Characterization of different soil types under cocoa, cashew and rubber fields in Center-West Region of Côte d'Ivoire

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ABSTRACT

Aims: This study was to characterize physical parameters of soils cocoa, cashew, and rubber fields.
Study design: the study had a random design. In each field 3 plots with 10 m apart was established.
Place and Duration of Study: Data collection was carried out in Haut-Sassandra region, located 31.5 km from Daloa (6°45’0”N, 6°34’60”W, at 235 m sea level), between February and April 2023.
Methodology: We dug 3 pits per plot for the description of the soil. Each pit was 80 cm wide, 100 cm long and 120 cm deep. The soil profile was described horizon by horizon where thicknesses were determined, physical characteristics and colors were distinguished. Soil samples were taken to determine the purposefulness, retention and permeability of soil types.
Results: The results revealed variations in soil type, texture, and porosity. Soils under rubber and cashew cultivation contained a higher proportion of fine elements compared to those under cocoa cultivation. The upper horizon of these soils was richer in organic matter and exhibited a darker color. The soil under cocoa cultivation was identified as a Modal Ferralsol (ferralitic soil of modal type), while the soil under rubber trees was classified as a desaturated Ferralsol (desaturated ferrallitic soil), and the soil under cashew trees was a Vertisol. Soil porosity measurements showed that cocoa soils had the highest values. Among the different soil types studied, cocoa cultivation is considered moderately favorable to this crop.
Conclusion: The particle size analysis reveals a higher proportion of sand in soils under cocoa trees, compared to those under rubber and cashew. In short, the soil of cocoa has properties particularly adapted to the cultivation of cocoa trees, promoting its optimal development.

Keywords: Soil characterization, Cocoa, Ferralsol, Porosity, Cashew, Rubber

1. INTRODUCTION

In Côte d'Ivoire, agriculture, a vital activity for rural populations, has intensified with the diversification of cash crops (Koffi & Oura, 2019a). In addition to cocoa, which accounts for 15-20% of the country's gross domestic product, cashew nuts and rubber are also essential resources for the national economy (Schroth & Ruf 2014). Rubber production, for example, increased from 60,000 tonnes in 1993 to 1.2 million tonnes in 2022 (FAOSTAT 2024). However, the most significant conversion of forest and agricultural land is in cashew nuts, which have increased from 8,500 to 350,000 tonnes in two decades (Koné et al., 2014; Ruf et al., 2019). The development of this crop began mainly in savannah area before spreading to forest areas (Dugué et al., 2002; Koffi and Oura, 2019). This diversification of crops was driven by volatile commodity prices and climate risks. Despite the importance of these monocultures for the Ivorian economy, they face many challenges, such as soil impoverishment and drought. Indeed, a large proportion of the farms were established without prior diagnosis of soil properties. The morphopheedological characteristics of the soil are a determining factor for successful arboriculture. Given the predominance of tree crops in the Haut-Sassandra region, it is essential to study the soils on which these crops are planted. This study therefore aims to analyse the morphopedological characteristics and water status of soils under cocoa, rubber and cashew trees.

2. MATERIAL AND METHODS

2.1. STUDY AREA

This study was carried out in the capital of the Haut-Sassandra region, more precisely in the sub-prefecture of Gboguhé, located 31.5 km from Daloa (6° 45 0 N, 6° 34 60 O, at 235 m altitude). The climate of the area is of Guinean type, characterized by two rainy seasons: a large (from April to July) and a small (from September to November). Annual temperatures range from 24.65°C to 27.75°C during the dry and wet seasons, respectively. Average annual rainfall is 1276 mm (Tra Bi et al., 2015).

The soil is ferrallitic, moderately leached, on ternary sediments. Its general morphology has a little developed humus horizon, topped by a thin litter of leaves on the surface. The underlying leaching horizon, 50 cm to 100 cm thick, is grey-beige or red brown in colour depending on the original richness of the parent rock in ferro-magnesium elements and has a sand to sand-clay texture (Dabin et al., 1960).

2.2. SOIL MORPHOLOGY STUDY

The morphological study of soil consisted in describing soil profiles through the opening of specific soil pits dug for this purpose. Thus, for each plantation, an elementary plot of 625 m2 (25 m x 25 m) was delimited. Within each plot, three soil pits were opened at the three corners of a nearly regular triangle 10 m in length (Figure 1). The pits were opened to standard dimensions of 80 100 120 cm (Jabiol and Baize, 2011). The description of the profiles of the various pits was carried out on the basis of the criteria defined by Baize et al. (2011), in addition to the simplified guide for the description of the soils of Delaunois (2022).

Tables should be explanatory enough to be understandable without any text reference. Double spacing should be maintained throughout the table, including table headings and footnotes. Table headings should be placed above the table. Footnotes should be placed below the table with superscript lowercase letters.

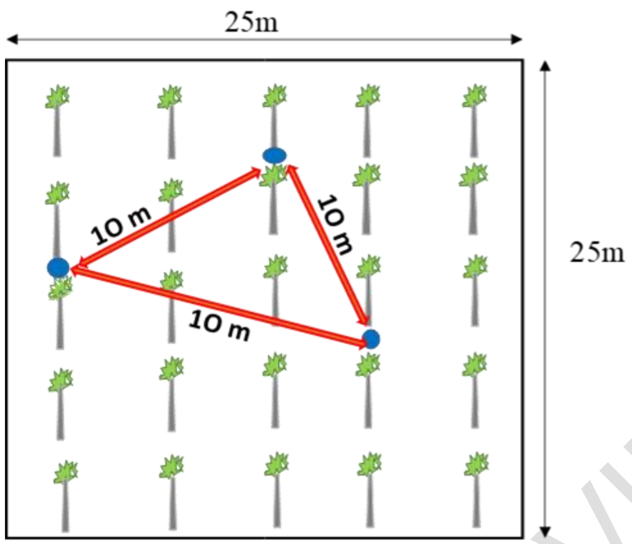

Figure 1: Pits Layout in each plot

1.3. DETERMINATION OF SOIL BULK DENSITY AND POROSITY

The soil bulk density for each horizon of the soil profile was determined from three samples taken using a constant volume cylinder (Blake and Hartge 1986). Each sample was wrapped in aluminum foil and dried at 105°C for 48 hours before being weighed using a Tscale electronic scale model NHB-(1500g x 0.01g). Total soil porosity was calculated from the apparent density (Da), assuming that the actual soil density is 2.65 g/cm^3 (Hao et al. 2008) using the following equation:

$$\text{Total porosity (\%)} = \frac{2.65 - \text{Da}}{2.65} \text{X}100$$

1.4. DETERMINATION OF SOIL PARTICLE SIZE COMPOSITION

The method used to determine soil particle size composition was the test of McRoberts and Nixon (1976). A soil sample dried at 105°C and sifted through a 2-mm sieve was taken and placed in a 200 ml test tube. Deionized water from air conditioner was added in a ratio of 2/3 water to 1/3 soil. The mixture was covered and vigorously stirred for 3 minutes, then allowed to settle for 24 hours. After this period, solid particles were settled and the height of the different layers of particles was measured to calculate the proportion of each type of particle. The resulting particle size composition was used to determine the soil type using the USDA Natural Resources Conservation Service (2020) textural calculator.

1.5. DETERMINATION OF SOIL PERMEABILITY AND RETENTION CAPACITY

Soil permeability of 0-10 cm layers was determined using 200 ml of deionized water to saturate 100 g of soil sifted through a 2 mm sieve (Colman, 1947). At the end of the flow, saturation humidity was measured by weighing.

1.6. DATA ANALYSIS

A variance analysis was performed using Statistix V.8 software to examine differences between the treatments studied. For comparison of the mean of each plot, the Tukey test was applied with a significance at 5%.

3. RESULTS AND DISCUSSION

3.1. EFFET OF COCOA, CASHEW AND RUBBER FIELDS ON SOIL MORPHOLOGICAL CHARACTERISTICS

The soil profile under cocoa trees consists of three distinct horizons. The first horizon, called A1, is 17 cm (0-17 cm) thick and is a humus horizon of a dark reddish brown color (2.5 YR 2.5/3). It has a high density of fine roots sub horizontal with diameter range from millimeter to decimeter. This horizon is characterized by a low compactness, absence of hydromorphic spots, an irregular boundary with a clear transition, a sandy texture and a lumpy structure, slightly polyhedral and sub-angular. The underlying layer B1, extends 36 cm and is a moderately humiferous-red (2.5 YR 4/6) horizon. There are few coarse elements (3%) and roots oriented sub horizontally, are millimetric to centimetric. The texture is clayey and the structure lumpy, with a tendency to polyhedral and sub-angular. This horizon is moderately porous and compact, with an irregular boundary and a clear transition. Drainage is medium. The third horizon, B2, is thicker 53-100 cm. Humiferous-red (2.5 YR 4/8) and contains no roots. The texture is clay and the polyhedral structure sub-angular.

This horizon is compact and not very porous. According to the CPCS classification (1967), this soil is modal ferralitic (Krasilnikov et al., 2009), while according to the WRB (2016) it can be classified as a Histosol. The soil profile under rubber is also divided into three horizons. The first A1 horizon, 36 cm thick, is a humus horizon of reddish black color (2.5 YR 2.5/1). Its structure is sub-angular, with a clumpy tendency, with many sub-horizontal roots (centimetric to decimetric sizes). It is very porous, not very compact, with an irregular boundary and a clear transition. The texture is sandy. The second horizon, A11, measures 32 cm (36-68 cm). Low humuferous, it is moderately compact and porous, dark red in colour (2.5 YR 2.5/2). Its structure is sub-angular polyhedral, with a lumpy tendency, and it contains few sub-horizontal roots (centimetric to decimetric). It is moist with medium drainage, and the boundary is irregular with a clear transition. The horizon is without spot of hydromorphy, and the texture is clay loam.

The third horizon (B1), measures 32 cm (68-100 cm). It is very humiferous, porous, compact and moist, with a dark reddish colour (2.5 YR 4/1) and a particulate polyhedral structure. This horizon does not contain roots and has a clay texture. Due to these characteristics, the soil of the rubber plantation is classified as a medium-desaturated ferrallitic soil (Krasilnikov et al., 2009).

The soil profile under the cashew trees is also made up of three horizons. The first horizon (A), has a thickness of 18 cm (0-18 cm). It is very humiferous and moderately porous, dark grey (5 YR 3/1). The structure is lumpy, slightly sub-angular, and there are some roots of centimeter size. It is not very compact, with a clear transition and an irregular boundary, the texture is clayey sand. The underlying horizon, B1, measures 32 cm (18-50 cm). Low humiferous and compact, it is grey in colour (5 YR 5/1). Its structure is sub-angular polyhedral, with few decimetric size roots and sub-horizontal. This horizon is wet, with good drainage, moderately porous and without hydromorphism. The transition is sharp with an irregular boundary, and the texture is clay.

The third horizon (B2), is 50 cm (50-100 cm) thick. Non-humiferous and porous, it is grey colour (5 YR 5/1) and contains no roots. Its structure is polyhedral sub-angular, with medium drainage and no hydromorphism. This horizon is compact, with a clay texture. This type of soil is characteristic of vertisols (Krasilnikov et al., 2009).

Soil profiles revealed deep soils (beyond 90 cm), which is an asset for the proper development of the root system in arboriculture (Koko et al., 2009). In addition, the surface layers of soil are very humid, which is a testament to the organic matter richness due to the degradation of crop biomass. Comparing the aerial biomass of different species, it appears that the rubber tree has a less developed canopy than those of the cocoa and cashew trees. These results confirm findings of Joncas et al. (2024), who measured aerial biomass values of cocoa, rubber and cashew trees, respectively, for 655, 69 and 73 tons. This biomass contributes to the enrichment of the soil’s surface horizons with nutrients, through humification and mineralization processes, thus promoting soil fertility. Soils observed are ferrallitic, characteristic of the region, and have a humus-rich surface horizon that gradually decreases in depth (Konan et al., 2022).

3.2. SOIL PARTICLE SIZE COMPOSITION

The soil particle composition of the three plots is summarized in Table 1. Results indicate that the average proportion of sand in the soil of the cocoa tree is 21% and 25% higher respectively than those observed in Cashew and rubber plots. On the other hand, the silt content is higher in the rubber plot, with a surplus of at least 16% compared to the soils of cocoa and cashew plots. The lowest clay content is found in the soil of the cocoa tree (8%), while the soils of the other two plantations contain at least 20% clay. These results reveal a sandy loam texture for the soil of the cocoa tree, a loam texture for the soil of the rubber, and a clay loam texture for the soil of the cashew tree. Analysis of soil particle size composition revealed varying textures between the crop plots. The soil under the cocoa tree is of sandy loam texture, with a low clay content, which could limit its chemical properties. Several studies have shown that low clay soil negatively affects the structure and the capacity to retain organic matter (Sauzet et al., 2024). On the other hand, the soil of the cashew nut plot, with a clay content above 30%, has better physical properties such as a structure favourable to the formation of good aggregates, a high cation exchange capacity in the presence of organic matter, and better water retention (Hwang, 2004).

However, this type of soil may be subject to compaction and crack formation during the dry season (Woldeyohannis et al., 2024).

Table 1: Particle size composition and soil texture of the three-crop plantations.

Field	Pit rep	Sand (%)	Slit (%)	Clay (%)	Textures
Cocoa	1	69	25	6	Sandy loam
	2	68	23	9	
	3	71	20	9	
	Mean	69	23	8	
Cashew	1	40	29	31	Clay loam
	2	43	31	26	
	3	49	14	37	
	Mean	44	25	31	
Rubber	1	54	29	17	Loam
	2	46	31	23	
	3	43	34	23	
	Mean	48	31	21	

3.3. SOIL BULK DENSITY AND POROSITY

Table 2 shows the average apparent density and mean soil porosity values for different crops. The variance analysis did not reveal any significant difference between the horizons for apparent density and, therefore, porosity values. The results indicate that the apparent density of soil under cashew cultivation decreases with depth, from 1.57 g/cm^3 to 1.43 g/cm^3 between 18 cm and 100 cm, while porosity increases from 39.73% to 44.97%. In the cocoa plot, the bulk density remains relatively stable, with an average of around 1.3 g/cm^3, and porosity is homogeneous over the entire soil profile. In contrast, under the rubber crop, the apparent density varies between 1.43 g/cm^3 and 1.54 g/cm^3, and porosity ranges from 41.63% to 44.93%. The results also show that porosity is particularly high at the surface horizon (0-36 cm). The mean values of porosity for the different horizons varied between 39.73% and 50.98%. From a soil physical quality criteria point of view, these values are considered average because according to Ouoba et al. (2014), an ideal porosity is between 50 and 70%, this would improve the hydrodynamic properties of soil

Table 2: Soil bulk density and porosity according to crop horizons

Field	Horizons	Bulk density (g/cm^3)	Porosity %
Cashew	0-18 cm	1.57±0.08	39.73±3.23
	18-50 cm	1.49±0.09	42.77±3.5
	50-100 cm	1.43±0.05	44.97±1.84
Probability		0.1602	
Cocoa	0-17 cm	1.29±0.04	50.37±1.43
	17-53 cm	1.30±0.15	49.91±1.64
	53-100 cm	1.27±0.16	50.98±6.31
Probability		0.9594	
Rubber	0-36 cm	1.43±0.12	44.93±4.48
	36-68 cm	1.54±0.09	40.83±3.40
	68-100 cm	1.52±0.05	41.63±2.06
Probability		0.3749	

3.4. SOIL WATER RETENTION AND PERMEABILITY

Table 3 shows the values of water retention capacity (Vr) and soil permeability (P) for different crops.

Soil water retention capacity ranged from 24.2% to 30.7%. The analysis of variance did not reveal any significant difference in retention capacity between different types of soil. In contrast, the soil permeability was significantly higher in the cocoa plot (19.8 ml/min), with infiltration four times faster than that of soil under rubber trees and twice as fast as that of soil under cashew trees.

Table 3: Water retention capacity and soil permeability as according to fields.

Fields	Temps (min)	V1(ml)	V2(ml)	Vr (ml)	Vr (%)	P(ml/min)
Cashew	18.3±2.5^{b}	200	148.7±4.2	51.3±4.2^{a}	25.7±2.1^{a}	8.2±1^{b}
Cocoa	7±0^{c}	200	138.7±7.6	61.3±7.6^{a}	30.7±3.2^{a}	19.8±1.1^{a}
Rubber	32.3±4^{a}	200	151.7±6.4	48.3±6.4^{a}	24.2±3.8^{a}	4.7±0.7^{c}

The study of the retention capacity and permeability of soils under different trees reveals that permeability is significantly higher in soils under cocoa trees compared to those under rubber and cashew. This could be attributed to the very sandy texture of the soil (about 70%). The infiltration rate is also faster, unlike soils under rubber and cashew trees, which have higher clay and silt contents. These results are in agreement with those of Khanh et al. (2024), who showed that the permeability of soils decreases as the proportion of fine elements (clay and silt) increases. Thus, soils with smaller coarse elements have a higher porosity, as also pointed out by Sauzet et al. (2024). This difference in permeability between plots is also related to variations in soil structure, which directly influence water distribution and movement. Sandy soils, such as those observed in cocoa trees, have a greater ability to allow water to infiltrate quickly, but this can lead to faster nutrient loss because the water drains away quickly, thus taking away nutrients (Hwang, 2004). On the other hand, more clay and silt soils in rubber and cashew tree plots, although they have slower infiltration, can retain better water and nutrient retention, which may be beneficial for crop growth over the long term, especially during dry periods. These results corroborate the work of Woldeyohannis et al. (2024), who observed that clay soils are able to better retain water and nutrients, although they are more likely to compact under certain conditions. However, it is important to note that clay-rich soils, while having better water and nutrient retention, are more likely to compact, especially during periods of high mechanical pressure (e.g., in agricultural activities). Soil compaction can lead to decreased porosity and permeability, creating adverse conditions for plant roots and reducing their access to water and nutrients. This could be a major problem for rubber and cashew crops, which are grown on soils with higher clay proportions. Thus, the management of soil physical properties, including texture and permeability, is crucial to optimizing agricultural yields. Proper management of plant cover, tillage and irrigation practices could maximize the benefits of these soils by limiting the risk of nutrient loss and improving water retention where necessary (Konan et al., 2022).

4. CONCLUSION

This study showed the variability of soils physical characteristics of cocoa, rubber and cashew. The soils under these crops are mainly characterized by their depth and richness in organic matter. The soil under cocoa crops is distinguished by a significantly higher permeability, which makes it particularly favourable for arboriculture. Density decreases significantly with depth. The soils of Gboguhé have an average density of 1.46 g/cm3. The particle size analysis also reveals a higher proportion of sand in soils under cocoa trees, compared to those under rubber and cashew. In short, the soil of cocoa has properties particularly adapted to the cultivation of cocoa trees, promoting its optimal development.

CONSENT (WHERE EVER APPLICABLE)

All authors declare that 'written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal."

Disclaimer (Artificial intelligence)

Option 1:

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 the writing or editing of this manuscript.

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