Impact of drought on the physicochemical properties of a hydromorphic soil in Bouaké (central Côte d'Ivoire)

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Abstract— **Drought is a constraint that preoccupies the farming community in hydromorphic soils. The purpose of this study is to evaluate the impact of drought on the physico-chemical properties of the hydromorphic soils of Bouaké. To do so, a soil profile 150 cm long and 75 cm wide, with 100 cm depth was opened and described. It is a hydromorphic Renkosol (arenic gleyic) soil that has developed under an equatorial four-season climate, including two rainy seasons and two dry seasons. It presents a temporary hydromorphy that varies with the seasons. The physicochemical analyzes show a soil that is not very acidic and very depleted of nutrients under the effect of drought, notably in nitrogen and phosphorus, in CEC as well as in exchangeable cations (K +, Mg ++ and Ca ++). However, the soil is rich in organic matter and the very high iron content exposes the area to iron toxicity. The presence of a water table around 70 cm attenuates the effects of the drought of the hydromorphic soil making it suitable for rainfed agriculture. This makes the hydromorphic soil of central Côte d'Ivoire a fragile ecosystem whose improvement of its nutritional quality can be done by the practice of the cultivation technique and an efficient fertilizer supply.**

Index Terms— **Drought, hydromorphic soil, physico-chemical properties, Bouaké (Côte d'Ivoire)**

I. INTRODUCTION

Drought is one of the most extreme climatic conditions affecting human activities, including rainfed agriculture and other forms of abiotic stress [1] - [2]. In recent decades, major droughts have occupied large territories on all continents, highlighting the importance of this phenomenon [3]. It results from rainfall conditions, particularly the irregularity and the poor distribution of rainfall [4]-[5], and / or a rise in temperature [6]-[7], thus defining the environment for agricultural practice. In the Gbêkê region of central Côte d'Ivoire, this variability in climatic parameters, defined by rainfall and temperature, describes four seasons of varying intensity and hardness that alternate, including two rainy seasons and two dry seasons [8]-[9]. Indeed, with the advent of global changes in the climatic environment, characterized by the temporal irregularity and the poor spatial distribution of rainfall as observed globally in Côte d'Ivoire [10]-[11]-[12]-[13], the center of the country has known for some time, a high vulnerability to water deficits [6]-[14]-[15]. This climatic environment introduces an increasingly pronounced drought with, as a direct consequence, drying coupled with sequences of high humidity of hydromorphic soils for rainfed agriculture. These extreme and contradictory environmental conditions, more or less intense and prolonged, are not without consequences on the physicochemical characteristics of transient hydromorphic soils between the lowlands proper and the plateau. This is why this study aims to determine the impact of drought on the physical and chemical properties of hydromorphic soils in order to evaluate their level of fertility. This involves carrying out a set of physicochemical analyzes on soil samples taken in this zone in order to determine the different physical and chemical properties under the effect of the current extreme climatic conditions, and thus to propose methods of effective fertility management to make this ecosystem more suitable for rainfed agriculture for the benefit of the rural world.

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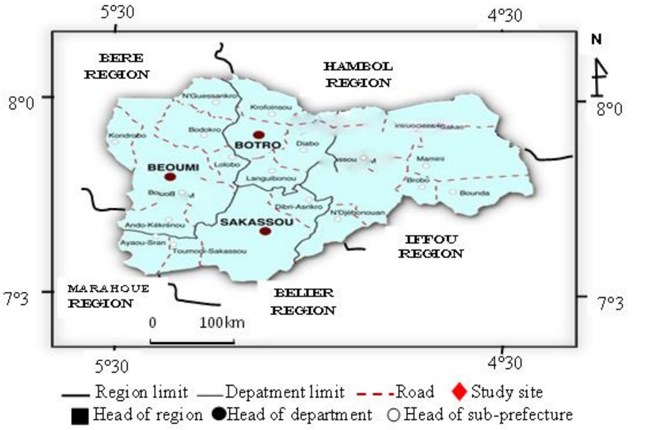
II. MATERIAL AND METHODS

- **Description of the study area**

The work was done at KONANKRO-N'ZO (07°52 N, 05°14 W, 261m asl) in the Gbêkê region of central Côte d'Ivoire (Fig. 1). This region was chosen because the KONANKRO-N'ZO area is full of immense agricultural activities of the populations, in particular, rainfed rice cultivation. According to [16], the Gbêkê region is an equatorial climate zone of transition between subequatorial and subtropical climates, known locally as the Baoulean climate. Four seasons are spread in this zone: two dry seasons (one large, November and a small, July-August) and two rainy seasons (March-June for the big season and September-October for the short season). The rainfall regime is bimodal, the annual rainfall is 1200 mm and the average temperature is around 27°C. Three soil coverings are distinguished in the Gbêkê region: upstream, Ferrasols, downstream, Gleysols and in the lowlands, Fluvisols. The soil cover that formed our substratum in this study is the hydromorphic soil cover (Gleysols) because of the high exploitation of this area for rainfed crops. It is an arenic soil without B horizon consisting of sandy and pedoturbated soils, monosiallitic, partially weathering clayey gray soils and compact, pedoturbated, bisiallitic, with incomplete alteration with in depth a groundwater about 70 cm [17]. It has been identified according to world reference base for soil resource classification [18], as a arenic gleyic soil due to silting and hydromorphy induced by the water table [19]. The vegetation is mainly herbaceous, colonized by *Imperata cylindrica* [20].



- **Data collection**

Data from this study were obtained in two main steps:

- The first step consisted in determining the climatic parameters conditioning rainfed agriculture in the central region of Côte d'Ivoire, more specifically in Gbêkê (Bouaké). Although diverse, the most relevant and perceptible accounting for the possibility of tillage in rural areas are rainfall and temperature. This is why the present study was particularly interested in the variation of its two climatic parameters over a period of fifteen years from 2003 to 2017. The rainfall and temperature data for the period under consideration come from the monthly and annual weather reports of agro-meteorological station AfricaRice (ex-WARDA) M'bé-Bouaké. From the rainfall reports, the drought was determined more particularly by McKee's standardized precipitation index (SPI) according to the following formula [21]:

$$SPI = \frac{R_i - R_m}{SE} \quad (1)$$

R_i: Rain fall amount of year i;
R_m: Average rainfall of a given period;
SE: Standard deviation of rainfall in a given period.
SPI values have been used to distinguish between dry years and wet years, and to assess the intensity of drought according to the drought sequence classification developed by McKee presented in Table 1 [21].

Table 1: SPI drought sequences classification

Value of SPI	Drought sequence
≥2	Extremely humid
1.5 – 1.99	Highly humid
1.0 – 1.49	Moderatly humid
-0.99 – 0.99	Likely normal
-1.00 - -1.49	Moderatly dry
-1.50 –1.99	Highly dry
≤-2	Extremly dry

the second stage consisted in opening the soil pits 150 cm long and 75 cm wide, with 100 cm depth along the hydromorphic zone in places not yet cultivated [22] (Délaunois et al. , 2008) and their description according to the variables defined in the French classification [23]. This description classifies soil according to the global soil resource base [18]. Then, a sampling of the soil was done by auger each time on the area of the site not yet contaminated by fertilizers, between 0-20 cm deep. These soil samples were mixed to obtain a composite sample and air-dried under cover and sieved (2mm) before being crushed. Finally, 1 kg of the composite sample was taken and used for laboratory analysis. Thus, the pH was determined at the glass electrode in a ratio of 1: 2.5 as described by Thomas [24]. The soil organic carbon content was determined by the Walkley and Black method described by Nelson and Sommers [25]. Total phosphorus and available phosphorus-Brayl were obtained by the method described by Olsen and Sommers [26]. The exchangeable bases (Ca++, Mg ++ and K+) were determined by extraction with buffered ammonium acetate at pH 7, before reading by atomic absorption spectrophotometry (Ca++ and Mg++) and by flame photometry (K+). Total nitrogen was determined by the kjeldahl method [27].

- **Data processing**

The resulting SPI data as well as the temperature data were entered into the Excel spreadsheet to construct curves that highlight the variation in climate parameters.

III. RESULTS

1. Climate characteristics of the Gbêkê region

o **Monthly and annual standardized precipitation index**

Fig. 2 presents the standardized precipitation index (SPI) respectively, monthly (Fig. 2A) and annual (Fig. 2B) in the Gbêkê region over a period of 15 consecutive years (2003-2017 periods).

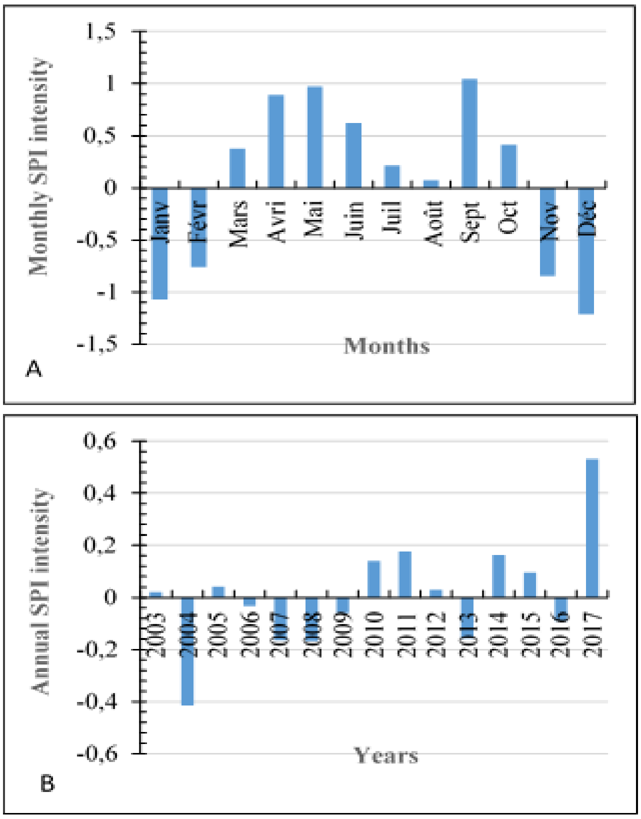


Figure 2: Monthly (A) and Annual (B) Standardized Precipitation Index (SPI) over the period 2003-2017 (15 years)

It is noted that the average of the monthly standardized precipitation indices observed is very variable and fluctuates with often a succession of months, sometimes dry, sometimes wet, highlighting both the bimodal nature of the rainfall regime and intermittent drought in the region. There are four months of deficit rainfall intensity (November-February) and therefore of intense drought with an SPI between -0.76 and -1.21 and then eight months of excess rainfall intensity (March-October) where the SPI is positive marking the wet months. However, a decrease in rainfall intensity is observed from June to August with an SPI ranging between 0.62 and 0.07. The months of May and September were wetter with an SPI substantially equal to 1.00. Moreover, the standardized precipitation indices recorded over the last fifteen years (2003-2017) indicate seven dry years (SPI < 0) with years 2006 and 2004 respectively where the drought was moderate and severe. Wet years (SPI > 0) were also recorded over the period considered in the order of humidity 2017 (SPI = 0, 53), 2011 (SPI = 0, 17) and 2014 (SPI = 0, 16). Overall, alternating dry months and wet months, as well as successive years of variable intensity during the last fifteen years.

o **Change in monthly and annual temperature**

Mean monthly and annual temperatures recorded during the same period (2003-2017) are shown in Fig. 3A and 3B, respectively.

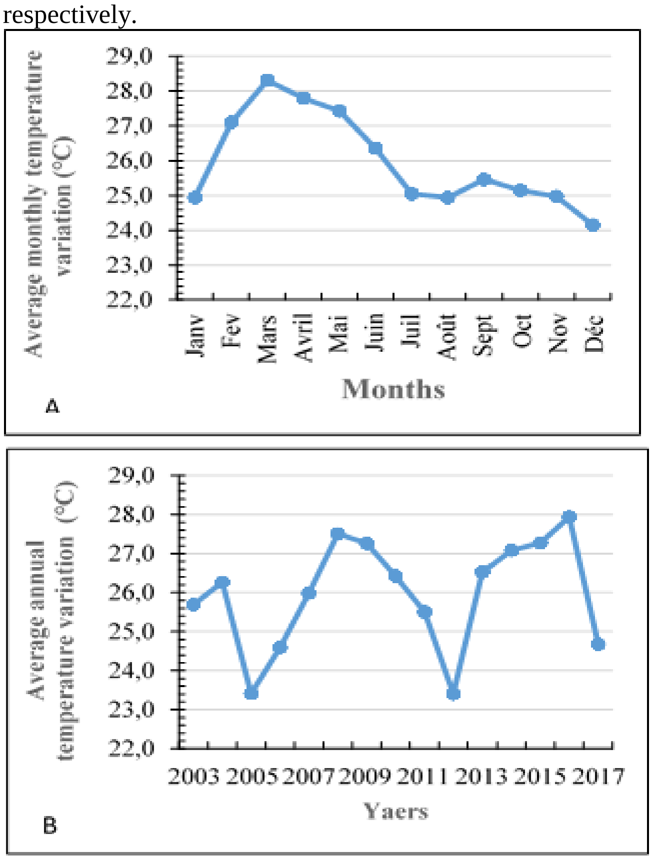


Figure 3: Variation monthly (A) and annual (B) temperature over the period 2003-2017 (15 years)

There are four distinct sequences where monthly temperatures fluctuate: two sequences where the temperature increases and two sequences where the temperature decreases. Thermal increases were recorded between January (24.9 ° C) and March (28.3 ° C) respectively, an increase of 3.4 ° C and between the month of August (24.9 ° C) and September (25.5 ° C), an increase of 0.6 ° C. Between March and August then September and December, temperatures are respectively down 3.3 ° C and 1.3 ° C. Regarding the multi-year variation, we can also observe that the temperatures are sometimes rising, sometimes decreasing with maxima respectively in 2004 (26.3 ° C), 2008 (27.5 ° C) and 2016 (27.9 ° C). ° C) then minima in 2005 and 2012 identical (23.4 ° C) and 2017 (24.7 ° C). Thermal increases recorded were 4.1 ° C and 4.5 ° C respectively between 2005-2008 and 2012-2016 while temperature decreases were respectively between 2004-2005 (2.9 ° C); 2008-2012 (4.1 ° C) and 2016-2017 (3.2 ° C).

- **Morphological and soil characteristics of the hydromorphic soil**

Fig. 4 shows the soil profile realized in the hydromorphic zone and its morpho-soil characteristics which have been described are presented in Table 2.

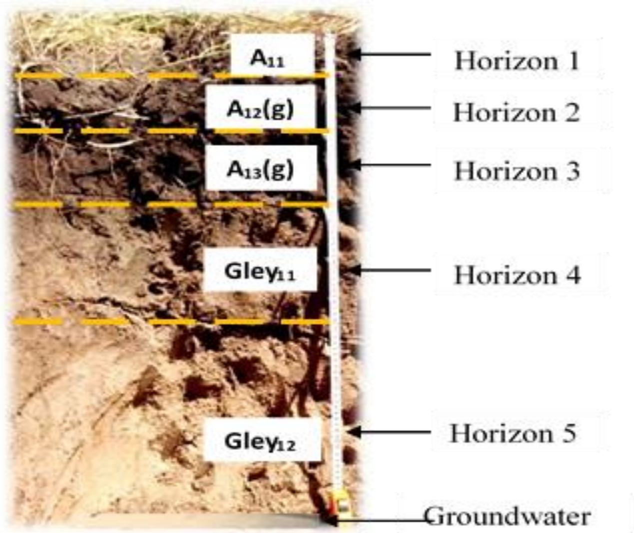


Figure 4: Hydromorphic soil profile of the site.

Table 2: Morphological and soil characteristics of the hydromorphic soil profile

Horizons	Depth	Color	Porosity	Roots	Texture	Structure
H1 (Furniture)	0 - 5 cm	Dark brown ; 7.5 YR 2.5/1	Highly porous	Enough many roots	Sandly	Particulate
H2 (Little compact)	5 - 15 cm	Spotted brown ; brown 7.5 YR 3/2 ; orange 7.5 YR 5/6,	porous	Enough many roots	Sandly	Particulate
H3 (Moderatly compact	15 - 28 cm	Spotted greyish brown ; brown 7.5 YR 4/2, orange 7.5 YR 6/8	Moderatly porous	Many roots	Sandly	Particulate
H4 (Compact)	28 - 50 cm	Spotted greyish brown ; brown 7.5 YR 6/2, Gley 1 7/N, orange 10 YR 6/8	Little porous	Some roots	Sandy-silty	Particulate to trend subangular polyhedral
H5 (Highly compact)	50 -70 cm	Spotted greyish brown ; brown 7.5 YR 6/1, Gley 1 7/N, orange 10 YR 6/8,	Not porous	Few roots	Sandy-silty	Particulate to trend subangular polyhedral
Groundwater	> 70 cm	-	-	-	-	-

There are five horizons ranging from A11 to Gley12 varying in thickness (0-70 cm), dark brown in color (7.5 YR 2.5 / 1) superficially to greyish-brown spotted; brown 7.5 YR 6/1, Gley1 1 / N, orange 10 YR 5/8 deep with a water table about 70 cm. They are coherent, very slightly porous and contain quite a few millimetric roots to a few rare, preferentially subhorizontal orientation up to 50 cm deep. Drainage was average at the surface and poor in the underlying layers. The transition was diffuse and of regular boundary in the superficial layers (A11-Gley1) and more or less clear in the underlying layers (Gley11-Gley12). The texture is sandy superficially with a particulate structure up to 28 cm and sand-silty, subangular polyhedral structure beyond 28 cm up to 70 cm deep. This description indicated a hydromorphic type soil without horizon B, characterizing its low level of evolution. It is a poorly evolved hydromorphic soil of colluvial input, and therefore an Arenic gleyic soil due to silting and hydromorphism induced by the water table.

- **Physico-chemical properties of hydromorphic soil**

o Granulometric composition

The analysis of the various grain size fractions of the composite sample in the 0-20 cm horizon is presented in Table 3.

Table 3: Granulometric composition of the hydromorphic soil in the horizon 0-20 cm

Granulométric fractions	Horizon (0-20 cm)
Clay (p.c.)	20.44
Fine silt (p.c.)	3.94
Coarse silt ((p.c.)	8.06
Fine sand (p.c.)	22.67
Coarse sand (p.c.)	44.89

It is a very sandy (67.56 p.c.) hydromorphic soil with a percentage of coarse sand (44.89 p.c.), twice as high as that of fine sand (22.67 p.c.). The percentage of clay (20.44 p.c.) is one third of that of total sand. In contrast, the silt level is very low (12 p.c.). These different proportions reflect the sandy character and partial or incomplete alteration of the hydromorphic soil cover of the area.

o Chemical composition

Table 4 presents the contents of the various minerals analyzed in the layer (0-20 cm) of the soil considered.

Table 4: Chemical characteristics of hydromorphic soil in the 0-20 cm horizon.

Chemical parameters	Horizon (0-20 cm)
pH (eau)	6.2
MO (gkg^{-1})	59.86
C (gkg^{-1})	34.7
N (gkg^{-1})	2.2
C/N	15.77
P_t ($mgkg^{-1}$)	50
P_{ass} ($mgkg^{-1}$)	7.67
Zn ($mgkg^{-1}$)	0.167
Fe ($mgkg^{-1}$)	2805
Cu ($mgkg^{-1}$)	<0.167
Mn ($mgkg^{-1}$)	43.33
K^+ ($cmolkg^{-1}$)	0.35
Ca^{2+} ($cmolkg^{-1}$)	0.63
Mg^{2+} ($cmolkg^{-1}$)	0.24
CEC ($cmolkg^{-1}$)	2.4

It indicates that the soil is slightly acidic (6.1 < pH < 6.5) and rich in organic matter (MO > 50 gkg^{-1}). Nitrogen and assimilable phosphorus levels are very low, respectively (N < 3 gkg^{-1}) and (Pass < 10 $mgkg^{-1}$), while total phosphorus is high (Pt > 50 gkg^{-1}). The C / N ratio is high (C / N> 12). The cation exchange capacity (CEC) is also low with a value of 2.4 cmol kg-1 relative to average (> 15 cmol kg^{-1}). The exchangeable cation contents in K+ (< 0.35 $cmolkg^{-1}$), Mg++ (< 0.5 $cmolkg^{-1}$), Ca++ (< 1 $cmolkg^{-1}$) are very low, as is the trace element content, in particular zinc (Zn < 0.8 $mgkg^{-1}$). On the other hand, the iron content is very high (Fe > 300 $mgkg^{-1}$) exposing the zone to iron toxicity. The manganese content is good (Mn < 50 $mgkg^{-1}$) and indicative for good germination of seeds compared to copper which indicates a very low level in the soil (Cu < 0.1 $mgkg^{-1}$).

o Mineral equilibria

The ratio of the different mineral balances established in this study is shown in Table 5.

Table 5: Chemical equilibria between hydromorphic soil minerals 0-20 cm

Mineral equilibria	Horizon (0-20 cm)
N/Pt	44
Ca/Mg	2.62
Mg/K	0.68
Ca/K	1.8
K /(Ca + Mg)	0.4
K/CEC	0.14

The value of the N / Pt ratio is very high (N / Pt = 44) while that of the Ca / Mg ratio is medium (Ca / mg> 2.62) and indicates a slight excess of calcium on magnesium in the soil. The ratios of Mg / K (Mg / K <4) and Ca / K (Ca / K <12) were also low. This indicates that magnesium and calcium are deficient compared to potassium in the soil. But, the sum of calcium and magnesium is in excess of potassium if we judge the K / Ca + Mg ratio (K / Ca + Mg <2). Potassium (K) and cation exchange capacity (CEC) also have a very low ratio (K / CEC <2). All these values of the different established reports show that the soil is variably very poor in nutrients.

IV. DISCUSSION

The study revealed that the hydromorphic soil of central Côte d'Ivoire studied, is physically present, as a soil little evolved colluvial input because of the absence of a horizon B. It is sandy, not very porous and compact appearance, recognized as an Arenic gleyic soil according to the international soil classification system [18]. The modifications of the climatic parameters of the region, characterized, in particular, by an irregularity and / or a bad distribution of the rainfall intensities more accentuated, and even associated with a variability of the current temperature [6]-[4] lead to a more or less severe drought from one year to the next. Indeed, some months and years were drier while others were more watered and therefore wetter. The soil, because of its sandy texture and its particle structure, remains very sensitive to evaporation in a drought condition [22]-[28], the direct consequence of which is the rapid drying of the soil [29] and also its flooding during the rainy season sometimes creating anoxia in the soil [30]-[31] where even water conditions in the soil [32], leading to a water deficit limiting the soil's water retention capacity [33]. These contrasting hydrodynamic properties of the soil constitute a constraint that significantly affects soil mechanisms [34]. They lead to an alteration of the soil structure by acting negatively on the porosity of the soil [35]-[36]-[37] thus explaining the porous aspect of the soil observed. In addition to changes in physical properties, dewatering or extreme soil moisture resulting from changes in soil moisture content leads to alteration of nutrient transformation [38] and their mobility in the soil [39]-[40] and the leaching of soluble forms of cations under moisture conditions due to the hydromorphic nature of the soil [41]. This explains the low levels of nitrogen, phosphorus, potassium, calcium, magnesium and cation exchange capacity observed. On the other hand, relatively high pH, carbon content and organic matter content indicate a slow decomposition of organic matter [42] due to drought conditions. The high iron content indicates that iron toxicity characterizes the area [43]. These modifications of the physical and chemical properties of the soil and even the fluctuation of the water in the soil confirm the impoverished nature of the transient hydromorphic soils between the lowland itself and the plateau. However, the presence of a water table around 70 cm attenuates the effects of drought at this level of the toposequence making it often suitable for rainfed agriculture. What makes hydromorphic soils, a fragile ecosystem whose improvement is a universal challenge [44]. In addition, the presence of numerous or rare roots, from surface horizons to deeper horizons, shows that the hydromorphic soils of central Côte d'Ivoire present no major obstacles to the rooting of annual herbaceous plants with fasciculated root systems [45]-[46]-[47], thus making them suitable for rainfed agriculture.

V. CONCLUSION

From our study, we consider that the hydromorphic soils of central Côte d'Ivoire are conducive to rainfed agriculture and more particularly to cereal or fruit crops with fasciculated roots, if we refer to the morpho-pedological description. However, it should be noted that these soils, due to their physical properties (sandy to sandy-loamy and compact texture, particulate structure with a subangular polyhedral tendency) are often exposed to drying by the evaporative effect of the soil. This event results from both the intensity and duration of drought on the one hand and the irregular distribution of rainfall and extreme moisture by accumulation of water saturating the soil. This led to the modification of the physical-chemical characteristics of the soil, thus making it poor. However, the impoverished character of the hydromorphic soils of central Côte d'Ivoire can be improved not only by the practice of cultivation techniques but also by a reasoned contribution of mineral fertilizers. In addition, the presence of the water table at about 70 cm in the hydromorphic soils of central Côte d'Ivoire mitigates the severe effects of drought, thus making them permanently suitable for rainfed agriculture.

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