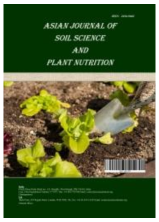

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Physico-chemical Characterization of the Soils of New Heveicolate Localities of Côte d'Ivoire: Case of the Departments of Man (West) and Toumodi (Centre)

Koffi Antoine[1*], Soro Dogniméton[1], Diomandé Métangbo[2], Konan Djézou[3], Essehi Jean Lopez[3] and Obouayeba Samuel[3]

[1]UFR Agroforesterie, Université Jean Lorougnon, Laboratoire Amélioration de la Production, Agricole, BP 150 Daloa, Côte d'Ivoire.
[2]Université Peleforo Gon Coulibaly, UFR des Sciences Biologiques, B. P. 1328 Korhogo, Côte d'Ivoire.
[3]Centre National de Recherche Agronomique (CNRA), Station de Recherche de Bimbresso, 01 BP 1536 Abidjan 01, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Author KA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SD and DM managed the analyses of the study. Authors KD, EJL and OS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In order to assess the suitability of soils for rubber cultivation in the departments of Man and Toumodi, two new rubber-growing areas, a study was carried out to evaluate the physical, physico-chemical and chemical characteristics of soils under rubber trees (*Hevea brasiliensis*). The methodology used consisted of a physical description of twelve soil pits, coupled with chemical analyses of the soil samples taken. The pedological profiles carried out revealed that these soils belong mainly to the Ferralsol class with distinctive characteristics, except for those of Kimoukro (Toumodi) which belong to the Cambisol class. The Toumodi soils, of silty-clay-sandy texture, are

**Corresponding author: Email: antoinekoffi7@gmail.com;*

provided with coarse elements (≥30 p.c) with good internal drainage in the surface horizons. More or less deep, depending on the topographical position, Toumodi soils are slightly acidic (pH = 6) and less supplied with nitrogen and exchangeable bases. The soils of Man, on the other hand, have a sandy-clay texture, with more than 30 p.c. of clay from the surface to the depths. The bulk density (Da = 1.6 ≥ 1.5 g/cm3) was higher for the soils of this locality compared to those of Toumodi (Da = 0.8 ≤ 1 g/cm3). The soils of Man, which are less rich in nitrogen and carbon, are more acidic (pH = 5.4). Exchangeable base contents and CEC are high, mainly in the upper surface horizons.

Keywords: New rubber growing areas; physico-chemical characteristics; Hevea brasiliensis; Côte d'Ivoire.

1. INTRODUCTION

Southern Côte d'Ivoire has always been the preferred area for the development of industrial crops [1]. Among these crops, the rubber tree (*Hevea brasiliensis*) was absent for a long time until 1956, when a sector of industrial plantations began [2,3]. According to [4], the first rubber plantations were developed in the Bonoua region in 1953 before spreading to other parts of Côte d'Ivoire. In 1956, experimental plantations were established near Dabou. After independence, the Ivorian state created a rubber estate with three plantations in 1966: Anguédou in the south-east, Bettié in the east and Cavally in the west [4]. Village rubber cultivation was introduced in 1968 on 100 ha [1]. The adoption of rubber trees by family farming through projects in the 1960s, 1980s and 1990s in Côte d'Ivoire can be analyzed as a process of innovation [5]. Hevea cultivation was for a long time confined below the 1500 mm isohyet [6]. From the 1990s onwards, the state and donors disengaged themselves for twenty years from the monitoring and financing of rubber cultivation. It was during this period that the farming community became more involved in rubber cultivation [5]. The growth in rubber production was impressive from this period onwards. From 100,000 tonnes in 2000 [5], Ivorian rubber production increased to 780,000 tonnes in 2019 [7]. The determining factors of this rubber boom in Côte d'Ivoire in the traditional production zones, which are favorable to rubber cultivation, are pedological and climatic. Indeed, these localities are subject to a transitional equatorial climate, characterized by an average annual rainfall of 1,710 mm [8]. This situation is an important condition for groundwater recharge [9]. Furthermore, the soil thickness in these areas is greater than 1.5 m, which allows optimal development of the taproots and improves the plant's water supply possibilities during the dry season [10]. In addition, these soils are rich in phosphorus and organic matter and the pH varies between 5.5 and 6.0 [11].

However, rapid population growth, coupled with the high demand for agricultural land in the traditional area, is reducing the availability of arable land, which is sought after by farmers in general. Indeed, cash crops (rubber, oil palm, coconut, pineapple, etc.), most of which are perennial, and food crops are actively competing for arable land [12]. All these constraints have led actors in the rubber sector to encourage the creation of rubber plantations in so-called marginal areas. According to [13], the practice of sustainable agriculture implies an understanding of the relationship between cultivated plant population and soil quality. According to these authors, these two factors determine the efficiency and sustainability of the cultivation system. This therefore indicates that knowledge and control of the physico-chemical characteristics of the soil of a cropping plot is a prerequisite for good cultivation practice. With this in mind, this study was initiated to determine the physico-chemical characteristics of the soils of two new rubber-growing localities in Côte d'Ivoire, namely Man and Toumodi. The general objective of the study is to assess the suitability of the soils of these two departments for rubber tree cultivation. More specifically, the aim is to evaluate the physico-chemical characteristics of the soils on the one hand, and to identify the different types of soil on the other. All these parameters will make it possible to determine the suitability of these soils for rubber tree cultivation.

2. MATERIALS AND METHODS

2.1 Study Environment

The study was conducted in the departments of Man in the west and Toumodi in the centre of Côte d'Ivoire (Fig. 1).

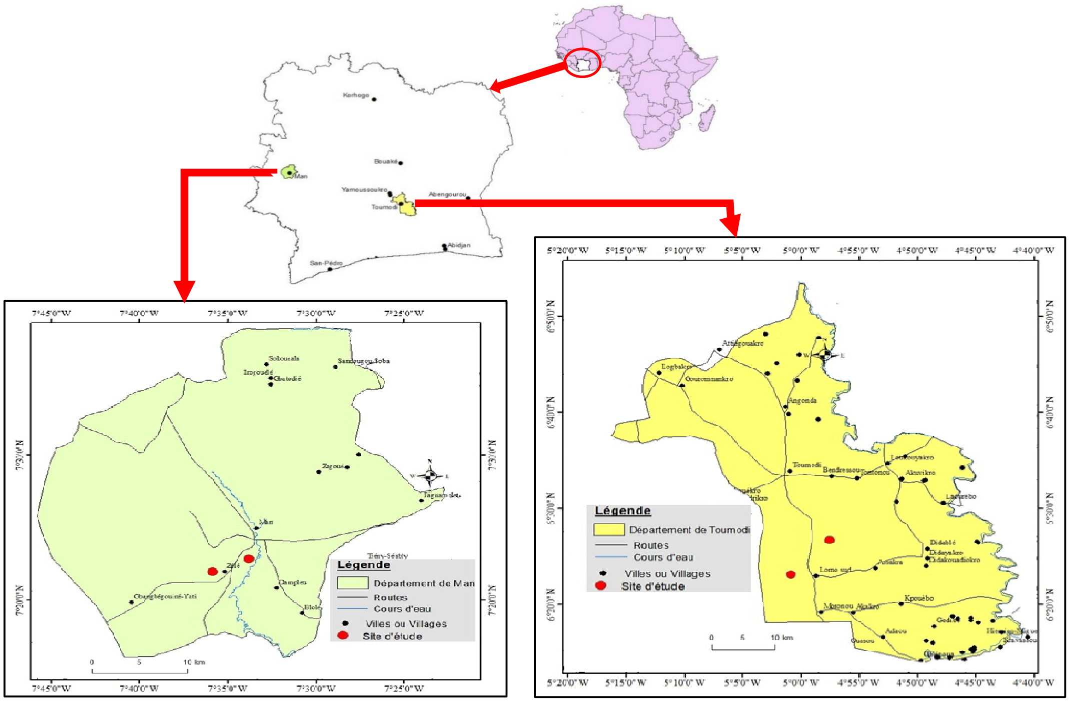


Fig. 1. Location of the departments of Man and Toumodi

The Department of Man is located between 7°20' and 7°30' North latitude and between 7°30' and 7°40' West longitude, in the administrative region of Tonkpi. Climatically, this semi-mountainous area of Man is distinguished from the rest of Côte d'Ivoire by its high rainfall, above 1,500 mm/year, and its very rugged relief [14]. The soils found in this locality are mainly Ferralsols [15].

The Toumodi department is located in the centre of Côte d'Ivoire, in the forest-savanna transition zone between 6°20' and 6°30' north latitude and between 4°55' and 5°10' west longitude. It is characterized by a transitional equatorial climate with two maxima and two minima [11,16]. The average annual rainfall is estimated at 1,200 mm, with an average temperature of 26°C and an average relative humidity of 77 p.c. [17]. The soils, quite varied, are classified among ferralitic soils (Ferralsols) moderately desaturated in bases, hydromorphic soils (Gleysols), tropical brown soils (Cambisols), etc.

2.2 Data Collection

Data collection focused on morpho-pedological and chemical characteristics. Data on the morpho-pedological characteristics of the soils were collected in the field from soil pits on the selected plots with dimensions of 1 m long, 0.8 m wide and 1.5 m deep without natural obstacles. The pits were opened according to the topographical positions of the upper (HV), mid-slope (MV) and lower (BV) slopes. The physical description focused on vegetation, local slope, topographical position and surrounding micro-relief [18]. A total of twelve soil profiles were described, including six per locality and three per study site.

Soil samples were taken from the most representative profiles in the study area. Thus, eight soil samples, i.e. four samples per locality and two per site, were taken and subjected to physical (granulometry, coarse element rate and bulk density) and chemical (pH, C, N, P, K, Ca, Mg, and CEC) laboratory analyses. Before any analysis, the samples taken and packed in coded plastic bags, were dried in the open air and sieved at 2 mm in diameter.

2.3 Physical Characteristics of Soils

Soil texture was estimated by the tactile method, which consists of forming a coil in the hand after moistening the soil with water [19]. This texture is specified in a textural triangle applied to the granulometry determined by Robinson's pipette method as described by [20].

2.4 Coarse Element Loading of Floors

The coarse element load of the soils was determined in the laboratory from soil samples taken from the different horizons. The samples were sieved using a 2 mm mesh sieve. The coarse elements (Ø > 2mm) were washed with water, dried in an oven at 105 °C for 24 hours and weighed. The mass of the reject was related to the total mass of the sample. The proportion of coarse elements was determined using the following formula:

Rate of coarse elements (p.c.) **=**

$$\frac{mass\ of\ the\ sieve\ residue}{total\ floor\ weight}\ x\ 100$$

2.5 Soil Bulk Density

Apparent density (Da) makes it possible to determine the nature and organization of the constituents and the porosity of the soil [21]. It thus indirectly assesses permeability, resistance to root penetration [22], cohesion of horizons [23,24] and soil water reserve [25]. The method used for determining bulk density is that of sand [23]. It is determined according to the equation:

$$Da = \frac{M}{V}$$

Da = bulk density (g/cm3)
M = dry mass of the sample (g)
V= volume of the sample taken and dried (cm3).
The volume (V) of the sample taken and dried is determined by the following equation:

V = (Weight of calibrated sand – Remaining sand weight) × 1,56

2.6 Chemical Composition of the Soils Sampled

Soil organic carbon (C) and total nitrogen (N) levels were determined using the methods of Walkley and Black [26] and Kjeldahl [27] respectively. Total phosphorus (P) was determined by colorimetry after extraction with perchloric acid [28]. Exchangeable bases were determined by flame emission spectrometry (K^+ and Na^+) and atomic absorption (Ca^{2+} and Mg^{2+}) after extraction with ammonium acetate.

2.7 Determination of the Different Types of Soil

The soils were described and named according to the morphological properties of WRB, version 2014. They were named based on texture, color, depth and chemical characteristics.

2.8 Statistical Analysis of the Data

The averages of the various parameters evaluated were compared by an analysis of variance, to observe or not any significant differences between the two localities, at the 5 p.c. threshold. ($p < 0.05$) with the STATISTICA software version 7.1. The difference is significant for values of $p < 0.05$.

3. RESULTS

3.1 Physical Characteristics of Soils

Evaluation of the physical characteristics of the soils at the two sites showed that the average depth is 150 and 116 cm at Man and Toumodi respectively.

In Man, the A horizon is high at a depth of 20 cm with a clay texture with 47.3 p.c. of clay (Table 1). This horizon consists of 5 p.c. of coarse elements. Horizon B has a silty-clay-sandy texture (43.5 p.c. of fine sand) with 33 p.c. of coarse elements. At mid-slope, horizon A is 16 cm thick and is mainly clay (50.8 p.c.); this gives it a Clay texture. It contains 11 p.c. of coarse elements. Horizon B has a silty-clay texture with 34.1 p.c. of fine sand and 22 p.c. of coarse elements. Horizon A on the lower slopes is thicker with 22 cm in depth. It has a sandy-clay texture overall with 42.7 p.c. of clay and consists of 10 p.c. of coarse filler.

At Toumodi, the A horizon at the top of the slope has an average thickness of 7 cm. The texture of this horizon is sandy loam with a dominance of coarse sand (47.5 p.c.). It consists of 15 p.c. of coarse elements. Horizon B has a silty-clay-sandy texture with 37.7 p.c. of coarse sand and 38 p.c. of coarse elements. At mid-slope, horizon A is 5 cm thick and has a sandy loam-clay texture with 42.9 per cent coarse sand. It contains 17 p.c. of coarse elements. Horizon B, with a silty-clay texture and a dominance of coarse sand (30.8 p.c.), is composed of 48 p.c. of coarse elements. At the bottom of the slope, horizon A is 10 cm thick and consists of 16 p.c. of coarse elements. The texture of this horizon is silty-clay with 36.1 p.c. of clay. Horizon B also has a silty-clay texture with 39.1 p.c. of clay and 53 p.c. of coarse elements.

Evaluation of the physical characteristics of the soils indicates that the soils of Man are deep with a thicker Arabic layer (horizon A) with a sandy-clay texture. The elemental load of these soils is lower. On the other hand, the soils of the Toumodi locality are shallower, as is their A horizon with a silty-clay-sandy texture with a high elemental load.

3.2 Apparent Density of the Soils in Both Localities

The determination of the apparent density of the soils indicates statically significant differences (p-value = 0.001) between the localities of Man and Toumodi. The apparent density of Man is 1.6 g/cm3, that of Toumodi is 0.8 g/cm3.

3.3 Chemical Composition of the Soils Taken from the Two Study Sites

Analysis of the chemical parameters of the soils shows that in Man, the soils are very acidic (pH = 5.4) (Table 2). This acidity is most noticeable on the upper slopes, with a pH between 4.5 and 5.4 (Table 2). On the lower slopes, the first two horizons are more acidic (5.4 and 5.2) than the last horizon (46-76 cm with pH = 5.9). The average carbon value of 1.8 g.kg-1 is normal. On the other hand, these soils are deficient in nitrogen (0.1 g.kg-1). The average C/N ratio of 14.5 reflects the rapid decomposition of organic matter. They generally have a low organic matter content (OM = 3 g.kg-1). On the other hand, the organic matter content is average (OM = 4.6 g.kg-1) in the first horizons (0-20 cm) of the upper and lower slopes. At the level of the absorbent complex, the soils of Man are characterized by an average cation exchange capacity (CEC = 9.9 cmol.Kg-1) and a low content of exchangeable base (S = 2.5 cmol.Kg-1). In these soils, the exchange complex (V = 26.6 p.c.) is highly desaturated.

At Toumodi, the soils are weakly acidic (pH = 6) and have a low organic matter content (OM = 2.7 g.kg-1). The average carbon content is normal (1.6 g.kg-1), in contrast to the total nitrogen content, which is very low (0.2 g.kg-1). The rate of decomposition of organic matter is acceptable with a C/N ratio = 11.3 < 12. With regard to the absorbent complex, Toumodi soils are characterized by a low cation exchange capacity (CEC = 7.4 cmol.Kg-1). The sum of the exchangeable bases (S = 2 cmol.Kg-1) and the saturation rate (V = 27.8 p.c.) are low in these soils, indicating high desaturation.

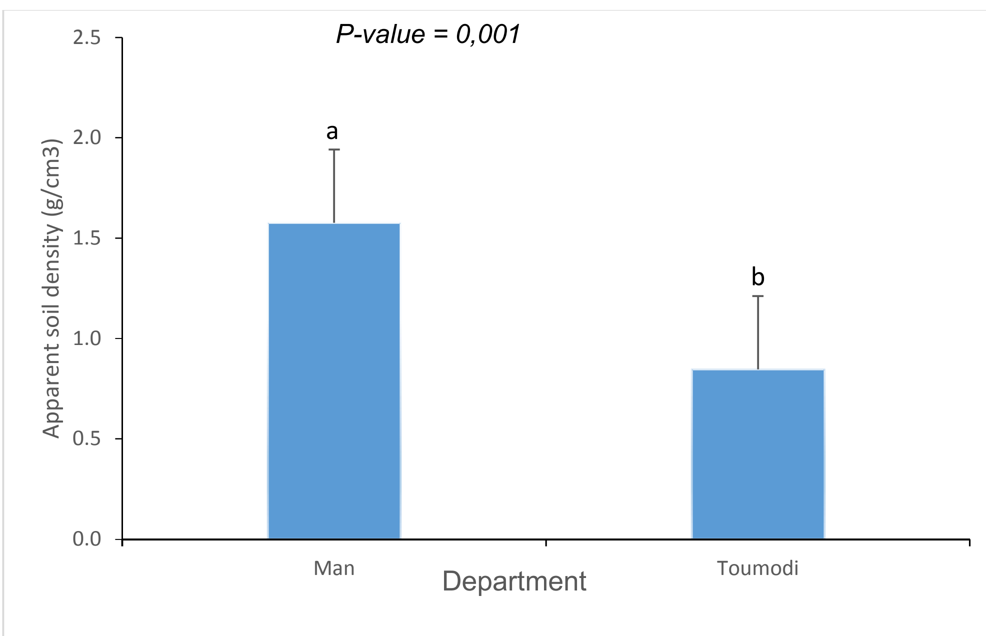


Fig. 2. Apparent soil density at the Man and Toumodi sites

Table 1. Physical characteristics of different soil horizons

Locality	Toposequence	Horizons	Depth (cm)	CEG (p.c.)	Granulometry (p.c)					Texture
					Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	
Man	HV	A	0-20	5c	47,3±3,3a	4,4±0,9b	8,7±1,4a	24,1±0,4b	14,8±1,1ab	Sandy clay
		B	20-150	33a	25,7±3,6b	5,3±0,5b	9,9±1,3a	43,5±3,6a	15,2±1,3ab	Limono-clay-sandy
	MV	A	0-24	11b	50,8±3,4a	3,6±0,9b	6,1±0,8b	24,8±2,1b	14,7±1,7ab	clayey
		B	24-150	22a	29,8±8,2b	6,4±1,2a	10,3±1a	34,1±9,4a	18,9±2,8a	Clay loam
	BV	A	0-22	10b	42,7±3a	5,7±0,9a	9,3±1,1a	25,1±1,5b	17±1,3a	Sandy clay
		B	22-150	19b	29,4±14,6b	6,1±1,6a	11,8±1,8a	33,6±9,8a	18,8±2,4a	Limono-clay-sand
	Average value		150	17b	32,9±2,0	5,6±0,5	10,0±1,1	33,9±4,1	17,1±1,8	Sandy clay
Toumodi	HV	A	0-17	15b	12,8±9,7b	8,9±3,9b	7,4±2,1b	22,7±3,7a	47,5±12,3a	sand-loamer
		B	17-122	38a	25,6±4,6b	10,1±8,9b	9,8±5,6a	16,6±2,3ab	37,7±19,5a	Limono-clay-sand
	MV	A	0-21	17b	20,6±6,4b	11,4±2,1b	7±2,6b	15,7±4,3ab	44,2±9,1a	Limono-clay-sand
		B	21-130	48a	35,7±10,1a	11,7±7,7b	11,2±9,8a	10±2,9b	30,8±9a	Clay loam
	BV	A	0-15	16b	36,1±6,3a	18,2±3,5a	11,6±2,5a	14±3,4b	20±7,2ab	Clay loam
		B	15-97	53a	39,1±1a	19,4±1,7a	13,1±1,8a	11±1b	17,3±2b	Clay loam
	Average value		116	31a	30,9±8,0	13,5±5,0	10,7±1,8	13,8±3,8	30,8±11,5	Clay loam

CEG: Coarse Element Load; p.c. = percentage; cm = centimete r; p.c.: percent; HV: High Slope; MV: Medium Slope; BV: Low Slope

Table 2. Proportion of chemical elements in the different soil horizons of the two localities

Locality	Topographical level	Depth	Organic material					Complex absorbant (cmol/kg)					
			pH	**C ($g.kg^{-1}$)**	**N ($g.kg^{-1}$)**	**C/N**	**MO ($g.kg^{-1}$)**	**CEC**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**S ($cmol.Kg^{-1}$)**	**V (p.c)**
Man	High Slope (HV)	0-20	4,5±0,2a	2,7±0,7b	0,2±0,04a	13,5±7,2bc	4,6±0,3a	14,8±1a	1,7±0,2a	1,2±0,3a	0,1±0,02a	3,1±0,1a	20,6±1,2c
		20-49	4,6±0,3a	2,1±0,7a	0,2±0,01a	10,5±5,2b	3±0,4b	10,7±1,4a	1,6±0,2a	0,9±0,3a	0,02±0,03b	2,5±0,1b	23,1±1,2c
		49-95	5,4±0,3b	1,5±0,6a	0,1±0,01a	15±10,2b	2,6±0,9c	10,4±1,4a	0,6±0,4b	0,7±0,3a	0,1±0,02a	1,5±0,02c	14,2±1,1d
	Middle Slope (MV)	0-20	5,7±0,3b	2,7±0,5b	0,1±0,04a	27±7,1bc	4,6±1,9a	10,7±0,3a	2,1±0,2a	1,1±0,8a	0,2±0,02a	3,4±0,8a	31,7±2,3b
		20-40	6,4±0,5c	1,9±0,4a	0,1±0,01a	19±5,3b	3,2±1,8b	9,8±0,2b	1,9±0,2a	0,8±0,8a	0,1±0,02a	2,8±0,01b	28,3±2,2c
		40-70	6±0,5c	1,8±0,5a	0,1±0,01a	18±6,5b	3,1±0,9b	9,2±0,2b	1,7±0,2a	0,5±0,1b	0,01±0,001b	2,2±0,01b	23,6±1,3c
	Bottom of Slope (BV)	0-22	5,4±0,3b	1,5±0,4a	0,2±0,02a	7,5±1,3d	2,6±0,2c	7,2±1c	1,8±0,2a	1±0,4a	0,1±0,02a	2,9±0,01b	40,6±2,7a
		22-46	5,2±0,2b	1,2±0,4a	0,1±0,03a	12±3,6b	2,1±0,1c	8,6±2,2ab	1,8±0,2a	0,8±0,2a	0,01±0,02b	2,6±1,6b	30,3±2,4b
		46-76	5,9±0,3ab	0,8±0,5ab	0,1±0,03a	8±2,2c	1,4±0,4d	7,5±1,4c	1,2±0,2a	0,5±0,2b	0,04±0,02b	1,7±0,5c	23,2±1,2c
	average value		5,4±0,6	1,8±0,6	0,1±0,03	14.5±5,2	3±1	9,9±2,1	1,6±0,4	0,8±0,2	0,1±0,05	2,5±0,6	26,2±7,1
Toumodi	High Slope (HV)	0-17	6,4±0,8c	1,3±0,1a	0,2±0,01a	6,5±5,2b	3,1±0,3b	7,5±1,4c	1,5±0,2a	1,1±0,1a	0,1±0,02a	2,7±1,1b	36,4±2,4b
		17-42	5,3±0,2b	1,6±0,2a	0,2±0,01a	8±7,2b	2,7±0,8c	6,2±1,6d	1,5±0,2a	0,6±0,2b	0,2±0,02a	2,2±1,1b	35,3±2,4b
		42-70	5,1±0,2b	1,8±0,1a	0,1±0,01a	18±19,1a	2,3±0,8c	7,6±1,5c	1,3±0,2a	0,4±0,2b	0,1±0,01a	1,8±0,5c	23,8±1,3c
	Middle Slope (MV)	0-21	6,4±0,4c	1,7±0,2b	0,2±0,01a	8,5±2,1bc	4,4±0,3a	5,7±1d	1,3±0,7a	0,9±0,3a	0,1±0,02a	2,3±1,1b	40,5±2,9a
		21-42	6,4±0,9c	2,6±0,4a	0,2±0,01a	13±5,3b	2,7±0,8c	6,9±0,4cd	0,9±0,5b	0,8±0,3a	0,2±0,02a	1,9±1,6c	27,3±1,6c
		42-65	6,5±0,6c	1,4±0,7a	0,1±0,1b	14±19,1a	2,3±0,3c	7,8±1c	0,7±0,5b	0,5±0,2b	0,1±0,02a	1,3±0,7c	17,1±1,1d
	Bottom of Slope (BV)	0-15	6,2±0,3c	1,5±0,8a	0,2±0,02a	7,5±3,1c	2,6±0,6c	10,4±2,7a	1,7±0,2a	0,9±0,3a	0,1±0,02a	2,7±1,2b	25,8±1,3c
		15-37	6,3±0,2c	1,7±0,5a	0,1±0,1a	17±5,2b	2,9±0,6c	7,9±2,2c	1±0,4a	0,9±0,3a	0,2±0,02a	2,1±1,5b	26,3±1,3c
		37-64	5,5±0,4b	0,9±0,4ab	0,1±0,01a	9±4,7c	1,5±0,4d	6,7±1,8d	0,5±0,4b	0,6±0,3b	0,1±0,1a	1,2±2,1c	17,6±1,1d
	average value		6±0,5	1,6±0,4	0,2±0,03	11,3±10,7	2,7±0,7	7,4±1,2	1,2±0,3	0,7±0,2	0,1±0,04	2±0,5	27,8±7,7

C=Carbon; N=Nitrogen; MO=Organic Matter; CEC=Cation Exchange Capacity; Ca=Calcium; Mg=Magnesium; K=Potassium; S=Sum of Exchangeable Bases; V=Saturation Rate; The letters a, b, c and d indicate significantly different average values in the column at the 0.05 p.c. probability threshold

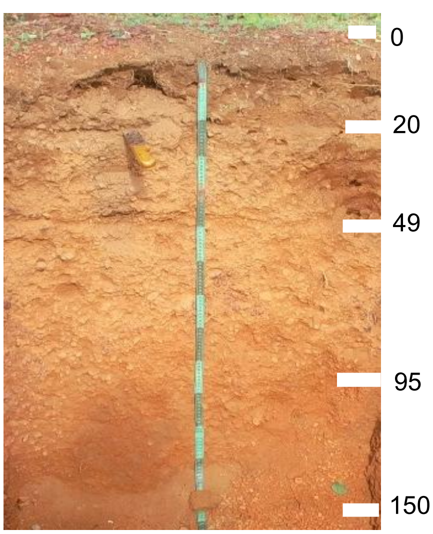
3.4 Soil Types in Both Localities

On the basis of morpho-pedological criteria (color, texture, depth, granulometry...) and the chemical characteristics of the soils described above, only one type of soil was observed in the locality of Man. These are ferralsols (Fig. 3A and B). These soils are characterized by a predominantly dark brown coloring ranging from 7.5 YR 3/2 to 7.5 YR 5/8 from the surface to the depth. They are generally highly evolved and moist with fewer coarse elements. Numerous millimeter and centimeter roots are found, mainly in the surface horizons, which are characterized by high biological activity. Their structure is generally subangular polyhedral in the horizons. Its horizons are relatively non-porous to very porous. The humus layer has an average thickness of 20 cm over all the toposequences studied.

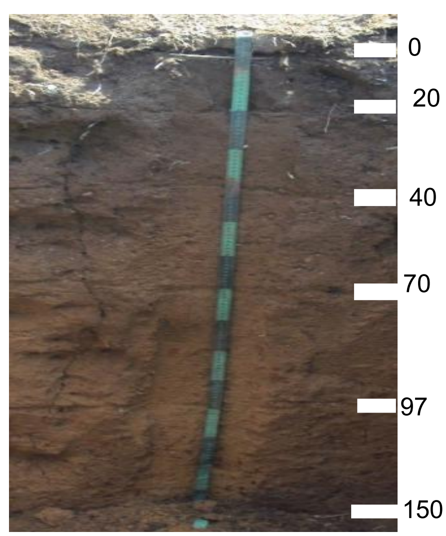
In Toumodi, in the centre of Ivory Coast, two types of soil have been identified. These are ferralsols and cambisols (Fig. 3C and D). Toumodi Ferralsols have dark reddish-brown colors ranging from 2.5 YR 3/4 to 5 YR 3/4 with average thicknesses (20 cm). As for the cambisols of this locality, they are mainly characterized by the yellowish-brown color varying from 10 YR 4/6 to 10 YR 5/8 from the surface to the depths. These soils are shallower than those of Man. The structure is generally lumpy in the surface horizons and polyhedral fragmentary in the deeper horizons. These horizons are relatively non-porous to porous. The open soil profiles at Toumodi show phenomena of rejuvenation, hydromorphism and deep armoring. Rejuvenation is characterized by ochre and yellowish ochre patches.

4. DISCUSSION

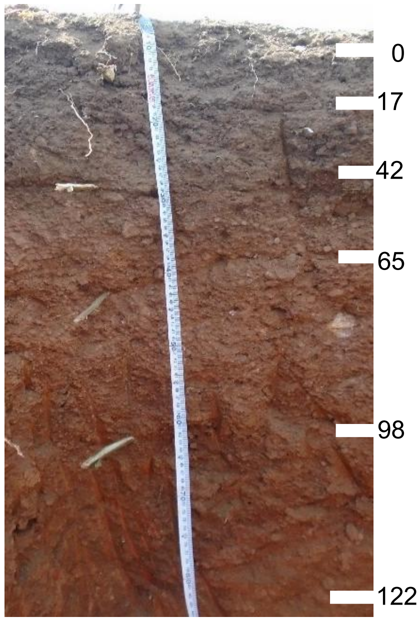
Evaluation of the physical characteristics of the soils indicates that the soils of Man are deep with a thicker Arabic layer with a sandy-clay texture. This texture is found throughout the depth of the profile with at least 30% clay. The elemental load of these soils is lower. This significant depth of the Man soils could be reinforced by the dense vegetation with large trees in this mountainous region, and by a large rainy season of more than three months, with an average rainfall of more than 1600 mm/year. In addition to this, there is a high activity of microorganisms observed in these soils, creating the conditions for a strong and rapid pedogenesis. Indeed, [16,29] confirm the good depth of the soils by these bioclimatic parameters and the intensity of rock weathering. The pronounced alteration of these rocks has strongly reduced the rate of coarse elements in these soils. According to [30], a soil with such a texture, deep and porous, offers very favorable conditions for rubber cultivation. Indeed, due to its large specific surface area and colloidal properties, clay has a high cation-binding capacity, which is responsible for the chemical fertility of the soil.



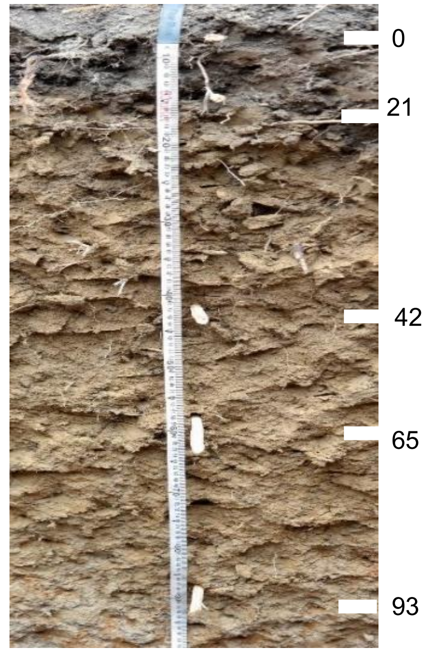
A: Ferralsol of Man



B: Ferralsol of Man



C: Ferralsol of Toumodi



D: Cambisol of Toumodi

Fig. 3. Some soil types in the study localities (A and B = Man soil; C and D = Toumodi soil)

Unlike the soils in Man, those in the locality of Toumodi are shallower. The surface horizon has a silty-clay-sandy texture with a high elemental load. The formation of these soil types is due to a high proportion of iron oxide, responsible for soil induration [31,18]. The process of induration and hydromorphy observed in the Toumodi soils would have the effect of reducing the volume of exploitable soil by the roots. Also, for soils with horizons whose coarse element load varies from 30 to 50 p.c., fertility could be significantly reduced, especially if this coarse element load is found over 20 to 30 cm in the upper horizons of the profile [32]. This load constitutes an obstacle to the elongation of the rubber tree's taproot [30], whose trajectory could be modified and growth slowed.

The study of the apparent density of the soils, indicates that the soils in the locality of Man are denser (1.6 g/cm3) than those of Toumodi (0.8 g/cm3). The high apparent density values of the soils in Man could be explained by the massive structure observed in connection with the high clay content [33]. On the other hand, the lower bulk density values in Toumodi would reflect good aeration of the soils with a high level of coarse elements [34]. The proportion of coarse sands in Toumodi soils is high (40 p.c. ≤) in the surface horizons (0-20 cm). This high coarse sand content makes these soils light, filtering and could give them low structural stability, making them highly sensitive to physical and chemical degradation.

The evaluation of the chemical parameters of these soils indicates, although acidic, that the soils of Man have a rapid decomposition of organic matter and are highly desaturated. Based on the analytical data, these are Ferralsols according to WRB [15] with a predominantly dark brown coloring (7.5 YR 3/2). Ferralsols develop on metamorphic rocks (schists, Gneiss and Migmatite) which are the basis of the soil acidity. [35,36] have also shown that the cultivation of these soils activates the mineralisation of organic matter, thus favouring the production of organic acid, nitric acid and the loss of alkaline (K^+, Na^+) and alkaline earth cations (Ca^{2+}, Mg^{2+}). However, [30] reports that the rubber tree is a plant that registers satisfactory growth on soils with acid pH values between 4 and 6.5. In Toumodi, the soils are less acidic and show an equally rapid decomposition of organic matter. Despite the normal cation exchange capacity of Toumodi soils, they are highly desaturated. Indeed, desaturated soils contain a higher or lower proportion of H^+ ions, which causes a decrease in biological activity in the humus horizons. This decrease in activity could therefore cause a decrease in nitrification and low nutrient content [37]. Also, work by [31,18] showed that Cambisols are rich in iron oxides which are responsible for soil induration.

5. CONCLUSION

The physico-chemical characterization of the soils of the new rubber-growing areas of the Ivory Coast indicates that the soils of the locality of Man belong to the Ferralsols class. These soils are deep, with a very thick topsoil layer. Its texture is sandy-clay with few coarse elements. These soils are dense, strongly acidic and desaturated with intense biological activity.

In the Toumodi area, Ferralsols and Cambisols can be found. They are shallow with a less thick Arabic layer. The texture is silty-clay-sandy with a high elemental load. The Toumodi soils are less dense, less acidic and highly desaturated with also a strong biological activity.

At the end of this study, the soils of the locality of Man seem to be more favorable to rubber cultivation than those of Toumodi. However, the agronomic characteristics of the rubber plantations, i.e. development, rubber productivity of the rubber trees and latex quality in the localities of Man and Toumodi need to be assessed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kouamé ANG, Amani MK, Gnaboa R, Traoré KS, Houenou PV. Analysis of hydrological phenomena in an urbanized watershed: case of the city of Yamoussoukro (central Côte d'Ivoire). LARHYSS Journal. 2014 ;17. P-ISSN 1112-3680 / E-ISSN 2521-9782
2. Losch B. Village rubber cultivation in the Côte d'Ivoire: Contribution to the study of the evolution of production systems in forest areas. Doctoral Thesis. 1983;153.
3. Hirsch R. Two perspectives on agricultural policies. The West African oilseed sectors: What perspectives in the face of integration and globalization? Oilseeds, Fats, Lipids. 2002;9(6):426-432.
4. Akmel MS. Socio-economic issues and constraints linked to rubber cultivation in ɔdjukru country in the region of Dabou (Côte d'Ivoire). European Scientific Journal. 2016;12(35):20.
5. Ruf F. The adoption of rubber in Côte d'Ivoire. Price, mimicry, ecological and social change. Rural economy. Agriculture, Food, Territories. 2012;330-331:103-124.
6. Sangare A, Koffi E, Akamou F, Fall CA. State of plant genetic resources for food and agriculture in Côte d'Ivoire. FAO, second national report; 2009.
7. APROMAC. Rubber production in Côte d'Ivoire. www Apromac.ci. Consult on June 11, 2020; 2020.
8. Ake GE. Impacts of climate variability and anthropogenic pressures on water resources in the Bonoua region (South-East of Côte d'Ivoire). Doctoral thesis, Univ. Cocody, Côte d'Ivoire.2010;200.
9. Banton O, Bangoy LM. Hydrogeology: environmental multiscience of groundwater. Montreal; 1997.
10. Essehi JL. Agronomic valuation of farm waste by composting for the improvement of vegetative growth in bagged nurseries of *Hevea brasiliensis* Muell. Arg. (Euphorbiaceae) in Ivory Coast. 2019;185.
11. Avenard JM, Brou. Aspect of geomorphology. The natural environment of Côte d'Ivoire, ORSTOM. 1971;391.
12. Yoro G, Godo G. Research on cassava-based cropping systems in farmers' areas in the south - east of the Côte d'Ivoire (Bonoua - Adiaké - Aboisso). Partial observations on family farms in the region. DRSTOM document (Adiopodoumél). 1983;35.
13. N'Guessan KA, Diarrassouba N, Koné B, Alui KA, Yao-Kouamé A. Morpho-pedological characterization and constraints to the development of *Lippia multiflora* on two tropical soils in Côte d'Ivoire. Journal of Animal and Plant Sciences. 2015;24;3:3814-3828
14. Boyossoro KH, Kouamé KF, Saley BM, Biémi J, Ibrahima T. Climate insecurity and geohazards in Côte d'Ivoire: study of the risk of water erosion of soils in the semi-mountainous region of Man (western Côte d'Ivoire). Science and Planetary Changes/ Drought. 2007;18(1):29-37.
15. WRB. World Reference base for soil of resources. World soil Resources reports N°. 2014;106.

16. Brou T. Climate variability in Côte d'Ivoire: Between social perceptions and agricultural responses. 2005;40.
17. Bakayoko O, Assa AM, Coulibaly B, N'Guessan K. Carbon storage in stands of *Cedrela odorata* and *Gmelina arborea* in Côte D'Ivoire. European Journal of Scientific Research. 2012;121.
18. Yao-Kouamé A. Study of brunified soils derived from materials from the Toumodi volcano-sedimentary complex on average Côte d'Ivoire. PhD thesis in Natural Sciences, University of Cocody / UFR STRM. 2008;210.
19. Yoro GR. Pedology for sustainable soil management. Introductory course for agents of Gabon's Stabilization and Equalization Funds. CNRA; 2002.
20. Anderson JM, Ingram JSI. Tropical soil biology and fertility. A handbook of methods. CAB International. 1993; 221.
21. Chauvel A. Research on the transformation of ferralitic soils in the tropical zone with contrasting seasons. Sci strasbourg thesis, and ORSTOM works and documents. 1977;532.
22. Maertens. Mechanical resistance to the penetration of some ferralitic soils North of Côte d'Ivoire. 1964;37.
23. Yoro GR. Apparent density measurement methods. Analysis of the dispersion of results over a given horizon. ORSTOM Notebook, Pedology Series. 1992;423-429.
24. Yoro GR, Assa A. Structural modification of two ferralitic soils in the northwest of Côte d'Ivoire under the effect of trampling by man. 1986;35.
25. Henin S, Gras R, Monier G.. The cultural profile Masson et Cie, Paris; 1969;332.
26. Walkley A, Black IA. An examination of the Degt jareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sciences. 1934;(37):29-36.
27. Mohammad A, Flowers TH. Evaluation of Kjeldahl digestion method. J. Res. (Sci.). 2004;15(2):159-179
28. Olsen SR, Sommers LE. Phosphorus. In Methods of soil analysis. Ed Page et al. Madison, Wisc: ASA and SSSA.1982;403-430.
29. Kassin KE, Koko L, N'Goran KE, Yao-Kouamé A, Yoro GR. Soils favorable to cocoa cultivation in west-central Côte d'Ivoire in a context of drying out Int. J. Biol. Chem. Sci. 2012;6(3):1148-1157.
30. Companion P. Natural rubber. Coste R. ed, G.P. Maisonneuve and Larose, Paris. 1986;595.
31. Boyer J. Ferrallitic soils. Fertility factors and land use. Initiations Documentations Techniques, N°52 X, ORSTOM, Paris. 1982;384.
32. Boa D. Characterization, hydrodynamic properties, constraints and potential of gravelly soils: Case of Booro-Borotou (Touba region, north-west of Côte d'Ivoire). Doctoral thesis. University of Abidjan. Abidjan. 1986;131.
33. Gala BTJ. Determination of the physical, chemical and hydrodynamic characteristics of soils for the optimization of irrigation in sugar cane cultivation. Advanced Agronomy Diploma Thesis, Pedology option. Yamoussoukro Higher School of Agronomy. Côte d'Ivoire. 2000;69.
34. Assi KH, Angui KTP, Tamia AJ. Effects of cultivation and natural constraints on some physical properties of a ferrallitic soil in Central West Côte d'Ivoire: consequences on soil degradation. European Journal of Scientific Research, vol. 23 n°1. 2008;149-166.
35. Dabin B. Study of a method for extracting humic matter from the soil. Soil Sciences. 1971;1:47-63.
36. Delaunois A. Simplified guide for the description of soils. Tarn Chamber of Agriculture. 2006;37. Available:http://www.agritarn.com.
37. Landon JR. Booker tropical soil manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Oxon, UK: Longman. 1991;500.

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