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Pedological Study under Cocoa Trees and its Implication on Production in Soubré, Southwest Region of Ivory Coast

Bouadou oi Bouadou Félix [a]*, Kouadio Konan-Kan Hippolyte [a], Kouakou N'guessan Joel [a], Tano Adjoua Germaine [a] and Ettien Djétchi Jean Baptiste [a,b]

[a] UFR Earth Sciences and Mining Resources (STRM), Soil, Water and Geomaterials Sciences Laboratory (LSSEG), Soil Science and Sustainable Agriculture (PAD), University of Félix Houphouët-Boigny (UFHB), 22 BP 582 Abidjan 22, Ivory Coast, Côte d'Ivoire.
[b] Switzerland Center for Scientific Research in Ivory Coast (CSRS), Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Author KK-KH supervised the work. Author BBF designed the research protocol for the study. Fieldwork was carried out by Author KN'J. Authors TAG and EDJB contributed to the drafting of the manuscript. All authors read and approved the final manuscript.

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**Corresponding author: E-mail: felixbouadou@yahoo.fr;*

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ABSTRACT

Maintaining the fertility of cultivated soils in tropical countries such as Ivory Coast remains a major concern for producers because of crop failures. The aim of this study is to determine the soil characteristics of a cocoa plantation in the Soubré region (southwest of Ivory Coast: 6° - 7° N latitude and 5° - 7° W longitude), in order to improve production. In the centre of the plantation, a section of land (50 m × 50 m) was identified. Five soil pits were opened on this section of land, one at each corner and one in the centre. Soil samples were taken from each of the pits, in the 0-20 cm and 20-40 cm layers. Composite samples were then taken at these two depths for the analytical data. The pH, sum of exchangeable bases (S), cation exchange capacity (CEC), saturation rate of exchangeable bases (V), particle size fraction and organic matter content were measured and compared with threshold values known from the literature. The results show that pH (5.6 - 6.8) and assimilable phosphorus [P ass (130 - 350 ppm)] increase with depth and are in good proportion. Concentrations of potassium (K+ : 2.9 - 2.3 cmol/kg), calcium (Ca2+ : 29.1 - 47.2 cmol/kg) and magnesium (Mg2+ : 2.7 - 22 cmol/kg), as well as chemical properties (S : 35 - 73 cmol/kg, CEC : 48 - 80 cmol/kg and V : 73 - 90 %) are relatively good for cocoa production. However, organic matter (1.38%) and total nitrogen (N = 0.1 - 0.05%) are low. And high levels of clay (48%) and silt (23%) were noted from the first 20 cm depth. Spreading organic matter in the form of compost could therefore be recommended in order to correct the defective characteristics of the soils caused by the abundance of these two mineral particles: clay and silt, on the one hand, and deficiencies in nitrogen and organic matter, on the other.

Keywords: Cocoa tree; physical; chemical properties; soils; Soubré; Ivory Coast.

1. INTRODUCTION

In Ivory Coast, cocoa plays an essential role in the economic and social prosperity of the population [1]. Since the 1970s, the country has remained the world's leading producer, with production estimated in 2022 at 2.4 tonnes [2]. Cocoa provides nearly 40% of Ivory Coast 's export earnings and contributes over 20% of the country's GDP [3]. Some 500,000 producers and their families benefit directly from the socio-economic advantages of this sector [4]. Despite this, cocoa production in Côte d'Ivoire faces certain difficulties [5]. Moreover, the Ivorian cocoa farmer has found himself in a situation where he can no longer reproduce his traditional system, due to the lack of forest and fallow land. At the same time, aging plantations continue to produce more or less satisfactory harvests under degraded, nutrient-depleted soils [6-7]. This situation can compromise the sustainability of cocoa farming and is detrimental to the Ivorian economy [8]. During the 1990s, attempts were made to find solutions, including the adoption of improved seeds and, more specifically, the use of chemical fertilizers to make plantations more profitable. However, this approach has encountered obstacles in its application [9], due to the inaccessibility of fertilizers to farmers because of their high cost [10]. In addition to their unavailability, chemical fertilizers are water and soil pollutants. Faced with this situation, it appeared necessary to find other alternatives, in particular the use of organic matter [11]. Indeed, studies have shown the importance of organic matter such as compost in agriculture, which justifies its use [12]. As part of this study, the Centre de Production Biologique Durable (CPBD), an agricultural company located in Soubré, wishes to encourage the use of compost in cocoa plantations where yields appear to be falling, with a view to improving production. To do this, it is important to assess the initial soil characteristics of these plantations, in order to ensure sustainable management of this input, which is compost. In concrete terms, this involves : - determining the chemical and physical properties of soils under cocoa trees; - comparing chemical and physical property values with threshold values or reference standards for cocoa farming.

2. MATERIALS AND METHODS

2.1 Description of Study Site

The study was carried out at the beginning of the wet season (month of May), in 2021, in the cocoa plantation of the Centre de Production Biologique Durable (CPBD: agricultural inputs research center) in the Soubré locality (6° - 7° N latitude and 5° - 7° W longitude), 412 km from Abidjan (Côte d'Ivoire). The equatorial climate is characterized by high rainfall totaling nearly 1,600 mm annually, and good atmospheric humidity [13]. The mean annual temperature ranges from 25°C to 27°C, with little variation of less than 3.5°C [14]. This is an area of dense forest in steep decline under increasing anthropic pressure [15]. The experimental site is a ten-year-old cocoa field located at the top of a gentle slope (2%). The soils encountered are essentially strongly to moderately desaturated ferralsols [16].

2.2 Soil Characterization of the Cocoa Farm

The cocoa farm's soils were morphologically and physico-chemically characterized. A square-shaped portion of 2500 m2 (50 m × 50 m) was delimited in the center of the experimental plot. Five points on this portion were chosen for the opening of five soil pits, one at each corner and one in the center [17]. The profiles were described. The 0 - 20 cm and 20 - 40 cm layers of each pit were sampled. A composite sample was then taken for each depth level. The composite soil samples were sent to the laboratory for analysis. The following parameters were determined: pH, organic matter (OM), assimilable phosphorus, exchangeable bases (Ca, Mg and K), total nitrogen (Nt), cation exchange capacity (CEC), sum of exchangeable bases (S), base saturation rate (V).

2.3 Data Analysis

Chemical soil analysis results were compared with threshold values, reference standards and results from previous work.

Table 1. Soil parameters and normal threshold values

Soil parameters	Normal threshold values
A (%)	10 - 20
L (%)	< 30
A+L (%)	< 30
S (%)	20 - 30
OM (%)	2 - 3
Nt (%)	> 1
C/Nt	8 - 10
Water pH	6 – 7.5
Pass (ppm)	> 20
Ca^{2+} (cmolkg^{-1})	2 - 3
Mg^{2+} (cmolkg^{-1})	0.25 – 0.35
K+ (cmolkg^{-1})	0.15 – 0.35
Na+ (cmolkg^{-1})	> 1
S (cmolkg^{-1})	> 10
CEC (cmolkg^{-1})	5 - 10
V (%)	50

A: clay; L: silt; S: sand. Sources: ([18,19,20])

3. RESULTS

3.1 Physical Parameters: Average Proportions of Sand, Silt and Clay in Soils from the Site Studied

The results of the particle size analysis of the soils studied are presented in Table 2. Almost 45% of sand is concentrated in the superficial layers (0 - 20 cm) of the soil. Its content decreases in the underlying horizon (20 - 40 cm), reaching around 30%. This is an acceptable level for most soils. From the surface horizon (0 - 20 cm) to that below (20 - 40), silt contents are almost identical, at 26% versus 23% respectively. In contrast to silt and sand contents, clay proportions increase with depth, with higher contents estimated at 48%.

Table 2. Average proportions of sand, silt and clay in soils at the study site as a function of depth

	Depths (cm)	
Physical particles	**0 – 20**	**20 – 40**
Sand (%)	45	29
Silt (%)	26	23
Clay (%)	29	48

3.2 Organic Matter, pH and Available Phosphorus (Pass) in Cocoa farm Soils

Table 3 summarizes the average contents of organic matter, nitrogen and assimilable phosphorus, as well as the pH values and C/Nt ratios according to depth. Soil pH values show the soil to be acidic (pH = 5.6) at the surface (0 - 20 cm) and weakly acidic (pH = 6.8) at depth (20 - 40 cm). Overall, organic matter and nitrogen are poorly represented in the soil layer (0 - 40 cm). Organic matter levels are moderate (1.38%) on the surface (0 - 20 cm), but drop to 0.69% in the first 20 cm of the underlying layers. Superficial horizons are depleted of nitrogen (0.1%), which tends to disappear below (0.05%). Compared with nitrogen, assimilable phosphorus, sufficiently supplied at the surface, accumulates in the deep layer at levels 3 times higher (133 ppm vs. 352.7 ppm). On the other hand, the C/Nt ratio remained stable at all depths (-20 cm or -40 cm), with values close to 11 or even 12.

Table 3. Average values for organic matter, nitrogen, Water pH and assimilable phosphorus (Pass) in soils at the study site, by depth'

	Depths (cm)	
Chemical elements	**0 – 20**	**20 – 40**
MO (%)	1.38	0.69
Nt (%)	0.1	0.05
C/Nt	12	11
Water pH	5.6	6.8
Pass (ppm)	133.1	352.7

3.3 Characteristics of the Adsorbent Complex

Table 4 shows the characteristics of the adsorbent complex in the soil at the study site: alkalis (K+ and Na+), alkaline earths (Ca2+ and Mg2+), sum of exchangeable bases (S), saturation rate (V) and cation exchange capacity (CEC). In terms of alkalinity, potassium (K+) is evenly distributed along the soil profile, from top to bottom, with average levels of around 2.6 cmol.kg^{-1}. These levels are considered to be well above the norm, which is 0.35 cmol.kg^{-1}.On the contrary, the deep layers are enriched in sodium with a high concentration (1.4 cmol.kg-1). In terms of alkaline earth elements (Ca2+ and Mg2+), the soils at the study site are highly enriched in calcium (Ca2+). Moreover, levels rise from 29 cmol.kg-1 to 47 cmol.kg-1 in the 0 - 20 cm and 20 - 40 cm layers respectively. Magnesium (Mg2+) is well represented at the surface (2.7 cmol.kg-1 vs. 0.5 cmol.kg-1 = threshold value). In addition, it accumulates in the underlying layers with high levels, above the norm (21.8 cmol.kg-1).

3.4 Sum of Exchangeable Bases (S) and Saturation Rate (V)

Sum of exchangeable bases varies almost twofold from 35 cmol.kg-1 to 73 cmol.kg-1 from one layer (0 - 20 cm) to the other (20 - 40 cm). Overall, both horizons, 0 - 20 cm and 20 - 40 cm, are highly saturated with exchangeable bases, with average contents of 73% and 91% respectively, compared with the reference threshold values (50 - 90%).

3.5 Cation Exchange Capacity (CEC)

There was a significant difference between the various CEC values at depths of 0 - 20 cm and 20 - 40 cm. The value 48 cmol.kg-1 was observed on the surface (0 - 20 cm). Below, double this value was recorded (20 - 40 cm). However, both layers showed capacities well above the normal threshold required for cocoa farming (10 - 20 cmol.kg^{-1}).

Table 4. Adsorbent complex characteristics of study plot soils by depth.

	Depths (cm)	
Chemical elements	**0 – 20**	**20 – 40**
CEC (cmol.kg^{-1})	48	80
S (cmol.kg^{-1})	34.8	72.7
V (%)	72.5	90.8
Ca^{2+} (cmol.kg^{-1})	29.1	47.2
Mg^{2+} (cmol.kg^{-1})	2.7	21.8
K^{+} (cmol.kg^{-1})	2.9	2.3
Na^{+} (cmol.kg^{-1})	0.1	1.4

3.6 Relationships between Chemical Elements in the Soils of the Study Site

The proportion of ions bound to the clay-humus complex (CAH) provides information on the possibility of antagonism. Poor calcium nutrition can occur if the ratio of Mg2+/Ca2+ and K+/Ca2+ is greater than 1 each. In Mg2+-poor soils, this element may be deficient if the K+/Mg2+ ratio is greater than 1. In the case of the present study, the ratios obtained are all less than 1, with the exception of K+/Mg2+. The concentration ratios between the various chemical elements in the adsorbent complex are shown in Table 5.

Mg2+/Ca2+ ratio : The ratio of Mg2+ to calcium ions in the surface horizons (0 - 20 cm) and at depth (20 - 40 cm) hovers around 0.09 and 0.46 respectively, all of which are less than 1.

K+/ Ca2+ ratio : Concentrations of potassium ions relative to calcium (K+/ Ca2+) give a value relatively similar to that of the Mg2+/Ca2+ ratio in humus-bearing surface horizons. At depth, however, the Mg2+/Ca2+ ratio is almost 10 times greater than that of K+/ Ca2+. This shows that K+ ions are likely to disappear in the presence of Mg2+ ions (or else express a deficiency of potassium ions in the deeper layers).

K+/Mg2+ ratio : At the surface, the K+/Mg2+ ratio is 1.07 times greater than 1. This figure also decreases almost 10-fold in the underlying horizons. On the surface, K+ ions are more prevalent than Mg2+ ions. This observation highlights the risk of massive loss of Mg2+ ions to the K+ ion profile. At all depth levels, calcium ions are strongly represented, testifying to the good chemical fertility of the soils at the site studied.

Table 5. Average chemical element content ratios of study site soils by depth

	Depth (cm)	
chimical element ratios	**0 – 20**	**20 – 40**
K^+/ Ca^{2+}	0.01	0.05
Mg^{2+}/Ca^{2+}	0.09	0.46
K^+/Mg^{2+}	1.07	0.11

4. DISCUSSION

4.1 Organic Matter Characteristics of the Soils Studied

The C/N ratio of soils is an indicator of the ability of organic matter to decompose more or less rapidly in soils. Those obtained from the soils studied, at around 11 and 12, confirm good mineralization of organic matter and show soils in good conditions to ensure cocoa tree development [21]. Such a situation leads to the over-rapid release of nitrogen into the environment [22], compromising its availability, in the soil solution due to the intense leaching process undergone by tropical soils, particularly those in southwest region of Ivory Coast, which are under conditions of heavy rainfall. Furthermore, the nitrogen concentrations obtained (0.1 - 0.05% ≤ 1%) indicate soils depleted in this element ([18,23). Like nitrogen, organic matter is poorly represented (< 1%). This low level of organic matter could be linked to the ageing of the plants, which return little litter to the soil [24], in addition to the rapid mineralization of organic matter. These inadequate soil organic matter and nitrogen levels indicate a decline in soil fertility, with organic matter and nitrogen as factors limiting crop yields. This situation can compromise cocoa production, since to produce one tonne of cocoa, at least 45 kgN/ha/year and soils with a minimum organic matter content of 3% are required [25,26].

The pH values recorded on the surface and at depth show the acidic (5 < pH = 5.6 < 6.8) and weakly acidic (5.6 < pHwater = 6.8 < 7) character of these soils respectively. These pH conditions do not represent a constraint for the development of cocoa trees, which can reproduce on acidic (pH 4.5- 6) or slightly basic (pH 6.7-7.5) soils [27]. What's more, these pH conditions make phosphorus available. Moreover, phosphorus bound to clays by calcium, and that complexed by organic matter, exists in appreciable quantities only in slightly acidic soils with pH values between 5.5 and 7 [28]. Many authors consider this range of pH values favorable to the development of crop plants and cereal crops, particularly rainfed rice [29]. Assimilable phosphorus levels in the soils studied are above 100 ppm, indicating good nutrition of cocoa trees in this element [24,30].

4.2 Characteristics of the Adsorbent Complex in the Soils Studied

CEC is a good indicator of potential soil fertility. The values obtained in the present study are considered to be good, and well above the threshold described by Sawadogo [31]. which places these soils in the category of fertile soils likely to ensure better cocoa production.The good cation exchange capacity recorded partly explains the high saturation of exchangeable bases noted in these soils, reflecting their high nutrient content. Contrary to Van [32], in farralsols in humid tropical zones, due to heavy rainfall, leaching processes are very pronounced. By eliminating exchangeable cations from surface horizons, these pedological processes deplete the specific surface area of clays in exchangeable bases in soils under cocoa trees in south-western Côte d'Ivoire [25].

4.3 Physical Characteristics of the Soils Studied

The upper layers of the region's soils have a high sand content (45%), well above the threshold (20 – 30%) recommended by Quittet [18]. At this proportion, the defective character of the sands is present but, at the same time, attenuated by the presence of silt and clay. These horizons showed good drainage, air circulation and easy root penetration during in situ morphological characterization**.** On the other hand, the underlying layers (20 - 40 cm) are enriched in clay (48%) due to partial desaturation of the colloidal complex of the surface layers in lime (Ca2+), which, dispersing in the soil solution, migrates downwards, making this layer an accumulation layer [18]. The large amount of clay observed in the underlying layers (20 - 40 cm) is also probably due to the weathering of the parent material. The connection between the origin of the clays in the soil and the material had already been pointed out in the work of Millot [33]. However, according to Boyer [34], soils with more than 40% clay are unfavorable for cocoa cultivation, as they promote waterlogging that can asphyxiate roots and lead to rootlet necrosis. Defective silt-related properties appear in soils with a silt content of 30% or more. The average silt content of the soils studied tends towards the critical threshold, regardless of soil depth. The average clay content evolves in the opposite direction to that of the sand. On the other hand, in the 20-40 cm horizon, the clay content increases, with higher contents around 48%. Above 20% clay content, clay-related defects increase and worsen. The risk of compaction and asphyxiation is high in these soils under cocoa trees, from the first 20 cm down, due to the high clay and silt content. The use of compost is therefore recommended.

5. CONCLUSION

The present work was carried out in the south-west region of Côte d'Ivoire (Soubré, 6° - 7° north latitude and 5° - 7° west longitude). The aim was to develop an appropriate and sustainable fertilization strategy for cocoa. The aim is to characterize some essential chemical and physical properties of soils under cocoa with a view to improving and increasing cocoa production. On the surface, soils are depleted in organic matter and nitrogen, which can limit yields. On the other hand, soil pH conditions favor the availability of assimilable phosphorus and cocoa production. The characteristics of the adsorbent complex are good. A high clay content is recorded from the first 20 cm depth. As things stand, there is no need to apply mineral fertilizer to the soil. However, the use of organic fertilizer (compost) is recommended to improve organic and nitrogen stocks, essential for better yields.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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