transition to the lower horizon is diffuse and no patches were observed. Horizon A10 (20–40 cm) is poor in organic matter, dark brown (7.5YR 3/3), sandy, with a particulate structure and microporous. It contains few coarse elements (<30%) and roots and no patches were observed. The transition to the AB horizon is gradual. The AB horizon (40–57 cm) is strong brown (7.5YR 4/6), non-humic, sandy-clayey and has a particulate structure. It is microporous with few roots. The presence of oxidation spots at depth indicates water stagnation due to low soil permeability. This profile is very deep. At the top of the slope, the Plinthic Petrosol duric (Fig 2-B) has four distinct horizons. Horizon A0 (0–5 cm) is humic, gray (7.5YR 5/1), sandy in texture and lumpy in structure, macroporeous and rich in roots, with a low coarse element content (<30%) and a diffuse transition. Horizon A10 (5–15 cm) is also humic, very dark gray (7.5YR 3/1), sandy, lumpy in structure and macroporeous. It contains a lot of coarse elements (>30%), numerous roots and no spots. The transition is diffuse. Horizon A11 (15–40 cm) is brown (7.5YR 4/2), low in humus, sandy, with a particulate structure and microporous. It is rich in coarse elements (>30%), contains a few roots and has no patches. The transition to the crust is clear. Below 40 cm, a hardened crust limits the depth of the soil, which is rich in coarse elements. The Arenic Petrosol duric (Fig 2-C) of the middle slope consists of three horizons. Horizon A0 (0–9 cm) is humic, very dark gray (10YR 3/1), sandy and lumpy in structure, macroporeous and containing numerous roots, with a diffuse transition. Horizon A10 (9–22 cm) is humic, very dark brown (10YR 2/2), sandy, with a particulate structure and macropores. It contains numerous roots and a low percentage of coarse elements (<30%), with a diffuse transition. Horizon A11 (22–42 cm) is dark yellowish brown (10YR 3/4), low in humus, sandy, with a particulate and porous structure, and few coarse elements. It contains some roots and oxidation spots. The transition is clear and the soil rests on a hardened crust. This profile is shallow and very sandy. At the bottom of the slope, the Arenic Fluvisol (Fig 2-D) is deep and has three horizons. Horizon A0 (0–7 cm) is humic, black (10YR 2/1), sandy and lumpy in texture. It is porous, contains numerous roots and has a very low coarse element content (<30%), with a diffuse transition. The A10 horizon (7–35 cm) is humic, very dark grayish brown (10YR 3/2), sandy, lumpy in structure and macroporeous. It contains a low percentage of coarse elements (<30%), numerous millimeter to centimeter-long roots and has no patches, with a clear transition. Horizon A11g (35–48 cm) is humic, dark yellowish brown (10YR 4/4), sandy, with a particulate to prismatic structure. It is porous, contains few gravel particles, centimeter-long roots and a few oxidation spots, with a diffuse transition. This soil also has an intrusion of gravel particles.

3.3 Impact of Seasons and Soils on Wheat Cultivation

Table 1 presents the average values of the agronomic parameters for wheat cultivation recorded during the study. The results show a highly significant effect of season on plant height, number of tillers and mortality rate (Pr < .0001). However, season has no significant effect on germination rate (Pr > .05). With regard to plant height and number of tillers, the variance between the mean values of these parameters is very significant, with the dry seasons (GDS–GRS and GDS) showing the highest values, while the mortality rate during these seasons is low. Overall, all plots sown on different soil types recorded germination, but when the emergence-tillering phase coincides with the rainy season, seedlings suffer significant losses. Conversely, crops grown in the dry season generally have a low mortality rate of less than 20%. Table 2 shows the average values of agronomic parameters according to soil type. It shows that soil type has a significant effect only on the germination rate (Pr < .001). Among the soils studied, Plinthic Petrosol duric has the highest germination rate, followed by Arenic Fluvisol.

3.4 Impact of Seasons and Soils on Wheat Yields

Table 3 shows the average wheat yields after harvest. There is a highly significant effect of season on yields with Pr< .0001 and the highest yields are obtained either in the great interseason (GDS-GRS) or in the great dry season. In terms of soil (Fig 3), the results show that Plinthic Petrosol Duric (green diagram) is the soil that best supports the cultivation of this cereal. Table 4 shows the influence of temperature on wheat cultivation. The results show that the number of wheat tillers/seedlings and yields are optimal when the average temperature is around or above 29°C. However, wheat cultivation is unsuccessful when the temperature is below 28°C.

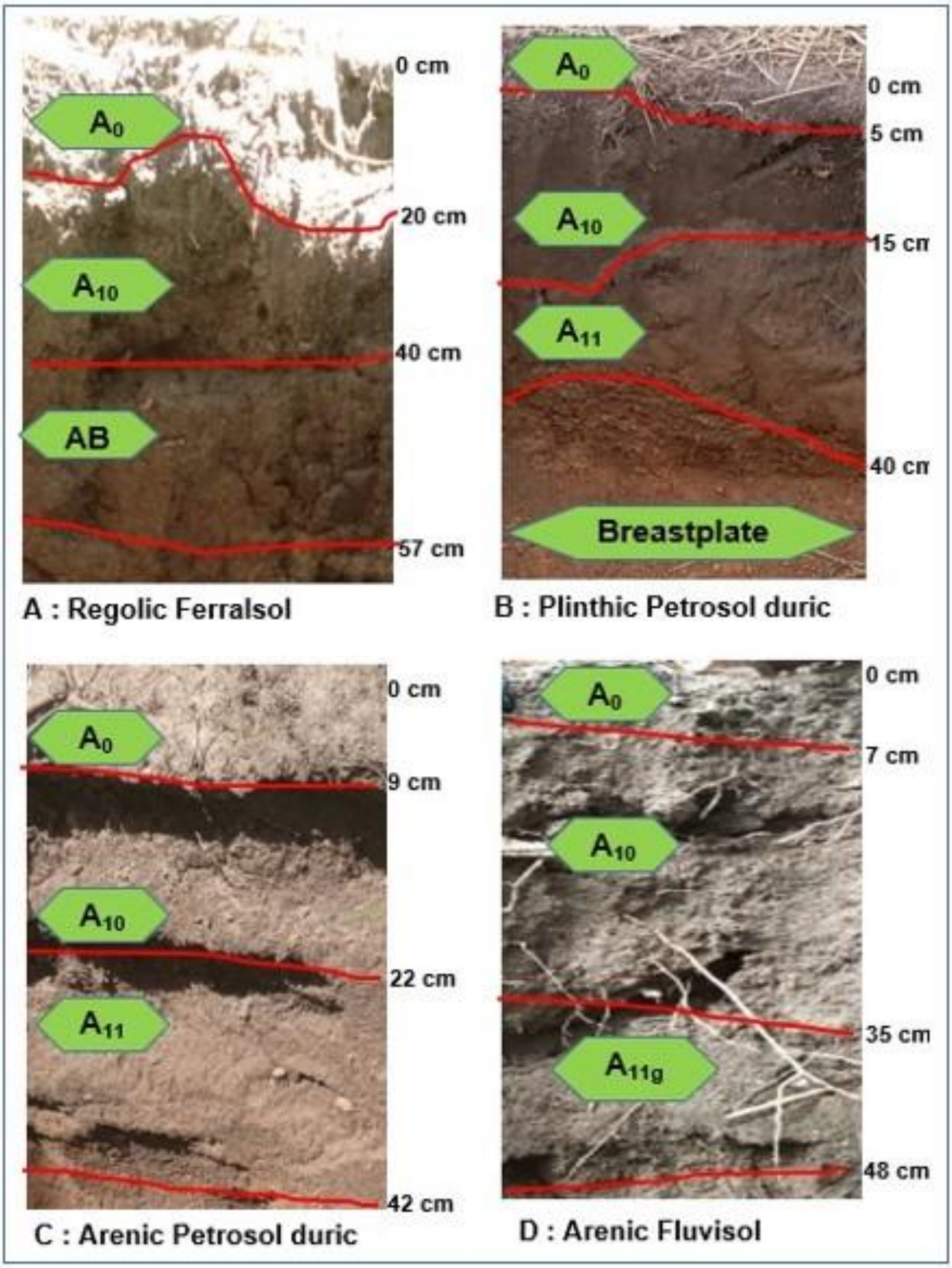

Fig. 2. Description of cultivated soils

Table 1. Effect of seasons on wheat growth and development parameters

Seasons	GR (%)	Height (m)	Number of tillers	FMR (%)
SRS 1	94.8a	.18c	0c	100a
GDS	94.5a	.60b	3ba	14.03cb
GDS-GRS 1	99.3a	.73a	4.3ba	2.69c
GRS	99.8a	.21c	0c	100a
SDS-SRS	91a	.54b	3ba	100a
GDS-GRS 2	93.5a	.76a	4.8a	20.04b
SRS 2	98.3a	.48b	2.3b	100a
CV(%)	6.36	14.67	47.07	13.6
Average	95.86	.499	2.46	62.39
Pr>F	<.37	<.0001	<.0001	<.0001

Table 2. Effect of soil types on wheat growth and development parameters

Soils	GR (%)	Height (m)	Number of tillers	FMR (%)
Regolic Ferralsol	96.86a	.50a	2.43a	61.16a
Plinthic Petrosol duric	99.29a	.56a	3.29a	59.03a
Arenic Petrosol duric	88.71b	.40a	1.14a	69.42a
Arenic Fluvisol	98.57a	.53a	3a	59.95a
CV(%)	4.95	46.54	80.31	76.35
Average	95.86	.499	2.46	62.39
Pr>F	<.001	<.61	<.21	<.98

Values marked with the same letter in the same column are not statistically different at the α threshold: 0.05. NB: CV: coefficient of variance; Pr: probability; GR: germination rate; FMR: mortality rate at flowering.

Table 3. Analysis of variance between seasons and wheat crop yields

Seasons	GY	SY	TDM	HI	1000-grain weight (g)
SRS 1	0b	0c	0b	0b	0b
GDS	1.3ba	1b	2.4b	55.9a	53.5a
GDS-GRS 1	2.6a	2.1a	4.6a	53.9a	58.3a
GRS	0b	0c	0b	0b	0b
SDS-SRS	0b	0c	0b	0b	0b
GDS-GRS 2	1.4ba	1.2b	2.6b	52.8a	52.2a
SRS 2	0b	0c	0b	0b	0b
CV(%)	91.5	78.7	85.5	14.8	16.6
Average	.76	.6	1.36	23.23	23.86
Pr>F	<.0001	<.0001	<.0001	<.0001	<.0001

Table 4. Impact of temperature on wheat cultivation

Parameters	SRS 1	GDS	GDS-GRS 1	GRS	SDS-SRS	GDS-GRS 2	SRS 2
Average Temperature (°C)	27	30	29	27	28	29	28
Number of tillers	0	3	4	0	3	5	2
Grain Yield ($t\ ha^{-1}$)	0	1.3	2.6	0	0	1.4	0
Straw Yield ($t\ ha^{-1}$)	0	1	2.1	0	0	1.2	0

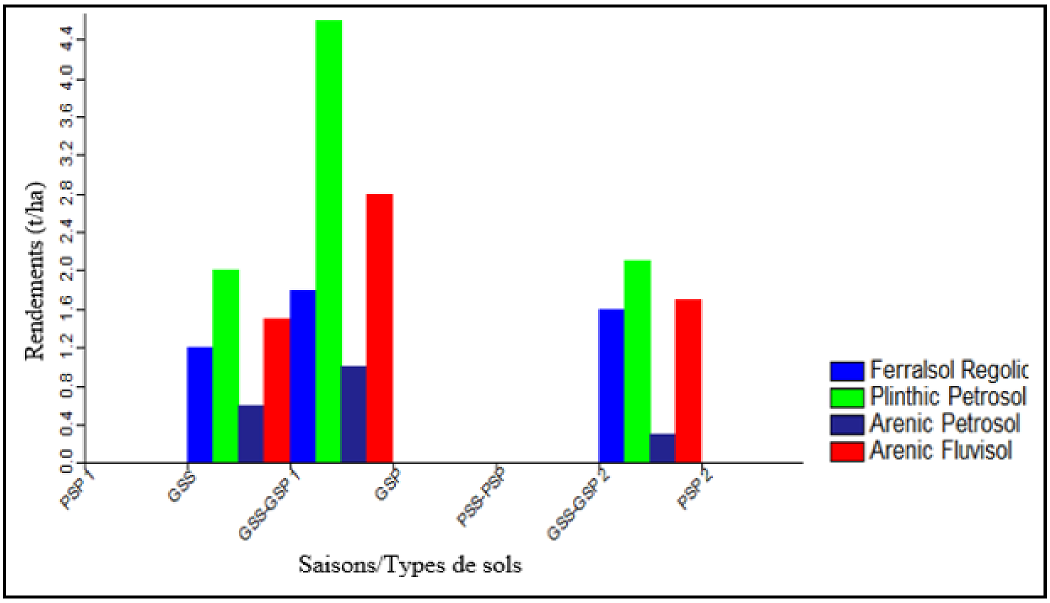

Fig. 3. Grain yield obtained

4. DISCUSSION

4.1 Gradual Climate Change

Analysis of climate data for the last 42 years in this area highlights a significant change in climatic conditions. These results are consistent with the work of Puget *et al.,* (2010), which highlights an acceleration in global climate change over recent decades. Indeed, our analyses reveal a gradual decrease in rainfall accompanied by an increase in temperatures, a phenomenon linked to the interaction between temperature and humidity. These observations suggest that the area studied is particularly vulnerable to drought and global warming. The conclusions of the IPCC, (2013) corroborate these results, indicating a general trend towards an increase in average surface temperature. The study also highlights a bimodal rainfall pattern, divided into four distinct seasons, with peak rainfall observed in June and minimum rainfall in January. These observations confirm the results of Ochou *et al.,* (1991), who described a similar bimodal pattern in the central climate zone of Ivory Coast. This seasonal structure is essential for understanding crop adaptation and sowing planning, particularly for cereals that are sensitive to periods of drought, such as wheat.

4.2 Characteristics of Cultivated Soils

The soils surveyed, notably Regolic Ferralsol, Plinthic Petrosol duric, Arenic Petrosol duric and Arenic Fluvisol, are generally sub-sandy and ando-gravelly or ando-plinthitic. The dominance of plinthite in these soils suggests heavy leaching and intense reworking. These observations are consistent with the work of Koné *et al.,* (2009), which indicates that leached and reworked characteristics are common in Ferralsols. In addition, these soils have horizons that vary in colour from dark on the surface to yellowish in the deeper horizons. The transition from dark to yellowish, often accompanied by oxidation spots, indicates active vertical drainage, promoting the accumulation of clay or ferruginous particles in deeper horizons. These observations are consistent with the work of Koné *et al.,* (2009), which shows that the accumulation of iron and clay in deeper horizons gives soils their red colour and may be accompanied by hydromorphism or oxidation spots. On the surface, these soils are humic and have a lumpy structure, characteristics that reflect their suitability for cultivation. These properties, combined with the depth and specific profile of each soil type, partly explain the differences observed in the response of wheat crops during the experiments.

4.3 Agronomic Yields

The experimental results reveal a notable variation in yields depending on the production cycles. Crops established during the Great Dry Season (GDS) and during the Great Interseason (GDS–GRS) had grain yields (GY) and straw yields (SY) that were 1.3 t ha^{-1} and 1 t ha^{-1} higher, respectively. In terms of the effect of soil types, Plinthic Petrosol Duric provided the highest yields, with a GY ranging from 2 t ha^{-1} to 4.6 t ha^{-1} and a SY ranging from 1.4 t ha^{-1} to 3.6 t ha^{-1}. This was followed by Arenic Fluvisol, with GY and SY ranging from 1.5–2.8 t ha^{-1} and 1.2–2.04 t ha^{-1} respectively. These values are consistent with those reported by He *et al.,* (2013), who indicate that wheat grain yield generally varies from 1 to 10 t ha^{-1} and straw yield from 1.25 to 5 t ha^{-1}. The agronomic superiority of these soils can be explained by their topographical position and their ability to accumulate nutrients. The Plinthic Petrosol duric, located before the break in the slope and associated with an armoured wedge, receives and retains the elements washed down from the top of the slope. As for the Arenic Fluvisol, located at the bottom of the slope, it benefits from the accumulation of nutrients from the upper segments. On the other hand, crops grown during the Short Rainy Season (SRS), the Great Rainy Season (GRS) and between the Short Dry Season and Short Rainy Season (SDS–SRS) had virtually zero yields, as the seedlings were destroyed by lodging caused by heavy and frequent rains accompanied by wind. This observation is consistent with that of the ARVALIS, (2022), which states that heavy rain and wind cause trampling, also known as lodging, of seedlings, resulting in crop loss. Furthermore, ARVALIS, (2023) adds that excess water has a considerable impact on wheat crops during their germination and three-leaf emergence phases as seedlings are sensitive to anoxia.

4.4 Soil-Climate-Wheat Interactions

The study shows that wheat cultivation is particularly sensitive to heavy and frequent rainfall during the seedling emergence and tillering phases, due to lodging or trampling and seedling anoxia, as described on the ARVALIS, (2022) and ARVALIS, (2023). On the other hand, when planting precedes the rainy season, so that emergence and tillering take place during the dry season, the crop develops optimally. These observations suggest that the dry season, when accompanied by controlled irrigation, is a favourable period for wheat establishment, which is confirmed by the ICARDA technical data sheet indicating that the dry season is the recommended season for wheat cultivation. The high yields observed on Plinthic Petrosol duric, Arenic Fluvisol and Ferralsol Regolic soils can be attributed to their pedological characteristics: these soils are slightly acidic, humic and porous on the surface, promoting water and air retention and thus enabling optimal water and mineral nutrition. The experiment also indicates that the germination rate depends mainly on the type of soil, while plant height, number of tillering and mortality rate are more influenced by the season. Furthermore, the interaction between soil type and season has a significant effect on yields. Thus, the best soils for wheat cultivation in the study area are Plinthic Petrosol duric, followed by Arenic Fluvisol and Ferralsol Regolic. The most suitable seasons for cultivation are the Great Dry Season (GDS) and the Great Interseason (GDS–GRS). In the case of the great interseason, it is recommended that the vegetative phase (sowing–emergence–tillering) take place during the Great Dry Season, while the reproductive phase (stem elongation–ear emergence–flowering) should coincide with the Great Rainy Season.

5. CONCLUSION

The study confirms the presence of climate change in the forest-savanna transition zone in central Ivory Coast. It also identified several soil types along a toposequence belonging to the large Ferralsols group. The agronomic results indicate that tillering and mortality rates are strongly influenced by the climatic season and crop performance is optimal when planted during the dry season with maximum yields observed on Plinthic Petrosol duric and Arenic Fluvisol soils. In summary, this study demonstrates that wheat cultivation in this area is viable provided that the choice of soil and sowing schedule are adapted to local agroclimatic conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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