Relationship between soil fertility indices under coffee and cocoa fallows in Daloa, Côte d'Ivoire

ABSTRACT

In the department of Daloa in Côte d'Ivoire, many coffee and cocoa plantations that have fallen into decline and been left fallow are in the process of being reclaimed by their former or new users. In order to prevent the failure of the planned new crops, this study was initiated to determine how the soils under these fallows function, which is essential for developing sustainable management strategies for them. Thus, seven fallows older than ten years were identified. In each of them, a 10,000 m^2 plot was delimited and three soil pits were set up. In one pit, three soil samples were taken. After analysis of these samples in the laboratory, correlations and balances between certain physico-chemical soil components were calculated. The results show that organic matter contributes in some places to the constitution of the CEC ($r > 0.70$) and thus participates in the soil's function as a reservoir of nutrients. On the other hand, when the soils are leached, the organic matter binds to the sand remaining in the profile and, because of its coarse particles, it hardly contributes to the constitution of the CEC ($r = -0.70$). However, whatever the case, the stability balances between the soil nutrients are globally favourable due to the long duration of the fallows (Ca/Mg close to 2 while K/Mg, (Ca+K)/Mg and C/N varied from 0.10 to 0.50, 15 to 30 and 9 to 12, respectively). Pending consideration of the functioning of the biological component of the soils studied, organic matter appears to be the most determining factor in their overall functioning.

Key words: soil, physico-chemical functioning, organic matter, fallow land, Daloa.

INTRODUCTION

Since independence, Côte d'Ivoire's economic performance has been driven by exports of agricultural commodities, mainly cocoa and coffee (Esso, 2009). Today, Côte d'Ivoire is only the fifteenth largest producer of coffee in the world and the third largest in Africa, whereas in the 1970s it ranked third in the world and first in Africa with an annual production of 400,000 tonnes (FAOSTAT, 2022). Cocoa production, estimated at 2.2 million tonnes in 2020, remains the mainstay of the agricultural sector and is therefore of strategic importance for the country's macroeconomic balance and social stability. However, over the past forty years, the cocoa sector in the West African Monetary Union (UEMOA), and hence in Côte d'Ivoire, has been confronted with several constraints that have hindered its full development (FAOSTAT, 2022). In total, among the obstacles to the development of the coffee and cocoa sector, the following stand out: the fall in international prices and their high volatility (FAOSTAT, 2022), coupled with the continuous decline in income received by producers (Eponon et al., 2017), insufficient knowledge of the morpho-pedological characteristics of the areas under cultivation (Koko et al., 2008), the dwindling of arable land and low yields (Assiri, 2007; Aguilar et al., 2003; Freud et al., 2000). Presumably, all these difficulties, including soil depletion, have led many farmers to abandon their fields. Today, as the time has come to reclaim abandoned land, it is of interest to know how it functions in order to develop sustainable management strategies for it, especially as tropical soils in general release only small quantities of nutrients for plants (Pieri & Moreau, 1986). Thus, the present study aims to determine and analyse the correlations and balances existing between certain physico-chemical components of some coffee and cocoa fallow soils, which will help explain the fertility of these soils (Zro et al., 2016; Doucet, 2006). In this way, the future crops envisaged will not experience a rapid decline like the first ones.

MATERIALS AND METHODS

Study area

The study was conducted in the department of Daloa located in the centre-west of Côte d'Ivoire. This department is very humid with a four-season climate: the long rainy season, which extends from April to mid-July, is marked by inter-seasons and thunderstorms; it is followed by the short dry season (mid-July to mid-September) and the short rainy season (mid-September to November); the long dry season covers the months of December to March. Annual rainfall has decreased from 1,868.5 mm in 1968 to 1,120.4 mm in 2005, a decrease of 40 percent (Ligban et al., 2009). The average annual temperature is 25.6°C. Hydrographically, the department is watered by the Sassandra River and its tributary the Lobo, whose branches, the Dé and the Goré, flood the department. The vegetation is homogeneous and consists of dense, humid forest in the south and wooded savannah in the north. This forest is experiencing accelerated degradation due to the intensification of cash crops (cocoa, coffee, oil palm and rubber). The relief of the department is made up of plateaus at 200-400m altitude cut in places by plains and lowlands (Avenard & Deluz, 1972). From a pedological point of view, studies by Dabin et al (1960) have shown that the soils of the department are generally ferrallitic and moderately desaturated. From a lithological point of view, the bedrock is made up of granitoids of constant mineralogical composition. These are alkaline to sub-alkaline granites contained in metamorphic formations (gneiss and migmatites) of very similar composition. These formations are very rarely visible in the outcrop because they are masked by a thick cover of clay and sand alteration. A total of seven sites on gently sloping plateaus (7 to 8 pc) in seven different localities were selected; These were the villages of Bla (N6°43'58" W6°29'37''), Gonaté (N6°53'41'' W6°16'13''), Loboguguia (N6°47'45'' W6°37'18''), Madoguhé (N7°03'77″ W6°29'18"), Wandaguhé (N6°50'51" W6°24'55"), Zépréguhé (N6°54'31" W6°22'10'') and the town of Daloa (N6°55'03" W6°22'10''). The sites of Loboguiguia and Zépréguhé are cocoa fallows, while those of Bla, Daloa, Gonaté, Madoguhé and Wandaguhé are coffee fallows.

Data collection

On a given site, a useful plot of 100 m x 100 m was delimited; In each of them, three soil pits were planted in a sequence determined by the diversity of the plant cover, since the topography of the plot was almost flat (slope between 7 and 8 pc) and the cropping history was identical throughout the plot, only the state of vigour of the vegetation (growth, development and health status, weed or pest infestation) could better reflect the nature of the underlying soil (Freschet et al., 2018). In each pit, three composite soil samples were taken. To avoid contamination, the first sample was taken at a depth between 120 and 80 cm, the second between 80 and 40 cm and the last between 40 and 0 cm. After air-drying and sieving on a 2 mm mesh, the fine fractions of the soil samples were packed in labelled plastic bags and sent to the laboratory for the physico-chemical analyses summarised in Table 1.

Table 1: Summary of applied soil testing methods

Variable types	**Variables**	**Methods**
Chemical	pH	Glass electrode pH meter (Diack & Loum, 2014)
	Organic carbon (C)	Walkley & Black (Hilhort & Balendonck, 1999)
	Organic matter	OM = 1,72 x C
	Nitrogen (N)	Modified Kjeldahl (Diack & Loum, 2014)
	Phosphorus	Modified Olsen (Hilhort & Balendonck, 1999)
	Calcium (Ca)	Atomic absorption spectrometer (Pansu & Gautheyrou, 2003)
	Magnesium (Mg)	
	Potassium (K)	
	Sodium (Na)	
	Cation exchange capacity (CEC)	Modified Kjeldahl (Diack & Loum, 2014)
	Iron (Fe)	Mass spectrometer (Lund *et al.*, 1999)
	copper (Cu)	
	Manganese (Mn)	
	Zinc (Zn)	
Physical	Sand	Robinson's Pipette (Douzals, 2000)
	Silt	
	Clay	

Data processing and analysis

The mode of functioning of the soil was analysed, on the one hand, in relation to the correlations existing between the indicator variables of the chemical fertility of the soils (pH, carbon or organic matter, total nitrogen, phosphorus, calcium, magnesium, potassium, sodium, copper, zinc, manganese and iron) and the explanatory variables of the fertility of the soils in general (CEC and texture) (Zro et al., 2016; Genot et al., 2012). On the other hand, the mode of functioning of the studied soils was analysed in relation to the states of saturation equilibria of exchangeable bases and the states of mineralisation of organic matter in soils in general. The thresholds for these equilibria are shown in Table 2. All correlations were calculated using R software (Version 3.6.3).

Table 2: Equilibrium thresholds analysed in the soils studied

Ratios	**Mineral balances**				
	Insufficient	Acceptable	Optimal	High	Too high
Ca/Mg	< 1	1-2	2-9	10-30	> 30
Acidiphilous plants			0.8-5		
K/Mg	< 0.05	0.05-0,10	0.10-0.50	0.5-1	> 1
(Ca+Mg) /K	< 12	12-15	15-30	30-40	> 40
Acidiphilous plants			6-8		
C/N	< 9		9-12	> 12-25	> 25

Source: Doucet (2006).

RESULTS

Correlations between soil variables

Tables 3 to 9 present for each site the lines of the matrices on which at least one correlation was found to be significant at $p < 0.05$ between, on the one hand, pH, carbon or organic matter, total nitrogen, phosphorus, calcium, magnesium, potassium, sodium, copper, zinc, manganese and iron taken as indicator variables of the chemical fertility of the soils and, on the other hand, texture and CEC, which are the explanatory variables of this fertility.

In Bla (Table 3), the rates of organic matter, total nitrogen, assimilable phosphorus and calcium increase with the sand and the CEC of the soil; on the contrary, these rates decrease in the presence of increasing amounts of silt: the sand is thus the main reservoir of carbon storage in the soil, which in turn actively participates in the constitution of the CEC.

In Daloa (Table 4), the soil is characterised by an increase in organic matter and calcium levels in the soil as CEC and sand levels increase. Silt lowers organic matter levels, but raises calcium and manganese levels: as in Bla, sand ensures the immobilisation of organic matter in the soil, which actively contributes to the constitution of CEC. The silt contributes to the constitution of the CEC by adsorbing calcium and manganese.

The Gonaté soil (Table 5) is such that CEC decreases with increasing acidity; organic matter, total nitrogen and available phosphorus, as well as iron, manganese and zinc, have the opposite effect on CEC. On the other hand, increasing amounts of organic matter, total nitrogen, available phosphorus and calcium are linked to similar amounts of sand: soil nutrients are thus replenished in the soil from the organic matter mobilised by the sand. Silt has the opposite effect on these same variables. Iron, manganese and zinc are positively correlated with CEC and are among the most available elements in the soil solution, thus underlying the high acidity of the soil.

In the Madoguhé soil (Table 6), silt, in contrast to sand, is associated with lower levels of organic matter, total nitrogen, available phosphorus, calcium, magnesium and potassium. This shows that sand acts as a nutrient reservoir in this soil, as has already been observed in other soils. A high clay content only has a significant positive effect on the manganese content. CEC, on the other hand, is improved by the presence of copper; the opposite effect on CEC is observed with magnesium.

The correlations from the Wandaguhé soil (Table 7) follow the same trend as those observed in Zépréguhé (Table 8). Indeed, while silt lowers the levels of organic matter, total nitrogen, calcium, magnesium, potassium, iron and manganese in these soils, sand raises the levels of these variables. The CEC of these soils is negatively impacted by organic carbon, total nitrogen and copper: organic matter is therefore trapped in the sand and appears to be the main reservoir of nutrients; this organic matter, being stable, hardly participates in the constitution of the CEC of the soil.

Contrary to the findings at the other sites, no soil variable contributes significantly to the CEC of the Loboguiguia soil (Table 9). However, the texture, due to the clay, raises the levels of organic matter, total nitrogen, magnesium and potassium and lowers the level of zinc. With sand and silt, it is, in this order, the level of assimilable phosphorus that is raised while that of copper is lowered.

Table 3: Significant correlations between Bla soil variables

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
C or OM	0.01	**-0.89**	**0.92**	**0.92**
N	-0.15	**-0.93**	**0.95**	**0.89**
P	0.17	**-0.96**	**0.97**	**0.81**
Ca	0.08	**-0.96**	**0.97**	**0.83**

Table 4: Significant correlations between soil variables in Daloa

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
C or OM	-0.12	**-0.82**	**0.84**	**0.73**
Ca	-0.20	**-0.92**	**0.94**	**0.75**
Mn	-0.02	**-0.72**	**0.77**	0.54

Table 5: Significant correlations between Gonaté soil variables

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
pH	-0.33	0.60	-0.58	**-0.78**
C or OM	-0.46	**-0.89**	**0.92**	**0.78**
N	-0.40	**-0.89**	**0.91**	**0.84**
P	-0.45	**-0.81**	**0.82**	**0.88**
Ca	**-0.77**	-0.64	**0.70**	0.60
K	0.21	0.67	**-0.72**	0.19
Fe	0.28	-0.69	0.68	**0.78**
Mn	-0.31	-0.56	0.57	**0.83**
Zn	0.34	-0.42	0.37	**0.76**

Table 6: Significant correlations between Madoguhé soil variables

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
C or OM	0.35	**-0.82**	**0.85**	-0.64
N	0.34	**-0.76**	**0.81**	-0.46
P	0.18	**-0.91**	**0.91**	-0.47
Ca	0.51	**-0.93**	**0.91**	-0.69
Mg	0.33	**-0.88**	**0.87**	**-0.80**
K	0.34	**-0.86**	**0.89**	-0.63
Mn	**0.79**	-0.52	0.58	-0.68
Cu	-0.68	0.32	-0.37	**0.76**

Table 7: Significant correlations between Wandaguhé soil variables

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
C or OM	-0.50	**-0.82**	**0.87**	-0.69
N	-0.46	**-0.87**	**0.88**	**-0,70**
K	-0.58	**-0.72**	**0.70**	-0.46
Mn	-0.34	**-0.90**	**0.88**	-0.62
Cu	0.60	-0.16	0.24	**-0.61**

Table 8: Significant correlations between Zépréguhé soil variables

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
C or OM	-0.50	**-0.85**	**0.86**	**-0.70**
N	-0.46	**-0.86**	**0.88**	**-0.70**
K	-0.58	**-0.70**	**0.70**	-0.46
Mn	-0.34	**-0.88**	**0.91**	-0.62
Cu	0.60	-0.16	0.24	**-0.71**

Table 9: Significant correlations between Loboguiguia soil variables

Indicator variables for chemical soil fertility	**Explanatory variables for soil fertility**			
	Texture			CEC
	Clay	Silt	Sand	
	Correlation coefficients (r)			
C or OM	**0.93**	-0.59	0.58	0.01
N	**0.93**	-0.51	0.50	-0.07
P	-0.04	**-0.77**	**0.73**	0.18
Mg	**0.80**	-0.36	0.34	0.45
K	**0.88**	-0.45	0.50	0.37
Cu	0.11	**-0.81**	**0.84**	0.12
Zn	**-0.85**	0.41	-0.41	0.35

Balances between some soil nutrients

Table 10 shows the variance of some commonly calculated ratios between cations (Ca/Mg, K/Mg, (Ca + Mg)/K) and between soil carbon and nitrogen (C/N). The Ca/Mg ratio, with means ranging from 1.368±0.144 to 1.803±0.047, is acceptable in Loboguiguia, Madoguhé, Wandaguhé and Zépréguhé. In Bla, Daloa and Gonaté, these averages, which vary between 2.097±0.652 and 2.573±0.760, are optimal. With respect to the K/Mg ratio, three groups of soils can be identified. In fact, this ratio, estimated at 0.056±3.093 in the Daloa soil, is acceptable, while those of the Loboguiguia, Madoguhé, Gonaté and Bla soils, which vary between 0.102±0.544 and

0.127±0.902, are optimal. For the soils of Wandaguhé and Zépréguhé, this ratio, which is greater than 1, is too high. The mean (Ca+Mg)/K ratios for the soils of Madoguhé, Wandaguhé, Bla, Zépréguhé and Gonaté are 16.00±0.005, 16.71±0.001, 24.83±0.003, 26.66±0.007, 28.16±0.002, respectively: all of these ratios are in optimal balance. However, for the Daloa soil, this ratio (52.71±0.009) is too high. The calculated C/N ratios are 14.98±5.56 in the Daloa soil, 8.84±1.76 in the Gonaté soil and 9 to 12 in the Bla, Loboguiguia, Madoguhé, Wandaguhé and Zépréguhé soils. These ratios are thus high and normal.

Table 10: Soil nutrient balances

Sites	Ca/Mg	K/Mg	(Ca+Mg)/K	C/N
Bla	2.198±0.420a	0.127±0.902b	24.83±0.003b	10.92±2.23ab
Daloa	2.097±0.652a	0.056±3.093a	52.71±0.009c	14.98±5.56a
Gonaté	2.573±0.760a	0.125±1.089b	28.16±0.002b	8.84±1.76b
Loboguiguia	1.720±0.420a	0.102±0.544b	26.80±0.009b	10.12±0.78ab
Madoguhé	1.760±0.740a	0.125±1.071b	16.00±0.005a	12.01±2.45ab
Wandaguhé	1.368±0.144a	16.71±0.989bc	16.71±0.001a	11.71±1.41ab
Zépréguhé	1.803±0.047a	26.66±2.043c	26.66±0.007b	11.55±1.42ab

Values with different letters in the same column are significantly different at the 5 pc level.

DISCUSSION

Plant production is possible by providing plants with only the necessary mineral elements, water, CO_2 and light energy. Soil organic matter (OM) facilitates this supply of necessary elements to plants by several actions. One of these actions is to participate in the soil's function as a reservoir of elements essential to plants: soil OM contributes to the constitution of the cation exchange capacity (CEC) of soils. This role was reflected in the present study by the significant positive OM-CEC correlations, especially in Daloa, where it was well marked, as is the case for tropical ferralitic soils in general, due to the fact that these soils are made of kaolinic type clays, a clay with low exchange activity. The contribution of soil OM to the constitution of CEC in such a case significantly increases the capacity of the soil to contain the cations needed by plants in a form that can be easily assimilated by them (Fallavier, 1995 ; Rahmani et al., 2022). Thus, the significant positive correlations between CEC-N and CEC-P observed in Bla and Gonaté are the expression of the availability of nitrogen and phosphorus to the plants. The idea that the nitrogen taken up by plants, even in the case of large fertiliser inputs, comes largely from mineralised soil OM (Ganry, 1990 ; Mosier et al., 2021), supports this analysis. However, the significant negative correlations MO-CEC at Zépréguhé and OM-N at Wandaguhé and Zépréguhé show that increases in soil OM can be accompanied by a decrease in CEC. An explanation for this observation can be deduced from the observations made by Fallavier (1995) who, in studying the contribution of the granulometric fractions of organic matter to the cation exchange capacity of leached soils in various tropical countries, including Côte d'Ivoire, showed that the 'clay' fraction of the soil is the one that normally contributes most to the CEC of the soil. This assumes that soil OM is the size of clay and therefore associated with it. However, when soil OM is positively correlated with sand and almost not at all with silt and clay, as is the case in most of the soils studied, it is a priori coarse and would not significantly contribute to soil CEC. Also, when Boissezon (1973) points out that some ferrallitic soils, particularly those located at altitude as here, are relatively rich in organic matter with coarse humus, and that the exchangeable bases of these soils, along with the clay, are carried away by leaching, it is easier to understand the lack of significant correlation observed between OM or CEC and exchangeable bases in the present study. These variables (OM or CEC) can only be related to the sand remaining in the profile.

CONCLUSION

The main significant correlations that emerged from this study link organic matter and the cation exchange capacity (CEC) of the soil in a positive way in some places, while in other places this relationship is negative. In the first case, organic matter contributes to the constitution of the CEC and participates in the soil's function as a reservoir of elements indispensable to plants. The second case generally occurs in very leached soils, where the organic matter, because it is coarse and bound to the sand accumulated in the upper layers of the soil, hardly contributes to the constitution of the CEC. This insignificant action of organic matter on CEC is probably not preponderant because, in either case, the stability balances between the soil nutrients are generally favourable. This good disposition in the soils has been attributed to the long duration of fallow maintained on these soils. Thus, pending consideration of the functioning of the biological component of the soils studied, organic matter appears to be the most important factor determining their overall functioning.

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