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Qualities of Soil Upper Layers Under Rubber Plantation and Various Previous Soil Histories in Zépréguhé (Daloa, west-central Côte d'Ivoire)

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ABSTRACT

This study focused on the diagnosis of soil fertility in Zépréguhé, a village located 8 km from Daloa in the center-west of Côte d'Ivoire. Four soil pits were planted according to a toposequence oriented West-East under rubber and under previous cultivation. All the pits have been described and soil samples in the 0-30 cm horizon have been analysed at the plant and soil analysis laboratory of the Institute National Polytechnique Félix Houphouet-Boigny in Yamoussoukro. The particle size, the organic matter and the characteristics of the adsorbent complex were determined. It emerges from this description and analysis that all soils in the study area are ferralsols. The values obtained were compared to the critical thresholds in order to determine the level of soil fertility. The results show that these soils, which appear to be rich in organic matter, were really low in organic matter and very low in acidity over the entire toposequence. Due to the crops in place, the upper slope and Upper mid-slope positions accumulate badly decomposed organic matter. Furthermore, the cation exchange capacity (CEC) is normal at the upper slope and upper mid-slope and very low at the bottom of the slope. The sum of exchangeable bases is small at the level of all the profiles. The soils of the study site have a low to moderate level of fertility. Rubber and sorghum crops have better soil fertility and particularly organic matter.

Keywords: Fertility, ferralsols, crop precedent, toposequence, Daloa, Côte d'Ivoire.

INTRODUCTION

In sub-Saharan Africa, population growth has led to an increase in food demand. Intensive agriculture and the search for new fertile land result in pressure on the ecosystem, which, in turn, leads to reduced soil fertility [1-2]. In most countries, soils have low fertility and exported nutrients are not adequately replaced. Moreover, the practice of long-term fallow is tending to disappear, giving way to short-term fallow and settled agriculture [3-4]. As a result, yields are

relatively low and land productivity decreases ([5-3]. Since soil is therefore the basis of all agricultural production, knowledge of its physical and chemical potential is important for crop development [6] For cultivated soils, the distribution of organic matter is likely to vary greatly [7]. Such heterogeneity is a limiting factor in the proper match between the characteristics of the soil and the doses of fertilizers to be applied to an agricultural plot. There is therefore an interest in increasing and enhancing knowledge of soils, particularly for agricultural issues that are ever increasing [8]. Thus, knowledge and mastery of the physical and chemical properties of the soil are a prerequisite for good practice However, few people in West Africa and especially in Côte d'Ivoire determine the soil fertility potential of their farm before its development. If, according to the farmers, certain indicators make it possible to make a diagnosis of fertility such as plants and animals that are indicators of soil fertility and the biophysical state of the plot [10], these prove to be insufficient and often unreliable. to determine the fertility potential of the soil. It is then necessary to resort to soil analysis in order to specify the agricultural potential of its soil before its development [6].

The soils of the study area being moderately to strongly desaturated ferralitic soils (ferralsols) are exposed to a rapid loss of their fertility potential [11]. Thus, the hypothesis underlying this study is that soils under perennial cultivation would limit the loss of fertility less than those under annual or seasonal cultivation.

The general objective of this study is to compare the level of soil fertility under perennial and annual crops in Zépréguhé.

Specifically, it was a question of evaluating the physico-chemical characteristics of the surface horizons of the soils under rubber and under different cropping precedents and deducing the fertility of these soils.

MATERIALS AND METHODS

Location of the Study Site

The study was carried out in Zépreguhé (6°54'13''N and 6°21'51''W) 8 km from Daloa in the Center-West of Côte d'Ivoire (Figure 1). The department of Daloa is characterized by a tropical climate, with a very hot and dry period from November-March and a rainy period from April-October. Chromoleana and Imperata are the dominant grasses. The site has low slopes.

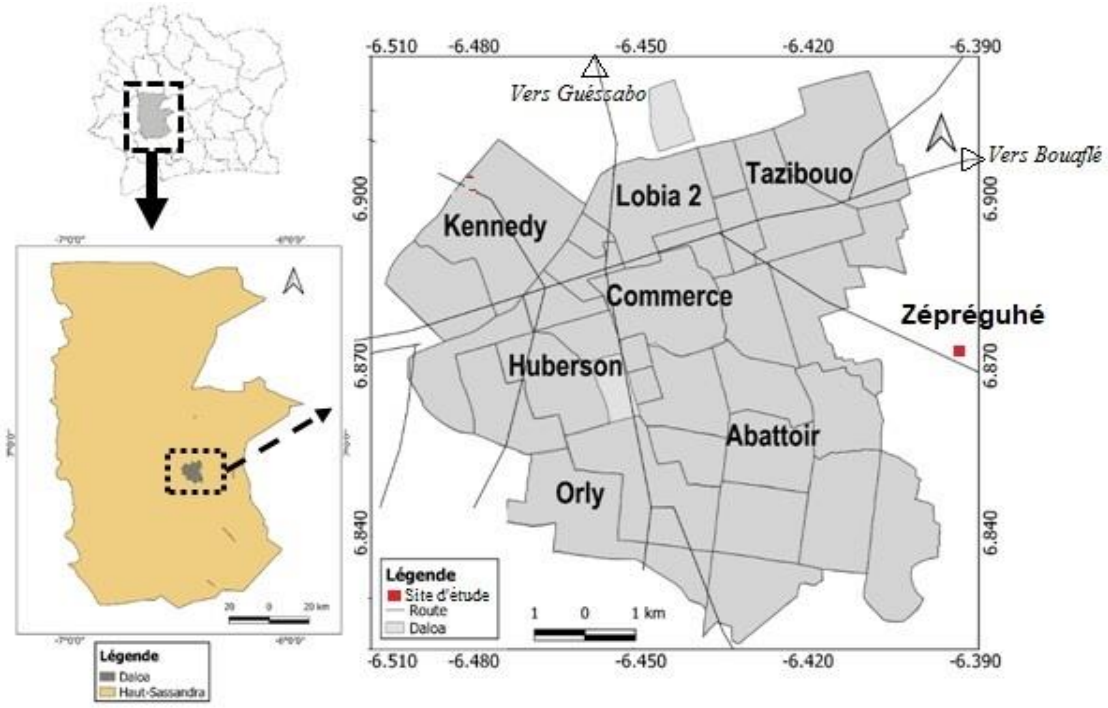


Figure 1: Study area and plot location

Methods

Morpho-Pedological Characterization of the Soil:

Four cultural pits were opened on a toposequence oriented West – East starting from the rubber plot, near the village in the lowlands (market gardening site). Each profile was identified by its topographic position (HV: upper slope; MVinf: lower mid-slope, MVsup: upper mid-slope and BP: lower slope). These soil pits have been described horizon after horizon. The classification used is that of [12].

The characterization of the profiles took into account:

- the useful depth of the soil and the thickness of the layers were made by direct measurement with a tape and by observation;
- the soil colour was determined using the Munsell code;
- the texture was made by observation in the field using the coil and ring method;
- the structure was determined by observing the organization and arrangement of soil aggregates;
- the porosity was determined by observing the aggregates;
- biological activity was assessed by visual observation of the quality and number of roots as well as microorganisms;
- the load of coarse elements was evaluated using the Munsell code;
- the organic matter content was assessed by visual observation;
- the humidity was assessed by direct visual observation of the horizons.

Physic-Chemical Characterization of the Soil:

Soil samples were taken at the end of each profile description in the horizons encountered in the first 30 cm of the soil for laboratory analysis. Thus, 8 (two per horizon) soil samples were taken and analysed in the laboratory. All the analysis were carried out at the plant and soil analysis laboratory of the National Polytechnic Institute Félix Houphouet-Boigny in Yamoussoukro. The parameters analysed are:

- The particle size is determined by the densiometric method using the Robinson pipette [13]. This method consists in separating the soil particles according to their dimensions. It allows to know in a weight form, the distribution of mineral particles of less than 2 mm in diameter according to different textural classes.
- The water pH of soil samples is measured by direct reading with a pH meter according to a soil/distilled water ratio of 1:2.5 after shaking the suspension [14-15].

Organic carbon was determined after calcination of soil samples in a muffle furnace according to the method of [16]. This determination was made by the method of cold sulfochromic attack after oxidation with potassium dichromate ($K_2Cr_2O_7$) in a strongly acid medium (H_2SO_4). The determination of the carbon rate made it possible to calculate the organic matter (OM) content:

$$OM = C \times 1.724 \quad \ldots\ldots\ldots\

RESULTS

Morpho-Pedological Characteristics of the Soil

The soil observed under the rubber tree is ferralitic, deep and well differentiated in horizons (figure 2). The profile at the upper slope (HV) presents four horizons. The A1 type surface horizon has a sandy-clay texture and a lumpy structure; it is fresh, very porous, dark brown in colour (7.5YR 2.5/2) and very humus-rich. Its thickness is (0-20/25 cm) and presents a regular limit. The soil observed under sorghum is ferralitic and deep. In fact, at Zépréguhé, this upper mid-slope soil (MVsup) has four horizons. The A11-type surface horizon has a sandy-loamy texture and a lumpy structure. This horizon is dry, very porous, dark brown in colour (7.5 YR 3/2) and humus. Its thickness varies from 0-13 cm and has few roots. The soil observed under cassava-maize is ferralitic. This lower mid-slope (MVinf) soil has four horizons. The A11-type surface horizon has a sandy-loamy texture and a lumpy structure. This horizon is dry, very porous and has few roots. It is dark brown in colour (7.5 YR 3/3), humus-rich and estimated at 27 cm thick. The soil observed under previous market gardening is hydromorphic, deep and well differentiated in horizons. This soil at the bottom of the slope (Bp) has five horizons. The A11-type surface horizon has a sandy-silty texture and a lumpy structure. This horizon is cool, humus, porous, well drained, loose and has abundant roots of millimeter size. It is dark brown in colour (gley1 3/N).

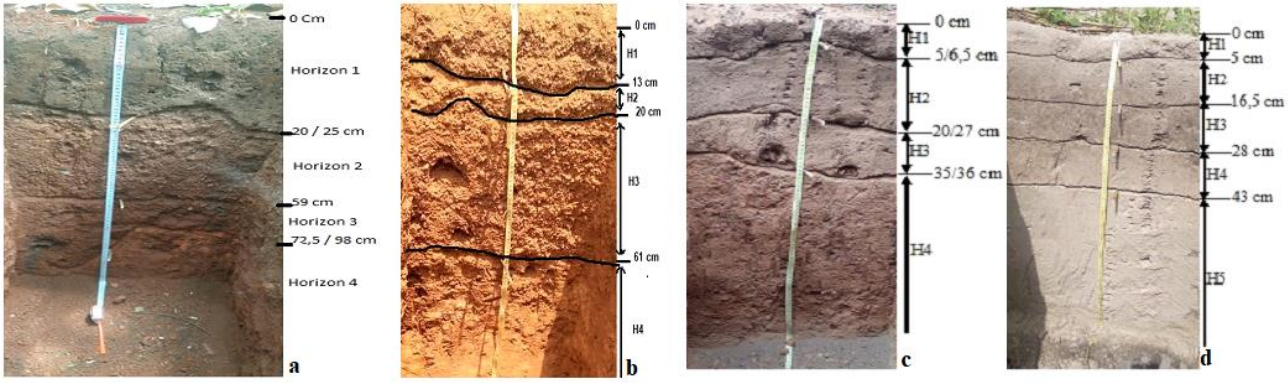


Figure 2: Soil profiles at different topographic positions corresponding to different land uses. a: ground under rubber at the upper slope; b: soil under previous sorghum at the upper mid-slope; c: previous cassava-maize soil at the lower mid-slope; d: soil under previous market gardening at the bottom of the slope

Physico-Chemical Parameters of Soils

Granulometry:

Table 1 summarizes the results relating to the particle size under the different positions on the toposequence. This reveals differences at various levels of significance between the topographic positions. Only the clay content was not influenced by the position on the toposequence. The proportions of Silt, Sand and the sum Clay + Silt varied highly significantly ($P < 0.001$) from one position to another. For the clay content, the upper mid-slope position (MVsup) and the upper slope position (HV) had the highest rates with 12.25 and 6.25% respectively. These same topographic positions presented the highest rates of Clay + Silt with 60.52% for MV sup and 42.67% for HV. However, the highest levels of silt (L) are observed at the MVsup and lower mid-slope (MVinf) positions with respectively 48.27 and 38.22%. The

bottom of the slope (Bp) and MVinf positions were the sandiest with 69.08 and 58.23% sand respectively.

Table 1: Soil granulometry

Topographical positions	Granulometry				
	A	L	A+L	S	Texture
Upper slope (HV)	6.25^{a}	36.42^{ab}	42.67^{b}	55.25^{b}	Loamy-sand
Upper mid-slope (MVsup)	12.25^{a}	48.27^{a}	60.52^{a}	37.03^{c}	Loam
Lower mid-slope (MVinf)	2.00^{a}	38.22^{ab}	40.22^{b}	58.23^{ab}	Loamy-sand
Bottom of the slope (Bp)	3.50^{a}	26.37^{b}	29.87^{c}	69.08^{a}	Sandy-loam
CV	0.75	0.216	0.257	0.213	
P	0.101	0.00925	0.00105	0.00175	
Effect	ns	**	**	**	

A: clay; L: silt; S: sand; In the same column, the means followed by the same letter are not significantly different at the threshold of α=0.05; **: highly significant difference P < 0.01; ns: non-significant difference P > 0.05; CV: coefficient of variation

Soil Acidity and Organic Matter:

No significant difference was observed between the different positions of the toposequence for soil acidity, carbon, total nitrogen, C/Nt ratio and organic matter content. The variations of these parameters between the different topographic positions are presented in Table 2. The pH generally varied between 6.50 in the rubber plantation (upper slope) and 6.90 in the previous market gardening (bottom of the slope) in a very low acid range. The carbon content of the soil, generally low, varied little on the plots and remained between 0.60% (BP) and 0.89% (MVinf). The highest carbon content was obtained on the upper mid-slope (MVsup) with a value of 1.41%. The soils of the area were also low in carbon. The Nt content of the soil, generally acceptable at all levels of the toposequence, is however low at the bottom of the slope with 0.060%. The soil C/Nt ratio in the plots varied between 8.80 (MVinf) and 16.20 (MVsup). This ratio was very weak at the lower mid-slope and quite good at the bottom of the slope (10.15) and a little high for the upper and upper mid-slope positions with 15.12 and 16.20 respectively. The O.M content of the soil, which varied between 1.04% at the bottom of the slope and 2.44% at the upper mid-slope, is in low proportions in the soils of the plots studied.

Table 2: Soil acidity and organic matter

Topographical positions	acidity and organic matter				
	pH	C (%)	Nt (%)	C/Nt	OM (%)
Upper slope (HV)	6.50^{a}	1.20^{a}	0.12^{a}	15.12^{a}	2.07^{a}
Upper mid-slope (MVsup)	6.65^{a}	1.41^{a}	0.10^{a}	16.20^{a}	2.44^{a}
Lower mid-slope (MVinf)	6.55^{a}	0.89^{a}	0.10^{a}	8.80^{a}	1.54^{a}
Bottom of the slope (Bp)	6.90^{a}	0.60^{a}	0.06^{a}	10.15^{a}	1.04^{a}
CV	0.031	0.477	0.636	0.433	0.470
P	0.345	0.531	0.923	0.613	0.531
Effect	ns	ns	ns	ns	ns

pH: hydrogen potential; C: carbon; C/Nt: carbon-nitrogen ratio; Nt: total nitrogen; OM: organic matter; In the same column, the means followed by the same letter are not significantly different at the threshold of α=0.05; ns: non-significant difference P > 0.05; CV: Coefficient of variation.

Chemical Parameters:

The results on the chemical parameters are recorded in Table 3. Only the CEC made it possible to observe a significant difference ($P < 0.01$) between the topographic positions. This CEC varied between 2.22 cmol.kg^{-1} and 11 cmol.kg^{-1}. The CEC is very low in the previous market gardening at the bottom of the slope (2.22 cmol.kg^{-1}) and on the previous cassava-maize at lower mid-slope (4.88 cmol.kg^{-1}). It was average on the upper mid-slope (sorghum) and upper slope (rubber) with respectively 11 and 10.20 and cmol.kg^{-1}. The sum of the bases between 1.2 cmol.kg^{-1} on the bottom of the slope (BP) and 3.4 cmol.kg^{-1} on the upper slope (HV) was very low in these soils when the saturation rate increased from low (22.4% for the previous sorghum) to medium (56.3% for the previous market gardening). The overall low assimilable phosphorus content varied from 19 cmol.kg^{-1} (bottom of the slope) to 21.75 cmol.kg^{-1} (lower mid-slope).

The calcium content (Ca^{2+}) varied within acceptable proportions. Thus, the calcium content varied between 0.772 cmol.kg^{-1} on the bottom of the slope (BP) and 2.525 cmol.kg^{-1} on the upper slope (HV). The high values were obtained on the upper mid-slope (MVsup) and upper slope (HV) positions with respectively 1.087 and 2.525 cmol.kg^{-1}. The magnesium content varied between 0.340 cmol.kg^{-1} (BP) and 1.052 cmol.kg^{-1} (MV sup). The high levels were obtained on the upper mid-slope (MVsup) and upper slope (HV) treatments with respectively 1.052 and 0.668 cmol.kg^{-1}. Overall, these levels are acceptable. The soil at the site was very low in potassium. Indeed, the highest potassium content was obtained in BP with 0.074 cmol.kg^{-1} for expected values greater than 0.1 cmol.kg^{-1}.

Table 3: Variation of some chemical parameters according to the position on the toposequence

Topographical positions	Chemical parameters							
	P.ass	CEC	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Sb	V
Upper slope (HV)	20,50^{a}	10,20^{a}	2,525^{a}	0,668^{a}	0,066^{a}	0,169^{a}	3,429^{a}	33,180^{a}
Upper mid-slope (MVsup)	19,25^{a}	11,00^{a}	1,087^{a}	1,052^{a}	0,066^{a}	0,161^{a}	2,366^{a}	22,484^{a}
Lower mid-slope (MVinf)	21,75^{a}	4,88^{ab}	1,009^{a}	0,561^{a}	0,059^{a}	0,129^{a}	1,758^{a}	39,019^{a}
Bottom of the slope (Bp)	19,00^{a}	2,22^{b}	0,772^{a}	0,340^{a}	0,074^{a}	0,047^{a}	1,233^{a}	56,357^{a}
CV	0,521	0,548	0,571	0,441	0,114	0,493	0,424	0,364
P	0,997	0,022	0,069	0,075	0,392	0,259	0,094	0,073
effete	ns	*	ns	ns	ns	ns	ns	ns

P.ass: assimilable phosphorus; CEC: cation exchange capacity; Ca^{2+}: calcium; Mg^{2+}: magnesium; Na^{+}: sodium; K^{+}: potassium; Sb: sum of bases; V: saturation rate; * significant difference $P < 0.05$. In the same column, means followed by the same letter are not significantly different at the threshold of $\alpha=0.05$; ns: non-significant difference $P > 0.05$; CV: Coefficient of variation.

Table 4 presents some equilibrium ratios between Ca^{2+}, Mg^{2+} and K^{+} cations in the soils studied. The K/CEC ratio was low in all the soils compared to the expected norms between 2 and 3. Indeed, this ratio varied between 0.006 (MVSup) and 0.06 (HV). It translates the extreme poverty of the soil in potassium. These values reflect a potassium (K) deficiency in these soils.

The Ca^{2+}/Mg^{2+} ratio was optimal for all positions except at MVsup where it is low. This ratio varied from 1.02 (upper mid-slope) to 4.1 $cmol.kg^{-1}$ (upper slope). The optimal values of the Ca^{2+}/Mg^{2+} ratios are between 2 and 9 according to [21].

The K^{+}/Mg^{2+} ratio is optimal in all the treatments except at BP where it is high, whereas the $(Ca^{2+}+ Mg^{2+})/K^{+}$ ratio is high in all the treatments.

Table 4: Equilibrium ratios between Ca^{2+}, Mg^{2+} and K^{+} cations in soils

Ratios	Upper slope (HV)	Upper mid-slope (MVsup)	Lower mid-slope (MVinf)	Bottom of the slope (Bp)
Ca^{2+}/Mg^{2+}	4,1	1,02	2	2,3
K^{+}/Mg^{2+}	0,09	0,05	0,08	0,20
$(Ca^{2+}+Mg^{2+})/K^{+}$	53	35,5	31,2	15,8
K^{+}/CEC	0,06	0,006	0,012	0,033

Linking the Parameters Studied:

The physico-chemical parameters of the soil establish between them positive or negative relationships (Table 5). Sand correlates negatively ($r = 0.81$ and 0.85; $P < 0.05$) with clay and saturation level. The A+L sum established a weak positive correlation ($r = 0.79$; $P < 0.05$) with clay, a strong positive correlation with CEC and magnesium ($r=0.84$ and 0.90; $P < 0.01$) and a strong but negative correlation ($r = 0.86$; $P< 0.01$) with saturation rate. The sum A+L also established a very strong positive correlation with silt ($r = 0.94$; $P < 0.001$) and negative with sand ($r = 0.99$; $P < 0.001$). Silt correlated positively ($r = 0.74$; $P < 0.05$) with magnesium, and established a very strong negative correlation ($r = 0.92$; $P < 0.001$) with sand and saturation rate.

Carbon established good positive correlations with clay ($r = 0.78$; $P < 0.05$) and sum of bases ($r = 0.74$; $P < 0.05$) and a negative correlation ($r = 0.79$; $P < 0.05$) with pH. The correlation was very strongly positive ($r = 1$; $P < 0.001$) with organic matter and strongly positive with magnesium ($r = 0.87$; $P < 0.01$) and nitrogen ($r = 0.86$; $P < 0.01$). Organic matter content correlated positively ($r = 0.78$; $P < 0.05$) with clay and sum of bases ($r = 0.74$; $P < 0.05$) and negatively ($r = 0.79$; $P < 0.05$) with pH. It also establishes a strong positive correlation ($r = 0.87$ and 0.86; $P < 0.01$) with magnesium and nitrogen.

Magnesium established a strong positive correlation ($r = 0.89$; $P < 0.01$) with clay and a negative one ($r = 0.92$; $P < 0.01$) with sand. Calcium (Ca2+) established a weak negative correlation ($r = 0.70$; $P < 0.05$) with pH and a very strong positive correlation ($r = 0.94$; $P < 0.0001$) with the sum of bases. CEC showed a weak positive correlation ($r = 0.78$; 0.75 and 0.74; $P < 0.05$) with silt, magnesium and sum of bases respectively. With sand and saturation rate, CEC establishes strong negative correlations ($r = 0.84$; and 0.88 respectively with $P < 0.01$).

Nitrogen establishes a strong negative correlation ($r = 0.83$; $P < 0.01$) with pH, which is weakly and negatively correlated ($r = 0.79$; $P < 0.05$) with the sum of bases.

Table 5: Correlation matrix of study parameters

	A	A+L	C	C/Nt	Ca2+	CEC	K+	L	MO	Mg2+	Na+	Nt	P.ass	pH	S	Sb	V
A	1																
A+L	0,79*	1															
C	0,78*	0,62	1														
C/Nt	0,08	0,38	-0,24	1													
Ca2+	0,30	0,15	0,55	-0,05	1												
CEC	0,67	0,84**	0,61	0,47	0,58	1											
K+	-0,11	-0,32	-0,38	0,45	-0,30	-0,27	1										
L	0,54	0,94***	0,42	0,48	0,04	0,78*	-0,38	1									
MO	0,78*	0,62	1,00***	-0,24	0,55	0,61	-0,38	0,42	1								
Mg2+	0,89**	0,90**	0,87**	0,09	0,30	0,75*	-0,29	0,74*	0,87**	1							
Na+	0,41	0,53	0,36	0,19	0,42	0,51	-0,43	0,50	0,36	0,49	1						
Nt	0,49	0,24	0,86**	-0,63	0,62	0,32	-0,54	0,05	0,86**	0,56	0,17	1					
P.ass	0,01	-0,05	0,45	-0,20	0,05	-0,07	0,12	-0,08	0,45	0,23	-0,18	0,39	1				
pH	-0,37	-0,36	-0,79*	0,34	-0,70*	-0,50	0,58	-0,30	-0,79*	-0,59	-0,39	-0,83**	-0,33	1			
S	-0,81*	-0,99***	-0,66	-0,34	-0,18	-0,84**	0,33	-0,92***	-0,66	-0,92**	-0,53	-0,29	0,01	0,40	1		
Sb	0,55	0,43	0,74*	-0,0002	0,94***	0,74*	-0,36	0,29	0,74*	0,59	0,57	0,69	0,11	-0,79*	-0,47	1	
V	-0,48	-0,86**	-0,48	-0,55	-0,26	-0,88**	0,28	-0,92**	-0,48	-0,70	-0,38	-0,14	-0,09	0,39	-0,85**	-0,45	1

A: clay; L: silt; S: sand; pH: hydrogen potential; C: carbon; C/Nt: carbon to nitrogen ratio; Nt: total nitrogen; OM: organic matter; P.ass: assimilable phosphorus; CEC: cation exchange capacity; Ca^{2+}: calcium; Mg^{2+}: magnesium; Na^{+}: sodium; K^{+}: potassium; Sb: sum of bases; V: saturation rate; * low correlation; **: strong correlation; *** very strong correlation

Projection on factorial plane 1-2 (Figure 6.A), associates positively, CEC, A+L, A, C/Nt, M.O, Mg^{2+}, C, L, Sb, Ca^{2+}, Nt and negatively V, S to axis 1. It associates positively with axis 2, pH and K^{+} but negatively with P.ass. The factor map (figure 6.B) thus defines three fertility groups:

Group 1 consists only of the soil at the bottom of the slope occupied by the previous market garden. It is characterized by pH, presence of sand (S) and saturation level (V). These soils are the least rich in organic matter and minerals. The lower mid-slope forms group 2, which was characterized by better availability of assimilable phosphorus (P.ass).

Group 3 includes the soils of the upper slope (rubber tree) and the upper mid-slope (previous sorghum). It is characterized by the highest availability of clay (A), silt (L), organic matter (MO) and total nitrogen (Nt), with a higher sum of bases (Sb) and cation exchange capacity (CEC). These two levels represent the most fertile soils in the toposequence.

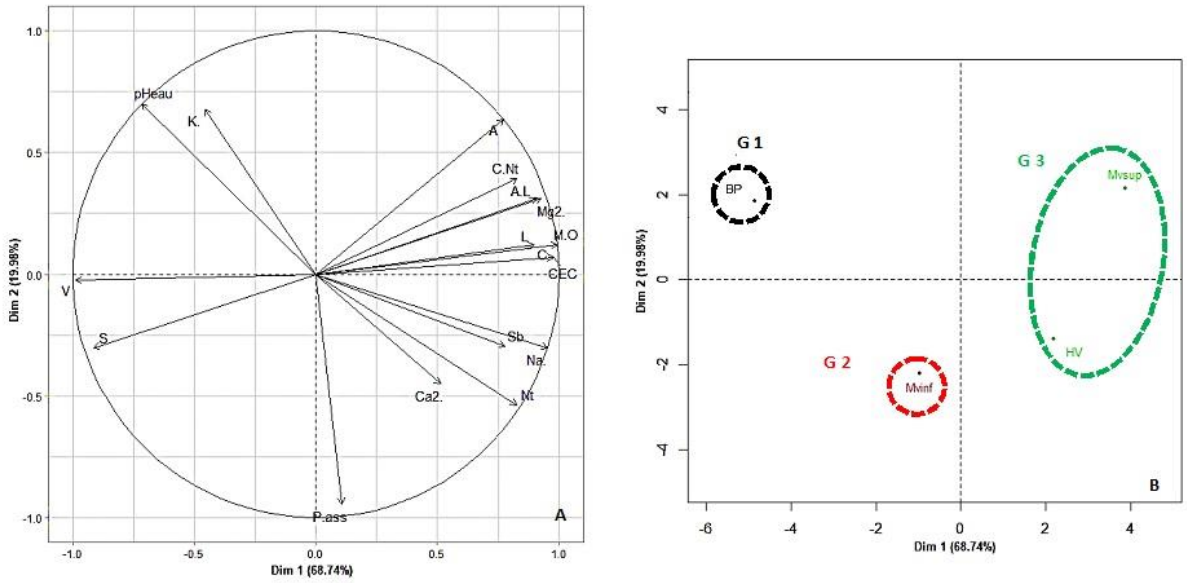


Figure 3: PCA associating soil parameters

A: clay; L: silt; S: sand; pHeau: hydrogen potential; C: carbon; C. Nt: carbon to nitrogen ratio; Nt: total nitrogen; M.O: organic matter; P.ass: assimilable phosphorus; CEC: cation exchange capacity; Ca2.: calcium; Mg2.: magnesium; Na: sodium; K.: potassium; Sb: sum of bases; V: saturation rate; BP: Bottom of the slope; HV: upper slope; MVinf: lower mid-slope; MVsup: upper mid-slope; G1: group1; G2: group2; G3: group3.

DISCUSSION

The physical description of the profiles showed that the soil of the study area presents few physical constraints for agricultural development in its lower half. Indeed, with the exception of the mid-slope with plinthic characteristics which presented an induration at less than 50 cm, all the other positions have deep soils that are more or less loose on the surface. The surface horizons of the soils of the area, with a loamy-sandy texture, are certainly poor in clay but seem to have a good content of organic matter (mostly gray to dark gray) especially on the upper part of the toposequence under rubber and sorghum mulch. These characteristics show that the soil of the site has good cultivation potential. These results corroborate those of [22] who

demonstrated that a lumpy structure associated with a loamy-sandy texture offers physical properties conducive to plant development. The realization of the textural triangles made it possible to locate the soils in the category of soils with a balanced texture for water management, with the exception of the soil at the bottom of the slope, which filters too much. The abundance of sand in the lower positions of the toposequence reveals a greater ease of displacement of this coarse fraction compared to the finer elements more solidly in links. Moreover, the good porosity of the soils can be explained by the abundance of roots and coarse elements in the upper horizons. This porosity is likely to promote good root growth and good plant development [23]. However, the low clay content could have consequences on the quality of the soils, in particular their chemical fertility as noted [9] on the soils of Gogbala in the North of Côte d'Ivoire.

The results of the particle size analysis confirmed the predominance of silts by the loamy texture of these soils. These results testify that the soils at Zépréguhé are suitable for agricultural practice in accordance with the studies of [24-25-26] which reported that the loamy texture of the soils is excellent and suitable for most crops.

The soils are very weakly acidic to almost neutral, with pH values ranging from 6.50 to 6.90. These pH values are in favour for good biological activity and good availability of the majority of mineral elements for plants, because they are better dissolved in them [27]. Since pH is a key factor in the life of soil microorganisms and determines the availability of nutrients and plant nutrition [21-28], it does not alone condition the cycle of matter. Indeed, the type of material, temperature and humidity also contribute. Thus, the low availability of mineral elements in these soils would be explained by the poor availability of organic matter in the previous market gardening and cassava-maize on the one hand and by a poor biological activity under rubber due to an excess of humidity. on the other hand.

The low level of carbon and nitrogen characterizes the soils of the lower part of the toposequence subject to continuous development without external inputs. Indeed, shifting or successive cropping systems influence the dynamics of organic matter [29] and do not give the soil enough time to build up its nitrogen and carbon stock [30]. The lower part was occupied by the cultivation of cassava-maize on the lower mid-slope and market gardening at the bottom of the slope. These speculations cover little soil and have a low level of renewal of organic matter with very little plant deposit for cassava-maize and permanent ploughing in the case of market gardening. On the other hand, the upper part of the study plot is occupied by a rubber plantation more than seven years old and a field of sorghum, a crop introduced by people from northern Côte d'Ivoire and Burkina Faso. While rubber trees provide strong litter, a source of slowly decomposing organic matter, harvesting sorghum leaves stumps and stumps that also decompose slowly. The low carbon and nitrogen content and the low availability of K^+ and Mg^{2+} are explained by a poor biological activity at these levels of the toposequence. These results are in agreement with those of [31] which states that the more natural vegetation gives way to agricultural land, the more there is a reduction in the production of biomass and organic matter in the soil. Organic restorations through long-term fallows make it possible to restore the fertility of soils depleted by several years of successive crops [32].

Permanent soil cover in rubber cultivation reduces material loss. The same is true for sorghum. Indeed, sorghum can be used as a previous crop providing plant cover to fight against erosion, due to its powerful root system, high biomass production, soil cover provided by cover crop residues dead.

The available phosphorus content is very low in all soils. These results are similar to those obtained by [33] under cocoa trees in the south-west of Côte d'Ivoire. The very low content of assimilable phosphorus is typical and specific to many soils of inter-tropical regions because of their strong fixing power ([34]. The low level of assimilable phosphorus would also be due to the low content in these soils of matter which is the main cause of the bioavailability of phosphorus in soils in tropical environments. Indeed, the work of [35] showed a similar effect of organic matter on the bioavailability of phosphorus in soils under cocoa crops.

Soil contents of calcium, magnesium, potassium and sodium and the sum of bases are low in most soils. Only the upper slope and upper mid-slope soils have an acceptable Ca^{2+} content for the first and an acceptable Mg^{2+} content for the second. This poor supply of exchangeable cations on the whole would be due to the export by the harvests over several years without a manure of restitution and the bad decomposition of the organic matter. This result is similar to those of [36] carried out on tropical soils in Burkina Faso which show the low sum of the bases of the soils under cultivation and of [37] obtained after analysis of the soils under cashew trees in Côte d'Ivoire. This low content will have a negative impact on productivity because these cations are involved in important physiological processes for plants, such as photosynthesis, fruiting and cell permeability. The cation exchange capacity is low at the bottom of the slope and lower mid-slope, associated with low saturation in the upper part, confirming low plant nutrition.

All these physical and chemical characteristics denote an ferralsol in this area. The soils present highly desaturated complexes reflecting their low availability of cations. Similar results were obtained by [9] on the soils of Gogbala in northern Côte d'Ivoire.

The K/CEC ratio is low in soils of all treatments according to [21]. Indeed, according to this author, the expected values of this ratio must be between 2 and 3. It therefore presents an imbalance for good potassium nutrition of plants. The Ca^{2+}/Mg^{2+} ratio is satisfactory in the rubber plantation at the upper of the slope and in the lower part of the toposequence, i.e., on the cassava-maize and market gardening plots. On the other hand, on the upper mid-slope, difficulties in assimilating calcium could be encountered. At the bottom of the slope, the low availability of Mg^{2+} would limit the assimilation of potassium for certain plants due to a high K^{+}/Mg^{2+} ratio. The high $(Ca^{2+}+ Mg^{2+})/K^{+}$ ratio over the whole toposequence confirms that the assimilation of calcium and magnesium can constitute factors limiting agricultural productivity in this zone. Indeed, the optimum of this last ratio must be between 12 and 15 for a good nutrition in calcium and magnesium [38-26].

Land occupation by crops in this area was made according to a fertility gradient from the top of the slope to the bottom of the slope with a succession of rubber-sorghum-cassava/maize-market gardening crops. This fertility gradient could, from the point of view of organic matter,

be due to speculation and the management of agricultural residues. Indeed, the rubber tree constitutes, through the seasonal loss of leaves, a reservoir of organic matter that is annually renewed, just like the cultivation of sorghum for which the harvest residues are kept on the plot. Thus, agriculture can mitigate climate change by implementing beneficial management practices that increase soil carbon storage capacity and limiting practices that contribute to soil organic carbon loss to the atmosphere. through crop choice and residue management.

CONCLUSION

The soils of the study area presented a cropping suitability ranging from low (bottom of the slope) to moderately good at the top of the slope. If this gradient comes from the position on the toposequence, it does not remain the only justification. Speculation and residue management have had a strong contribution to this differentiated fertility on the toposequence. The introduction of sorghum in the area seems, in addition to satisfying a food need imported from the regions of origin, to bring an improvement in the management of soil fertility if crop residues are kept on the ground. The cultivation of rubber trees has the advantage of favouring the protection of the soil against erosion, while maintaining a microclimate that can slow down the decomposition of organic matter, just like the previous sorghum. Rubber and sorghum manage soil fertility better than the other crops in this study. The previous cassava-maize appeared to have the most detrimental effect on organic matter management and, in turn, on overall soil fertility. The bottom of the slope, which immediately presents a physical constraint due to its richness in sand, occupies the lowest level of fertility due to continuous exploitation by crops with a low level of organic matter constitution. The multiplicity of species on the plot and the repeated number of plantings is a factor in soil depletion because various nutrients are simultaneously taken up in large quantities by these vegetables.

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