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Soil Health of Rubber Plantations in Southern Côte D'ivoire: The Case of Cnra Anguédédou Rubber Plantations

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The rubber tree, a species of Amazonian forest tree, is cultivated for its natural rubber-rich latex. Its cultivation is of economic, social, climatic and environmental importance. However, it has been criticized as a soil-destroying crop. To clear up this ambiguity, a study was launched to assess the health of soils under rubber cover in southern Côte d'Ivoire. The methodology involved selecting

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rubber plantations of [1 to 5 years], [6 to 10 years], [11 to 20] and [20-40 years], and two (02) 42-year-old rubber tree plantations, abandoned for 8 years, were compared to those of a forest. In these biotopes, soil samples were taken using an auger and a metal cylinder, then analyzed in the laboratory to determine soil fertility and ecological parameters. The results showed that the saturated soils of young plantations aged 6 to 10 years are poor in organic matter and cation exchange capacity, mainly calcium and magnesium. However, organic carbon stocks are high in abandoned plantations (182.38 mg/ha) and plantations over 20 years old (164.5 mg/ha). The assessed deterioration index reveals that soils in young plantations aged 6 to 10 years are degraded, with an SDI = -40%. These soils recovered as the plantations aged, with a SDI of 151% in abandoned plantations.

Keywords: Soil health; rubber plantation; southern Côte d'Ivoire; CNRA Anguédédou.

1. INTRODUCTION

The rubber tree (Hevea brasiliensis), a species of Amazonian forest tree, is cultivated for its latex, which is used in the manufacture of tires, condoms, surgical gloves and other products. In response to the world's growing need for natural rubber, rubber-producing countries are steadily expanding their rubber plantations. This is the case in Côte d'Ivoire, where the area planted to rubber rose from 550,000 ha in 2016 [1] to 650,000 ha in 2022 [2]. 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, Côte d'Ivoire rubber industry plans to further increase the area under rubber plantations, by expanding into new so-called marginal zones [3]. Thousands of hectares of land are used for rubber plantations. The sheer size of the area planted with this crop in Côte d'Ivoire is currently a source of controversy. For a long time, rubber plantations have been criticized as soil-destroying crops, although this has not been demonstrated by scientific studies [4]. The few studies carried out on this subject have indicated that the soils of rubber-growing agroforestry systems show variations in physico-chemical properties compared with those of the original forest [5,6]. Thus, to remove this ambiguity, a better understanding of the health, mode of operation and evolutionary process of soils in rubber plantations through the determination of the fertility and ecological parameters of these soils is necessary. The general objective of this study is to assess the impact of rubber plantations on soil health in southern Côte d'Ivoire. Specifically, the aim is to determine the soil fertility of rubber plantations of different age classes, and to assess the ecological parameters of the soils in these biotopes.

2. STUDY AREA

The study was carried out in the rubber plantations of the Center for National Agronomic Research (CNRA), located at Anguédédou in the south of Côte d'Ivoire in the District of Abidjan, precisely in the Songon municipality, between 5°22' and 5°25' north latitude and 4°8' and 4°10' west longitude (Fig. 1). The town is characterized 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 [7]. The soils are ferralitic [8]. According to [9], the population of Songon is made up of 64.25% Ebrié natives, 12.60% allochthones and 18.68% allogènes. 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 [10].

3. METHODOLOGY

3.1 Data Collection

Data were collected in 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]), and two (02) 42-year-old rubber tree plantations, abandoned for 8 years, were compared to those of a forest. Within these biotopes, soil samples were taken along a 100 m transect, at three sampling points 50 m apart. At each point, after clearing the soil of litter, soil samples were taken from two horizons (0 - 20 cm and 20 - 40 cm) using an auger.

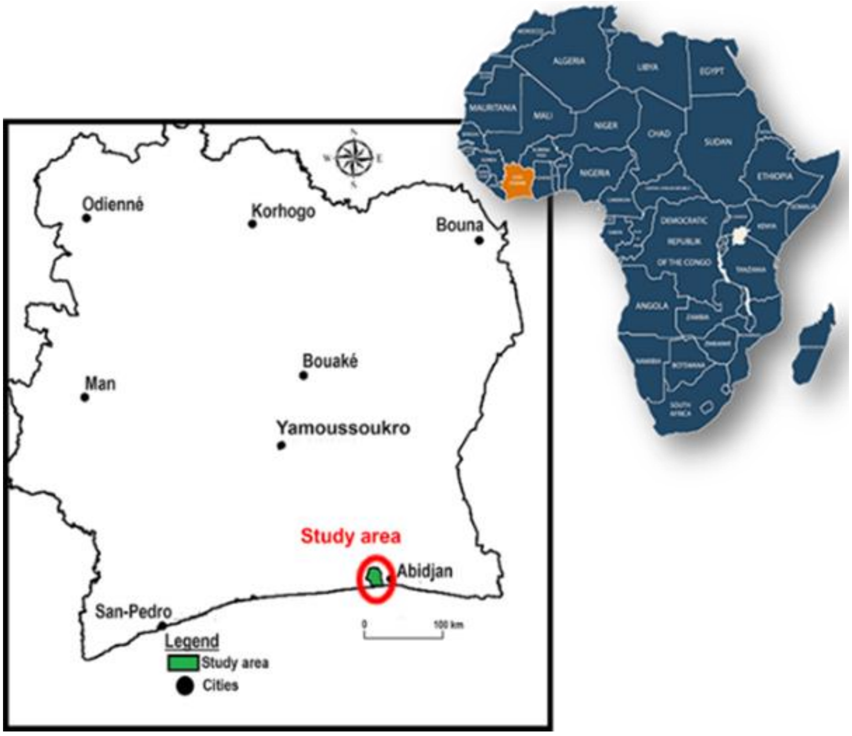

Fig. 1. Location of study area

Along the transect, samples from the three sampling points at the same depth were mixed in a bucket to make a composite sample. Two composite samples per plot were taken in labelled bags. A total of 24 soil samples were taken from all 12 plots and air-dried in the laboratory for two weeks. A 100 g quantity of each soil sample, sieved to 2 mm mesh size after drying, was used for laboratory analysis. Three soil cores were also taken vertically and carefully from each plot at a depth of 0 to 20 cm, using a 4 cm-diameter metal cylinder [11]. The soil contained in the cylinder is collected and weighed in situ to determine the fresh mass, and then taken in an envelope to the laboratory to be dried in an oven at 105°C. After 48 hours, each sample is weighed again to determine the dry mass. All these methods were used to determine soil fertility and ecological parameters.

4. DETERMINATION OF DATA

4.1 Assessment of Soil Fertility

4.1.1 Organic characteristics

- **Organic matter**

The evaluation of organic matter (OM) considered total organic carbon (C) and the value coefficient 1.724. Total organic carbon was determined wet at a reaction temperature of 120°C [12]. Organic matter (OM) is calculated by international convention according to the following relationship: O.M (%) = Carbon (%) x 1.724 [13]. The interpretation standard for organic matter is presented according to the following classes: OM < 1: soils very poor in OM; 1 < OM < 2: soils poor in OM; 2 < OM < 4: soils moderately rich in OM; OM > 4: soils rich in OM.

- **Carbon/nitrogen ratio**

The carbon/nitrogen (C/N) ratio is an essential concept for understanding the fertility mechanisms of a given biotope. It is an indicator of the degree of evolution of organic matter, i.e. its ability to decompose more or less rapidly in the soil. The carbon/nitrogen ratio is deduced from total carbon and nitrogen values. According to [14], the carbon/nitrogen ratio can be interpreted as follows: C/N < 9: very low = rapid decomposition of organic matter; 9 < C/N < 12: normal = good decomposition of organic matter; 12 < C/N < 25: high = reduced biological activity and mineralization encounters difficulties.

- **pH water**

The pH was measured in the laboratory, assessed by direct reading on a pH meter according to the soil/distilled water ratio of 1/2.5

after agitation of the suspension [15, 16]. INRA pH interpretation standards [17] were defined by class: pH < 3.5: hyper-acidic soil; 3.5 < pH < 5.0: very acidic soil; 5.0 < pH < 6.5: acidic soil; 6.5 < pH < 7.5: neutral soil; 7.5 < pH < 8.7: basic soil; pH > 8.7: very basic soil.

4.1.2 Characteristics of the absorbent complex

The absorbent complex of a soil is characterized by the Total exchangeable bases (TEB), such as potassium (K+), calcium (Ca2+) and magnesium (Mg2+), and by its cation exchange capacity (CEC). Exchangeable bases (K+, Ca2+ and Mg2+) were determined after extraction with an ammonium acetate solution (NH4OAC) at pH=7. The standard for interpreting the Total exchangeable bases [14] is: SBE < 1.5 $cmol.kg^{-1}$: very low TEB soils; 1.5 < TEB < 3 $cmol.kg^{-1}$: low TEB soils and 3 < TEB < 6 $cmol.kg^{-1}$: medium TEB soils.

CEC was also determined at pH=7 after displacement of NH4+ ions by KCl on the pellet of the saturated sample remaining after base extraction [18]. The CEC interpretation standard is defined by the following classes [14] : CEC < 2 $cmol.kg^{-1}$: very low CEC soils; 2 < CEC < 3 $cmol.kg^{-1}$: low CEC soils; 3 < CEC < 8 $cmol.kg^{-1}$: medium CEC soils; 8 < CEC < 15 $cmol.kg^{-1}$: high CEC soils and CEC > 15 $cmol.kg^{-1}$: very high CEC soils.

The base saturation rate (V) was determined by the following relationship: V = (SBE/CEC) × 100. The saturation rate is interpreted as follows: V > 70%: saturated soils; 50 < V < 70%: moderately saturated soils; V < 50%: desaturated soils.

4.2 Ecological Parameters

4.2.1 Soil organic carbon stock

Soil organic carbon stock (SCOS) was calculated according to the equation: SCOS(mg⁄ha) = C×Da×e [19], where C: carbon; Da: bulk density and e: depth of soil sampled.

4.2.2 Soil degradation or deterioration index

The impact of rubber cultivation on soil quality was assessed using the soil degradation or deterioration index (SDI) [20]. The SDI is calculated using the equation: SDI= ((Ac-Af) / Af) ×100, where Ac: soil property values (organic carbon, bulk density, water content and pH) of rubber plantations of various ages; Af: soil property values (organic carbon, bulk density, water content and pH) of secondary forest. Negative SDI values indicate soil deterioration [21]. According to [22], indices from 0 to -5% indicate no deterioration. Indices between -5% and -10% indicate slight deterioration, moderate deterioration ranging from -10% to -20% and severe deterioration, for an SDI greater than -20%.

4.3 Statistical Analysis

4.3.1 Analysis of variance

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

4.3.2 Influence of different parameters on soil organic carbon stock

The influence of various parameters on soil organic carbon stock was determined using Pearson's correlation test. This analysis highlighted the degree of relationship between soil variables X (Da, TEB, CEC, V soil infiltration capacity) and Y (SCOS). Y is the dependent variable and X the independent variable. This means that Da, soil infiltration capacity, TEB, CEC and V are predictive of soil organic carbon stock in Anguédédou rubber plantations, but it is not evident that the converse is true. This analysis was carried out using XLSTAT software version 16.0.

5. RESULTS AND DISCUSSION

5.1 Assessment of Soil Fertility

5.1.1 Organic characteristics

Organic characterization of soils under rubber cover indicates that the soils of all Anguédédou rubber plantations, of all age classes, are poor in organic matter (Table 1). The low quantity of organic matter observed in the soils of these rubber plantations could be explained by reduced microbial activity, reflected by the high carbon/nitrogen (C/N) ratio, especially in plantations aged 6 to 20 years, with values between 14.00 and 14.66. This indicates slow decomposition of soil organic matter, and therefore immobilization of soil nitrogen by microorganisms [23]. The reduced microbial activity in these biotopes is thought to be due to the excessive use of herbicides to maintain young rubber plantations in full operation, based on interviews with plantation managers. Indeed, the work of [24] has shown that the use of pesticides in crops disrupts soil life by affecting the efficiency of microorganisms in utilizing organic matter. In plantations 1 to 5 years old, over 20 years old and in abandoned plantations, the C/N ratio is between 11.14 and 11.95. The low C/N values in plantations over 20 years old and in abandoned rubber plantations could be linked to good microbial activity, promoting rapid decomposition of organic matter and releasing into the soil the nutrients assimilated by plants [25].

5.2 Characteristics of the Absorbent Complex

Cation exchange capacity (CEC) is 1.38 cmol.kg-1 for soils in plantations 6 to 10 years old, and over 2.01 cmol.kg-1 for those over 10 years old (Table 2). Compared with [14] interpretation standard, the CEC of soils from young rubber plantations aged 6 to 10 years at Anguédédou is very low. This low CEC is linked to the low organic matter content of the soils in these plantations. According to [26], the richer a soil is in stable organic matter, the higher its exchange capacity. Otherwise, CEC decreases. Examination of the low CEC values of young plantations shows that they have a low nutrient retention capacity. In fact, soil cation exchange capacity (CEC) affects the soil's ability to retain essential nutrients and acts as a buffer against soil acidification. It is therefore used as a measure of soil fertility.

Total exchangeable bases (TEB) in soils are very low for all biotopes compared with reference values (TEB < 1.5 cmol.kg^{-}1). They range from 1.21 cmol.kg^{-1} to 1.36 cmol.kg^{-1} (Table 2). These low levels of total exchangeable bases (TEB) in the soils of these biotopes, particularly calcium and magnesium, can be explained by the low CEC content of the soils and their high saturation rate [27]. According to this author, TEB is positively linked to cation exchange capacity and negatively to soil saturation rate. In other words, higher CEC and lower soil saturation rates lead to lower TEB values.

Soils in young plantations aged between 6 and 10 years are saturated, with an exchangeable base (V) saturation rate of 94.84%, much higher than the standard 70%. In plantations over 10 years old, soils are moderately saturated, with saturation rates ranging from 58.49% (plantations over 20 years old) to 62.90% (plantations 11 to 20 years old). Soil saturation in these environments can be explained by the pH values of the soils, which are inclined towards alkalinity, pH = 6.30 [28]. Thus, a saturated soil will have fewer sites occupied by H^+ ions, and its pH will therefore be alkaline. A soil less saturated with nutrient cations, on the other hand, will have an acid pH.

5.3 Ecological Parameters of Soils in Different Biotopes

5.3.1 Soil organic carbon stock

Determination of soil organic carbon stock (SCOS), with the exception of the youngest plantations aged 1 to 5 years, shows a decrease in SCOS from the upper to the lower depths (Fig. 2). In the 0-20 cm depths, organic carbon stocks are highest in secondary forest soils (193.14 mg/ha) and abandoned plantations (182.38 mg/ha). Plantations of 11 to 20 years old and over 20 years old follow with 142.36 and 164.5 mg/ha respectively. In the 20 to 40 cm depth, SCOS is highest in soils from plantations over 20 years old (151.37 mg/ha) and from secondary forest (172 mg/ha). The significant quantities of soil organic carbon stock in surface depths, especially in old rubber plantations over 20 years old, could be explained by the very pronounced defoliation of rubber trees in these plantations, mainly in the dry season. This defoliation creates significant soil organic matter. According to [29], this organic matter contains 50% carbon, whose degradation under the effects of rain and biological action contributes to the soil's carbon stock. This would explain the significant organic carbon stock in the soils of these biotopes. These results, indicating that the youngest plantations of 1 to 5 years, where the SCOS is 76 mg/ha compared with 193.14 mg/ha for secondary forest, corroborate those of [30], who stipulate that soil carbon stocks in the first years of plantation decline after conversion of native forest to crops.

5.4 Impact of Different Parameters on soil Organic Carbon Stock

Evaluation of the influence of various parameters on soil organic carbon stock indicates two trends. The first trend is characterized by the impact of bulk density (Da), soil infiltration capacity and total exchangeable bases (TEB) on soil organic carbon stock (SCOS), with coefficients of determination R^2 ranging from 0.68 to 0.87 (Fig. 3).

Table 1. Organic characteristics

Sites	OM	C	N	C/N	Standard	Interprétation
[1-5 years]	1,08	0,63	0,05	11,95	Normal 9<C/N<12	▪ Good microbial activity, ▪ Good OM decomposition, providing plants with a lot of mineral nitrogen
[6-10 years]	1,24	0,70	0,05	14,00	high	▪ Reduced biological activity in the soil
[11-20 years]	1,50	0,88	0,06	14,66	12<C/N<25	▪ Slow decomposition of OM ▪ Immobilization of soil nitrogen by microorganisms
[20-40 years [	1,35	0,78	0,07	11,14	Normal	▪ Good microbial activity
Abandoned plantation	1,57	0,80	0,07	11,42	9<C/N<12	▪ Good OM decomposition, providing high levels of mineral nitrogen for plants
Secondary forest	1,23	0,76	0,07	10,85		

C:Carbon ; N:Total nitrogen ; C/N:total carbone/nitrogen ratio ; OM:Organic matter

Table 2. Absorbent complex characteristics

	Biotopes						
	[1 - 5 years]	**[6 - 10 years]**	**[11 - 20 years]**	**[20 - 40 years]**	**Aband. Plant.**	**Second. forest**	**P-v*alue***
Ca^{2+} (cmol.kg $^{-1}$)	0,18 a	0,14 a	0,14 a	0,14 a	0,14 a	0,15 a	*0,075*
Mg^{2+} (cmol.kg $^{-1}$)	0,27 a	0,27 a	0,27 a	0,28 a	0,27 a	0,26 a	*0,504*
K^{+} (cmol.kg^{-1})	0,48 a	0,47 a	0,47 a	0,45 a	0,48 a	0,46 a	*0,511*
EBS (cmol.kg $^{-1}$)	1,36 a	1,28 a	1,23 a	1,21 a	1,30 a	1,21 a	*0,106*
CEC (cmol.kg $^{-1}$)	1,85 b	1,38 c	2,11 a	2,01 a	2,04 a	1,91 b	*0,034*
V (%)	72,56 a	94,84 a	62,90 b	58,49 b	62,48 b	61,50 b	*0,011*
pH eau	6,32 a	6,32 a	6,33 a	6,28 a	6,35 a	6,21 a	*0,103*

V:saturation rate of exchangeable bases ; TEB:Total Exchangeable Bases ; CEC:Cation exchange capacity ;
Ca^{2+}:Calcium ; Mg^{2+}:Magnésium ; K^{+}:Potassium. Means with different letters on the same line indicate a significant difference (Fisher test, Lsd 05 a= 0.05)

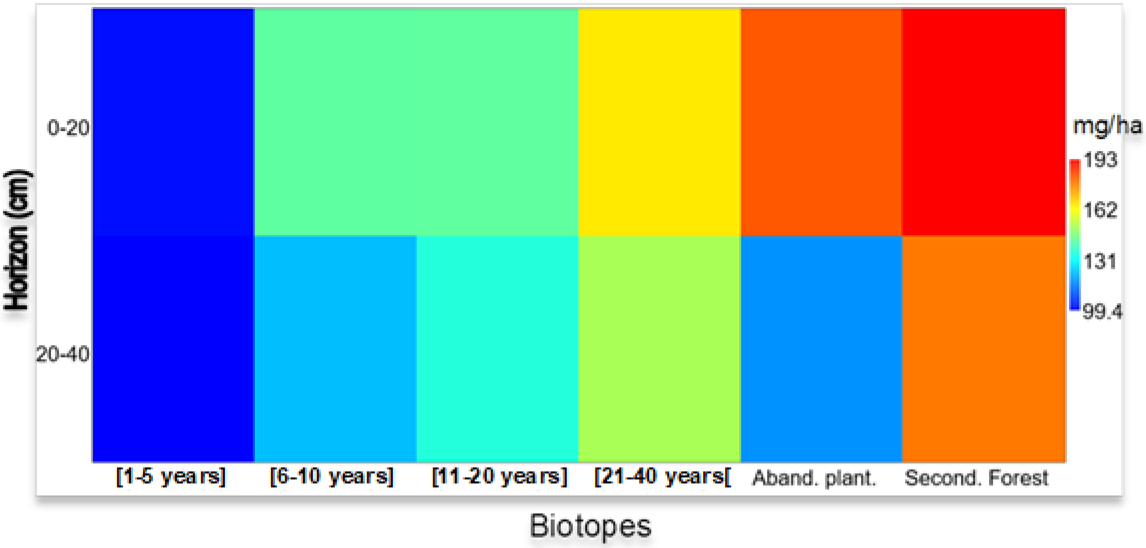

Fig. 2. Matrix plot showing the distribution of soil organic carbon stocks in soils of different biotopes following depths

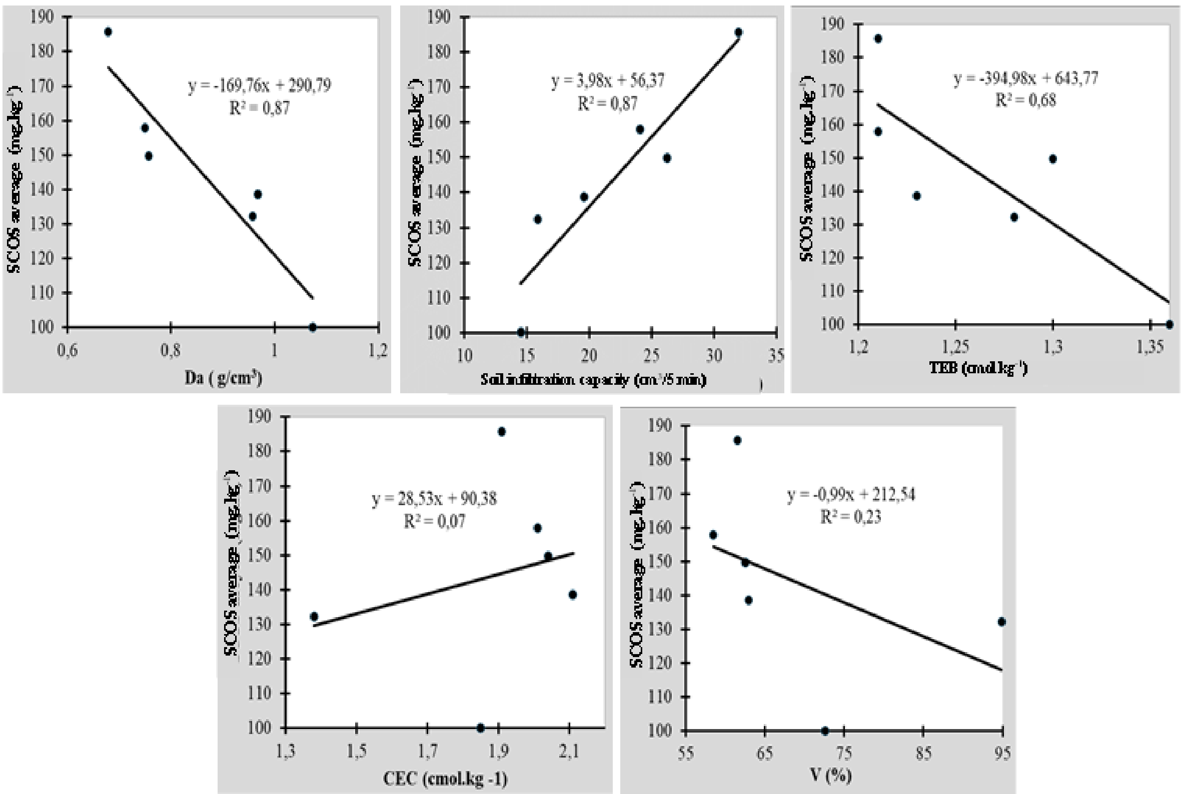

Fig. 3. Correlation line for variables

(Da, Water infiltration capacity, TEB, CEC and V with SCOS)

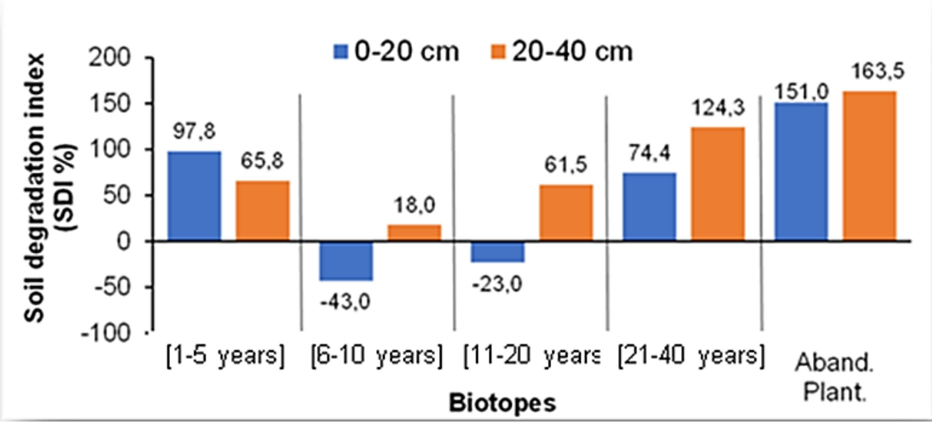

Fig. 4. Soil degradation or deterioration index for different biotopes following depth

Da and TEB have a negative effect on SCOS. In practical terms, this means that when soil Da and TEB are high, SCOS is low, and conversely. The negative impact of TEB on SCOS could be due to carbon mineralization, whose level influences that of soil carbon stocks. This has been demonstrated by the studies of [31], which indicate that significant mineralization in a given environment decreases the soil's carbon stock. As for Bulk Density, its negative influence on SCOS could be explained by the compact state of the soil. This compactness makes the soil impervious and induces deep soil transformation, while considerably reducing carbon stocks [32]. This is all the more true as soils with high carbon stocks are generally relatively less compact or softer. Soil water infiltration capacity has a positive influence on soil carbon stock. When it is higher, the SCOS is also higher. This could be due to the transport and incorporation of organic matter by water into the soil in the form of carbon.

The second trend indicates that Cation Exchange Capacity (CEC) and Exchangeable Base Saturation Ratio (V) do not influence SCOS in Anguédédou rubber plantations. The coefficients of determination confirm this assertion, with values of 0.07 for CEC and 0.23 for V.

5.5 Soil Degradation or Deterioration Index

Determination of the soil degradation index (SDI) shows an evolution in the impact of rubber plantations on soil health at Anguédédou along the plantation age gradient (Figure 4). This index indicates soil degradation in the surface depths (0-20 cm) of young rubber plantations aged 6 to 10 years and 11 to 20 years, with SDI values of -42.95% and -22.95% respectively. The soil degradation observed in young plantations aged 6 to 10 years can be explained by the intensive use of herbicides. For example, the results of work by [33] show that herbicides reduce soil microbial biomass and earthworm populations from 20 to 50%, and then inhibit soil bacteria. Yet these soil micro and macro fauna contribute effectively to the degradation of organic matter, enabling the proper functioning of the nitrogen and carbon cycle, phosphorus mobilization, soil porosity and water infiltration. So toxic chemicals, by reducing micro and macro fauna, actively contribute to soil degradation.

However, these soils recover from the twentieth year of plantation with SDI values ranging from +74.44% for plantations between 20 and 40 years old to +151.00% for abandoned plantations. The restoration of rubber soils could be due to the abandonment of herbicide use in these old plantations over 20 years old, almost at the end of their economic life. This means that, as rubber plantations age and are maintained manually, their SDI becomes more similar to that of a secondary forest. This observation is confirmed by the work of [34], who indicates that the high negative SDI values in young crops decrease as they age.

In the lower depth (20-40 cm), IDS values are high for all biotopes. They range from 18% (6 to10 year-old plantations) to 163.52% (abandoned plantations).

6. CONCLUSION AND PERSPECTIVES

The study to assess the impact of rubber cultivation on soil health showed that the soils of the CNRA Anguédédou rubber plantations are poor in organic matter and cation exchange capacity, especially in young plantations aged 6 to 10 years, where microbial activity is reduced. The total content of exchangeable bases (TEB) is also low in all biotopes, particularly in calcium and magnesium. Soils in the same young plantations, 6 to 10 years old, are saturated with exchangeable bases, while those in plantations over 10 years old are moderately saturated. Evaluation of soil ecological parameters reveals that organic carbon stocks are high in the surface soil horizons of rubber plantations over 10 years old, and low in the youngest plantations, aged 1 to 10 years. Soil organic carbon stocks in these rubber plantations are negatively impacted by soil bulk density and the total amount of exchangeable bases. On the other hand, they are positively influenced by soil water infiltration capacity. This study, carried out on industrial plantations under the supervision of the agricultural institution CNRA, shows that the soils of young rubber plantations in full operation are in a state of degradation. These soils recover as the plantations age. For an objective assessment of the impact of rubber cultivation on soil health, it would be worthwhile extending this investigation to smallolders plantations in different agro-ecological zones.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Gbodjé J. Expansion of rubber cultivation and risk of food insecurity in the Lakota department (South-West Ivory Coast). Geographical Space and Moroccan Society Magazine. 2021;45-46.
2. APPROMAC. Rubber production in Ivory Coast. Accessed on 03 2023, 12, on www.apromac.ci. 2023.
3. Koffi A. Agro-pedological characterization of new rubber production zones in Ivory Coast: case of the departments of Man, Toumodi and Prikro. Doctoral thesis, Jean Lorougnon Guédé University, Daloa Côte d'Ivoire. 2023;157.
4. Epron D, Ngao J, Dannoura M, Bakker M, Zeller B, Bazot S, Loustau D. Seasonal characterizations of belowground carbon transfer assessed by in situ labeling of 13 CO2 pulses of trees. Biogeosciences. 2011;8(5):1153-1168.
5. Zhang H, Zhang GL, Zhao YG, Zhao WJ, Qi ZP. Chemical degradation of Ferralsol (Oxisol) in the context of intensive rubber (Hevea brasiliensis) cultivation in tropical China. Research on soils and tillage. 2007;93(1):109-116.
6. Selma RM, Dalziza O, Sonia MSS, Celso JM, Leclerc M, Riddle CW. Potential carbon sequestration in rubber tree plantations in the northwestern region of the Paraná State, Brazil. Acta Scientiarum, Agronomy Maringá. 2014;3 6(2):239-245
7. SODEXAM. Weather bulletin for the lagoons district. 2023.
8. Brou T. Climate, socio-economic change and landscape in Ivory Coast. Summary dissertation of scientific activities presented with a view to obtaining authorization to direct research, University of Sciences and Technologies of Lilles. 2005.
9. Kambiré B, Maimouna Y, Sotia O. Management of liquid waste and vulnerability of populations to diseases: Case of Songon-Agban, District of Abidjan. Tropicultura. 2018;271-280.
10. Yéo P, Amani Y. Problems of sustainable management of the peri-urban forest of Anguédédou (Abidjan, Ivory Coast). Journal of Tropical Geography and Environment. 2016;(2):40-50.
11. Yoro G, Godo G. Methods for measuring apparent density: analysis of the dispersion of results in a given horizon. Cahiers-ORSTOM. Pedology. 1990;25(4): 423-429.
12. Voko B, Nandjui J, Séry DJM, Fosto B, Niamke S, Zézé A. Abundance an diversity of arbuscular mycorrhizal fungal communities associated with cassava (Manihot esculenta CRANTZ) rhizosphere in Abengourou, East Côte d'Ivoire. I DO NOT. 2013;5(11):360-370.
13. Namri M. Les stocks de carbone des sols du Congo. Bilan spatial et recherche des facteurs de répartition. Mémoire de Maitrise. Université Louis Pasteur. 1996; 120.
14. Assa J, Caspi Y, Cohen-Or D. Action synopsis: pose selection and illustration. ACM Transaction on Graphics (TOG). 2005;24(3):667-676.
15. Anderson JM, Ingram, JS. Tropical soil biology and fertility: A handbook of methods. CAB International. 1993;12.

16. AFNOR. Soil quality. In Determination of the particle size distribution of soil particles - Pipette method. 2003.
17. Baize D, Jabiol. Guide to soil description. INRA. Paris, France. 1995;1.
18. Eponon EC, Snoeck D, Konaté Z, Kassin KE, Camara M, Legnaté H, Koné D. Characterization of soil fertility in Coffee (*Coffea spp.*) production areas in Côte d'Ivoire. 2019.
19. Duprarque A, Rigalle P. Composition of MOs and turnover; Roles and functions of MOs, conference proceedings « Management of the organic state of soils ». Agrotransfert. 2011.
20. Mbagou MZ, Endamane N, Eba F, Minko DM. Impacts of rubber cultivation (Hévéa brasiliensis) on the physicochemical characteristics of soils in the Kango region (N-W, GABON). African Agronomy. 2021;2(33): 133-148.
21. Dawoe EK, Quashie-Sam JS, Oppong SK. Effect of land-use conversion from forest to cocoa agroforest on soil characteristics and quality of a Ferric Lixisol in lowland humid Ghana. Agroforestry Systems. 2014;(88):119-127.
22. Wang T, Zhu ZD. Study on sandy desertification in China: 1. definition of sandy desertification and its connotation. Journal of Desert Research. 2003;23(3): 209-214.
23. Chantigny M, Anbers D. Microbiological activities and soil quality: what's new under our feet. Reference center in agriculture and agri-food in Quebec. 2005;10.
24. Ouattara B, Savadogo WP, Traoré O, Koulibaly B, Sedogo PM, Traoré SA. Effect of pesticides on the microbial activity of a tropical ferruginous soil in Burkina Faso. Cameroon Journal of Experimental Biology. 2010; Flight. 06 No. 01:11-20.
25. Rouat S. Trees, guardians of the Earth, new species to save the climate and the soil. Science and the future. 2022;126.
26. Koull N, Halilat MT. Effects of organic matter on the physical and chemical properties of sandy soils in the Ouargla region (Algeria). And. Gest. Floors. 2016; 23(1):9-19.
27. Ndiaye O. Characterization of soils and vegetation in the Ferlo area, Northern Senegal thesis, Cheikh Anta Diop University, Dakar, Senegal. 2013;131.
28. Collaud G, Ryser J, Schwarz J. Cation exchange capacity. Soil-Conseil sheets. Swiss magazine Agric. 1990;22(5):285-289.
29. Adoum AA. Organic matter and carbon storage in Bol polder soils northeast of Lake Chad in the context of global changes in a semi-arid environment. Inst Doctoral Thesis University of Sciences and Industries of Life and the Environment in Monpellier (France). 2021.
30. Guo L, Gifford R. Soil carbon stocks and land use change: a meta analysis. Global Change Biology. 2002;8:345-360.
31. Sana S. Evaluation of carbon stocks in a ferruginous soil under the addition of urban waste composts: case of Gampèla in Burkina Faso. Thesis of Agricultural Engineer multipurpose agricultural center of Matourkou, Burkina Faso. 2018;57.
32. Lal R. Soil conservation and ecosystem services. Soil Water Conserv. Res. 2014; 36-47.
33. Mäder P, Peng S, Fliessbach A. Effects of plant protection products on soil microorganisms. VBB-Bulletin. 2002;6:6-7.
34. N'Guessan K. Effect of village rubber tree plantations (Hevea brasiliensis Muell. Euphorbiaceae) on macroinvertebrates and physicochemical characteristics of the soil in the Grand-Lalou region (southwest Ivory Coast). Master's thesis, Nangui Abrogoua University, Abidjan. 2016.

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