Original Research Article

Physical and hydrodynamic textural parameters of soils: the case of the rubber plantations of the Centre National de Recherche Agronomique (CNRA) Anguédédou in south-eastern Côte d'Ivoire

ABSTRACT

The rubber tree, a species of Amazonian forest tree, is cultivated for its latex, which is rich in natural rubber. Its cultivation is of economic, social, climatic and environmental importance. However, it is often accused of destroying the soil. To clear up this misunderstanding, a study was carried out to characterise the physical and hydrodynamic characteristics of soils under rubber in south-eastern Côte d'Ivoire. According to the biotope (rubber plantation, abandoned rubber plantations and forest) and the age of the rubber plantations, this study selected 12 plots. These included ten rubber plantations that were divided into four age categories: 1-5 years, 6-10 years, 11-20 years, and 21-40 years. Additionally, a secondary forest was also selected as a control, which was located in close proximity to these plantations. Furthermore, a rubber plantation that had been abandoned for more than eight years was also selected considered as a transition between the active plantations and the secondary forest. In these biotopes, soil samples were taken using an auger and sent to the laboratory to determine soil texture. Using the Yoro sand method and the single ring device, the apparent density, porosity and water infiltration rate of the soils were determined. The results show that the soil texture of the CNRA Anguédédou rubber plantations in southern Côte d'Ivoire is generally clayey. On the other hand, the texture of the soils of the youngest plantations (1 to 5 years old) is silty-clayey with more than 37% clay and a low water content. However, the soils of old rubber plantations with a clay texture have high water content. The soil compactness observed in young rubber plantations is corrected as the plantations age.

Key words: physical and hydrodynamic parameters, soil, rubber canopy, Anguédédou, Côte d'Ivoire.

INTRODUCTION

The rubber tree (*Hevea brasiliensis*), a species of Amazonian forest tree, is grown for its latex, which is used in the manufacture of tyres, condoms, surgical gloves, etc. In response to the world's growing need for natural rubber, producing countries are steadily expanding their rubber plantations. This is the case in Côte d'Ivoire, where the area under rubber plantations rose from 550,000 ha in 2016 (Gbodjé, 2021) to 732,000 ha in 2022 (APROMAC, 2023). According to this author, production from these plantations is 1.39 million tonnes of dry rubber. This makes Côte d'Ivoire the third largest producer in the world and the largest in Africa. Today, rubber is the country's third largest agricultural export after cocoa and oil palm. To maintain this performance in the long term, the Ivorian rubber industry plans to further increase the area under rubber plantations, by expanding into new so-called marginal zones (Koffi, 2023). Thousands of hectares of land are being used for rubber plantations. The sheer size of the areas planted to this crop in Côte d'Ivoire is currently causing controversy. For a long time, rubber trees have been singled out as a soil-destroying crop, although this has not been demonstrated by scientific studies (Epron et al., 2011). A number of studies carried out on this subject have shown that soils in rubber agroforestry systems have different physico-chemical properties to those in primary forest (Zhang et al., 2007; Selma et al., 2014). In order to remove this ambiguity, we need to gain a better understanding of the health, functioning and evolution of rubber plantation soils by determining their physical and hydrodynamic properties. The general objective of this study is to assess the impact of rubber cultivation on the physical and hydrodynamic parameters of soils in south-eastern Côte d'Ivoire. Specifically, the aim is to determine the soil texture of rubber plantations of different age classes and to assess the hydrodynamic parameters of the soils in these biotopes.

I. STUDY SITE

The study was conducted in the rubber plantations of the Centre National de Recherche Agronomique (CNRA), located in Anguédédou in the south-eastern of Côte d'Ivoire in the District of Abidjan, specifically in the commune of Songon, between 5°22' and 5°25' north latitude and 4°8' and 4°10' west longitude (Figure 1). The commune is characterised by an average annual temperature of 28.8°C. Total annual rainfall is 1,545 mm, with a long dry season from December to February, followed by a long rainy season from March to July, a short dry season in August and a short rainy season from September to November (SODEXAM, 2023). The soils are ferralitic (Brou, 2005). According to Kambiré et al (2018), the population of Songon is made up of 64.25% Ebrié natives, 12.60% non-natives and 18.68% non-natives. Agriculture is mainly dominated by food crops such as maize, cassava, rainfed rice, pineapple and plantain, followed by perennial crops such as rubber and oil palm (Yéo & Amani, 2016).

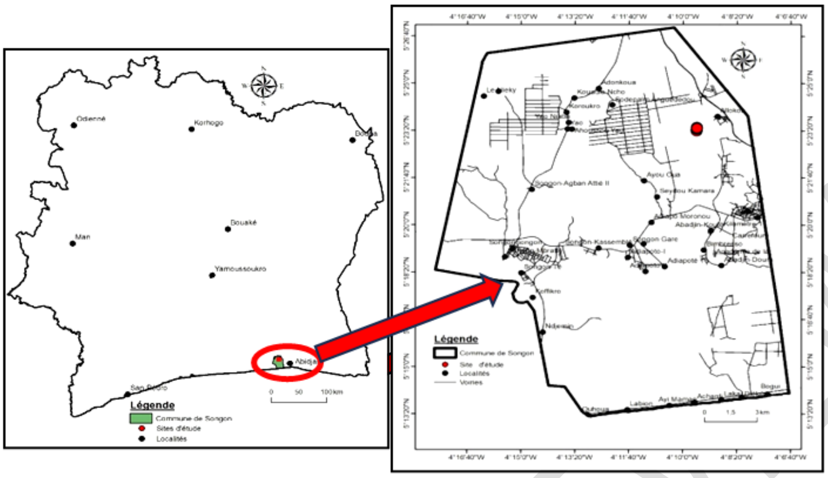

Figure 1: Location of the study site (Source: CNRA, 2022)

II. METHOD

1. Choice of study sites

The study sites were selected according to the biotope (rubber plantation, abandoned rubber plantations and forest) and the age of the rubber plantations. This investigation led to the selection of 12 plots, including 10 rubber plantations grouped into four (04) age classes ([1 to 5 years], [6 to 10 years], [11 to 20 years] and [21 to 40 years]), a secondary forest, close to these plantations, taken as a control and a rubber plantation abandoned more than 8 years ago, considered as a transition between the plantations and the secondary forest.

2. Data collection

Inside these biotopes, soil samples were taken at three (03) sampling points along a 100 m transect (Figure 2). A distance of 50 m was maintained between two (02) successive sampling points. At each point, after clearing the soil of litter, soil samples were taken from 0 to 20 cm and from 20 to 40 cm depth using an auger (Figure 3A). Along the transect, samples from the three sampling points at the same depth were mixed in a bucket to make a composite sample (Figure 3B). Part of this composite sample was placed in a labelled bag. In other words, two (02) composite samples per plot were taken. In total, 24 soil samples were taken from all 12 study plots. These samples were air-dried in the laboratory for a fortnight. A quantity of 100 g of each soil sample, sieved to 2 mm mesh after drying, was used for chemical and textural analyses. The study of hydrodynamic parameters involved the careful vertical sampling of three soil cores per plot at a depth of 0-20 cm using a metal cylinder 4 cm in diameter (Yoro & Godo, 1990). The soil contained in the cylinder is collected and weighed in situ to determine the fresh mass and then taken to the laboratory in an envelope to be dried in an oven at 105°C. After 48 hours, each sample was weighed again to determine the dry mass. This method was used to determine the apparent density, total porosity and water content of the soil. Water infiltration capacity was assessed using a 15 cm diameter cylinder into which water was poured until it was full. The amount of water infiltrated into the soil was measured every five minutes for 90 minutes using a graduated ruler and stopwatch (Figure 3C).

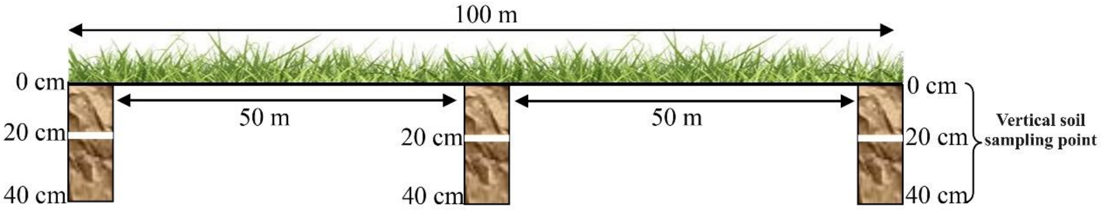

Figure 2 : Transect configuration for taking soil samples

Figure 3 : Field data collection
A: Auger sampling of the soil; **B:** Composition of the composite sample ;
C: Assessment of soil water infiltration capacity

3. Determination of data

3.1 Soil texture of different biotopes

Soil texture was determined by granulometric analysis in the laboratory using the "Robinson pipette" method (Buol et al., 2011). The method involves separating soil particles according to their size (clay, silt and sand). Soil textural classification was based on the USDA textural triangle (Buol et al., 2011).

3.1. Soil hydrodynamic parameters

3.2.1. Apparent density

Apparent density (Da) is an indicator of soil compaction. It can be used to determine porosity and thus indirectly assess permeability, resistance to root penetration (Maertens, 1964), the cohesion of horizons (Yoro, 1982) and soil water reserves (Henin et al., 1969). Da was determined by equation (1):

$$\boxed{\mathbf{D_a = \frac{M_s}{V}\,(g/cm^3)}} \qquad \mathbf{(1)}$$

Ms = Mass of dry sample (g); **V =** Volume of cylinder (cm3). According to Fies et al (1981), a well-structured soil generally has an apparent density of around 1.3 g/cm3.

3.2.2. Total soil porosity

Total porosity (TP) is the primary factor in soil fertility. It favours rooting, water storage for the plant and the circulation of air necessary for the proper functioning of the roots. Total porosity (TP) is estimated from the real density (Dr), which is a constant of 2.65 g/cm3, and the apparent density (Da) of soil samples according to equation (2):

$$\boxed{\%\boldsymbol{TP} = \mathbf{100} - \left(\frac{\boldsymbol{Da}}{\boldsymbol{Dr}}\right) \times \mathbf{100}} \qquad \mathbf{(2)}$$

3.2.3. Soil water content

The water content (W) of a soil is the quantity of water contained in a soil sample. It is a function of the porosity and permeability of the soil. The water content was evaluated by equation (3):

$$\boxed{\%\boldsymbol{W} = \left(\frac{\boldsymbol{mf - ms}}{\boldsymbol{ms}}\right) \times \mathbf{100}} \qquad \mathbf{(3)}$$

mf: mass of fresh sample and ***ms:*** mass of dry sample

3.2.3. Soil infiltration capacity

Soil infiltration capacity is the maximum quantity of water that can infiltrate the soil in a given time t. It depends on the constituents and porosity arrangement of the substrate. The infiltration capacity was determined by gradually observing the quantity of water infiltrating the soil every 5 minutes for 90 minutes.

3.3. Analysis of variance

An analysis of variance and comparison of means was applied to the various parameters calculated, to determine whether or not there were any significant differences between the biotopes, with an error of 5% ($p < 0.05$). This analysis was performed using XLSTAT software version 16.0.

III. RESULTS

1. Soil texture

Assessment of soil texture in the different biotopes showed that the texture of the youngest rubber plantations, aged 1 to 5 years and not tapped, is silty-clay with 44% sand, 18.7% silt and 37.3% clay (Figure 4). On the other hand, in plantations aged between 6 and 40 years that have been tapped and abandoned rubber plantations, the soils have a clay texture with 30% clay. The same is true for the soils of the secondary forest, taken as a control, (31.8% clay). These results indicate that the soil texture of old rubber plantations is comparable to that of a secondary forest.

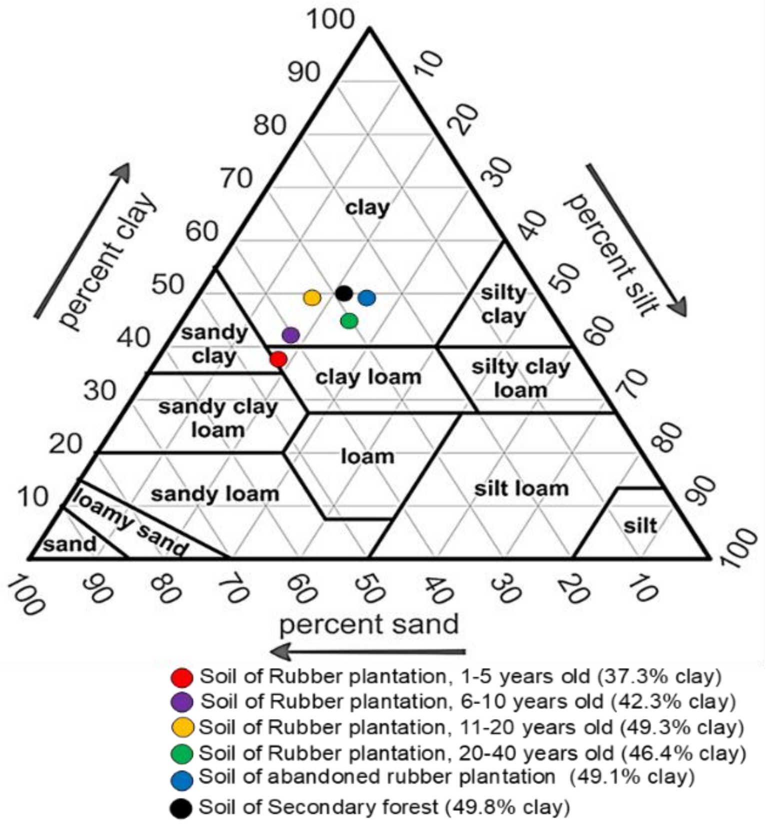

Figure 4 : Granulometry and texture of soils

2. Apparent density and water content of the soil

The study of apparent density indicates a gradual decrease in soil density from the youngest plantations to the oldest plantations (Figure 5). This density is 1.07 g/cm3 in plantations 1 to 5 years old and 0.75 for plantations over 20 years old.

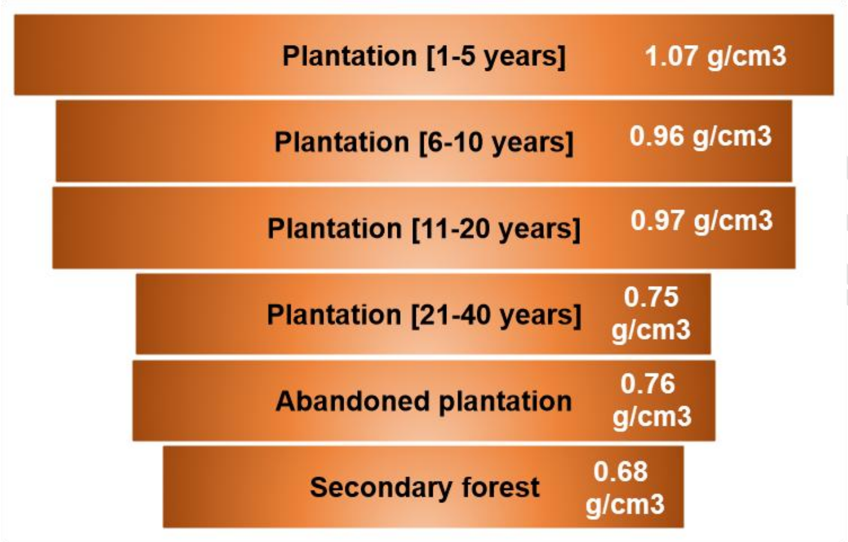

Figure 5 : Densité apparente (g/cm3)

3. Total soil porosity

The evaluation of total porosity shows a statistical difference (p-value = 0.041) between young plantations of 1 to 20 years and old plantations of more than 20 years (Table 1). The proportions of soil porosity in young plantations varied between 59.62% (plantations 1 to 5 years old) and 63.77% (plantations 6 to 10 years old). The porosity of old rubber plantations is over 71%. These values indicate that the soils of old rubber plantations are very porous, and those of young plantations porous.

Table 1: Assessment of total soil porosity

Biotopes	**Porosity (%)**	**Kaouritchev (1983) interpretation**
Rubber plantation [1-5 years]	59.62 b	Porous soils
Rubber plantation [6-10 years]	63.77 b	
Rubber plantation [11-20 years]	63.40 b	
Rubber plantation [21-40 years]	71.70 a	Highly porous swollen soils
Abandoned plantation	71.32 a	
Secondary forest	74.34 a	
p-value	0,041	

4. Soil water content

Water content, determined in the different biotopes, is highest in secondary forest (40.57%), abandoned rubber plantations (36.08%) and old plantations over 20 years old (20.89%). Soil water content in young rubber plantations between 1 and 20 years old is low, ranging from 12.47% to 19.19% (Figure 6).

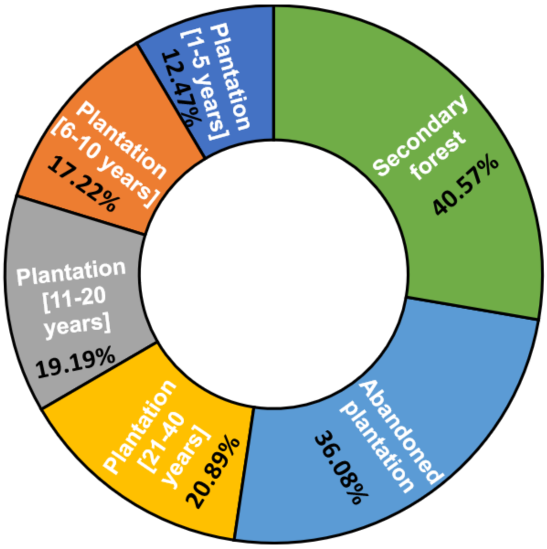

Figure 6 : Soil water content (%)

1.1 Water infiltration capability

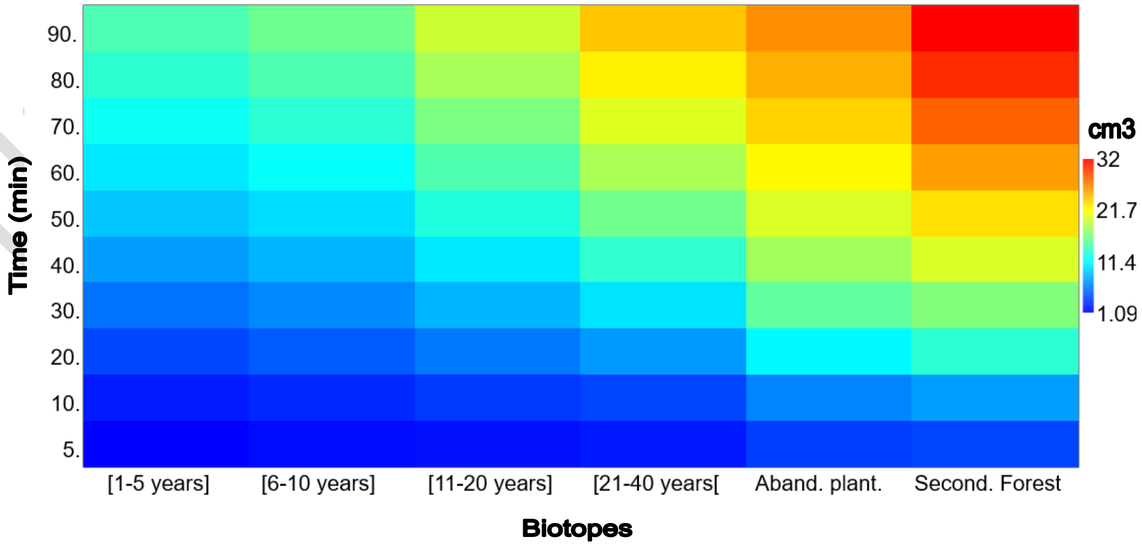

Figure 7 : Matrix plot of water infiltration capacity of biotope soils (cm^3)

Determination of soil water infiltration capacity shows that it varies from one biotope to another (Figure 7). In the first five (5) minutes, the infiltration capacity of soils of all plantation age classes is practically identical. It was around 1.09 cm3. At the same time, the infiltration capacity of soils in abandoned plantations is comparable to that of secondary forest. After 90 minutes, 32 cm3 of water had infiltrated into the soil of the secondary forest. Old plantations over 20 years old and abandoned plantations followed with values ranging from 21.7 to 32 cm3. The lowest values were recorded in young plantations between 1 and 10 years old (11.4 to 21.7 cm^3).

IV. DISCUSSION

The characterisation of soil texture under rubber cover indicates silty-clay soils in the youngest plantations of 1 to 5 years. In plantations over 6 years old, the soils are clayey like those of the secondary forest, considered as a control. The silty-clay texture observed in the first few years of planting could be due to the total destruction of the original vegetation. According to Pomel & Salomon (2019), the destruction of vegetation cover affects soils very quickly. Vegetation cover maintains the soil's richness in terms of soil fauna and organic matter. Added to this is the extensive superficial root network that promotes very high edaphic permeability. All these combined actions help to improve soil structure. The destruction of this plant cover exposes the soil to erosion and to the action of temperature, which partly destroys its physical structure (Martin, 1983). The harmful effects of bulldozers used to clear plantation plots at Anguédédou should also be noted. The caterpillar tracks of these machines cause spatial heterogeneity, which affects the evolution of soil properties (Alégré & Cassel, 1986). According to Gerson & Gnamba-Yao (2020), this results in the concentration of medium-sized particles (silt) and large-sized particles (sand) in the surface horizons. The work of Brad (2005) has also shown that the movement of machinery in an environment leads to changes in soil structure and texture. According to this author, preparatory and cultivation practices that deplete the soil of organic matter damage the soil structure and increase its erodibility. During erosion, clay soils generally give way to sandy, silty-sandy, silty or silty-clay soils (Breune et al., 2000). This is the case in the youngest plantations (1 to 5 years old) at Anguédédou. The clayey texture of plantations over 6 years old could be explained by the development of the rubber trees and the closure of the canopy with the appearance of secondary forest. The vegetative configuration of rubber plantations, with their thermoregulatory and nutrient leaching reduction actions, improves the physical structure of the soil (Ahiekpor, 2011). This would therefore have played an appreciable role in the clay texture of soils in plantations over 6 years old. In addition, soils in all biotopes with more than 37% clay meet the requirements of rubber trees for their development, which is optimal on soils with 25% clay (Essehi, 2019).

The apparent density of the soil in the youngest plantations (1 to 5 years old) is the highest. This is thought to be due to the tracks of the machinery used to clear the plantation plots, which have caused soil compaction, rutting and erosion (Feller et al., 2001; Brad, 2005). This could have a strong negative impact on the soil's potential macrofauna and flora, which are responsible for the soil's porosity, allowing water and air to circulate more easily. The compactness of the soil in the early years of rubber cultivation at Anguédou is fortunately corrected as the plantations age. This may be due to the extensive root development of the rubber trees, which helps to aerate the soil (Pradier, 2016). The high apparent density in the youngest plantations (1 to 5 years old) has a negative impact on water infiltration capacity in these soils. The same applies to water content, which is also low in the soils of these biotopes. Waithaisong et al (2023) observed the same results in the soils of Acacia mangium and Eucalyptus forest plantations in Brazil and Congo. Furthermore, the high water content in the soils of old plantations is thought to be linked to their clay texture. According to N'Guessan et al (2015) and Koffi (2023), the presence of clay in an environment favours water retention in these soils.

CONCLUSION AND PERSPECTIVE

The study of textural and hydrodynamic parameters showed that the soils of the CNRA Anguédédou rubber plantations are silty-clayey in the first years of planting and clayey like those of the secondary forest, after six years of cultivation. However, the proportion of clay in the textural composition of soils in all biotopes, whatever the age of the plantation, is over 37%. This indicates that the soils in this locality are well suited to rubber cultivation. In the youngest plantations (1 to 5 years old), the soils are compact, with high bulk densities, low water infiltration capacity and low soil water content. The compactness of the soils in the early years of rubber cultivation at Anguédou is corrected over time as the plantations age. The clay-textured soils of older plantations have high water content. This study, carried out on industrial plantations under the supervision of the agricultural research institution CNRA, shows that the texture and hydrodynamic parameters of the soils of young rubber plantations in full operation are mediocre. The structure of these soils improves as the plantations age. In order to obtain an objective assessment of the impact of rubber cultivation on soil structure and texture, with a lasting and reproducible effect, it would be worthwhile extending this investigation to rural areas in different agro-ecological zones.

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