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The Impact of traditional cocoa-based agroforestry systems on chemical soil fertility in southwest of Côte d'Ivoire

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Abstract

The sustainability of cocoa farming is a major concern for Côte d'Ivoire. Extensive and "full sun" cropping systems need to be reviewed. Against this backdrop, a study was carried out in the south-west of the country (Soubré and Méagui), a major production zone, with the aim of assessing the impact of traditional agroforestry systems on soil fertility.

Twenty-seven cocoa farms in the three sectors were visited. To assess the impact of cocoa-based agroforestry systems on soil chemical parameters, four criteria guided the choice of plots. These were mid-slope plots, 25 to 35 years old, unfertilized and denser in associated trees. Soil samples were taken from the 0-20 cm horizon. Organic carbon, total nitrogen, assimilable phosphorus, exchangeable bases (Ca, Mg, K and Na), cation exchange capacity and saturation rate were measured.

The results show that traditional cocoa-based agroforestry systems have not impoverished the soil. In fact, chemical fertility in these plots respects the needs of cocoa trees. However, the study did not show an increase in soil organic matter due to the fall of leaves from associated trees.

These results will enable the use of traditional agroforestry systems without fear of soil impoverishment due to any competition between cocoa trees and associated trees.

Keywords: Agroforestry; Sustainability; Cocoa Tree; Soil; Côte d'Ivoire

1. Introduction

Côte d'Ivoire, the leading cocoa-producing country with 2.034 million tones in [1], that is to say. 35 p.c. of world production according to the Cocoa Coffee Council (CCC) [2], is facing a problem of sustainability of its production [3, 4]. Indeed, the extensive cultivation system and the management of cocoa plantations in "full sun", that is to say without shade, have reached their limits. Faced with the depletion of the country's forest reserves, climate change (lower rainfall, longer drought periods) [5] and declining soil fertility [6], Côte d'Ivoire needs to explore other production approaches. In particular, agroforestry systems are renowned for their sustainability, productivity, ecological, environmental and economic characteristics [7].

Faced with these challenges, the Cocoa Coffee Council (CCC), through the Interprofessional Fund for Agricultural Research and Consultancy (IFARC), has initiated the Quantity, Quality, Growth (2QG) program for the cocoa coffee sector. This program is implemented within the framework of a Public-Private Partnership involving research and development support structures (notably CNRA: National Center of Agronomic Research and ANADER: National Agency

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:for Rural Development Support), as well as the coffee-cocoa industry. Several research activities are led by CNRA as part of this program. In particular, they aim to develop high-performance, sustainable cocoa farming systems, as well as to update and regionalize cocoa growing techniques in Côte d'Ivoire. Agroforestry is one of the major areas of research. It began with basic studies, namely the characterization of existing systems and assessment of their impact on cocoa orchards. The characterization component was conducted in several departments [8, 9]. The South-West region, and in particular the Soubré and Méagui departments which are areas of high cocoa production, have not yet been covered. Thus, our study involved characterizing the impact of cocoa-based agroforestry systems on chemical soil fertility in these departments.

2. Materials and methods

2.1. Study area

The study took place in the departments of Soubré and Méagui, in south-western Côte d'Ivoire **(Fig. 1)**. These departments lie between 5°35'32'' and 5°58'44'' north latitude and between 6°34'24'' and 6°36'00'' west longitude.

The climate is sub-equatorial, characterized by two rainy and two dry seasons. Average annual rainfall is relatively abundant, ranging from 1,203.6 to 1,392 mm. The average monthly temperature is between 25.8 and 26.3°C [10]. The vegetation used to be dense forest, but has now given way to remnants of forest. The plots are reworked or typical ferralitic soils (Ferralsols), hydromorphic soils (Gleysols) with Gley and pseudo-Gley derived from alluvium and eutrophic (eutric) tropical brown soils (Cambisols) [11].

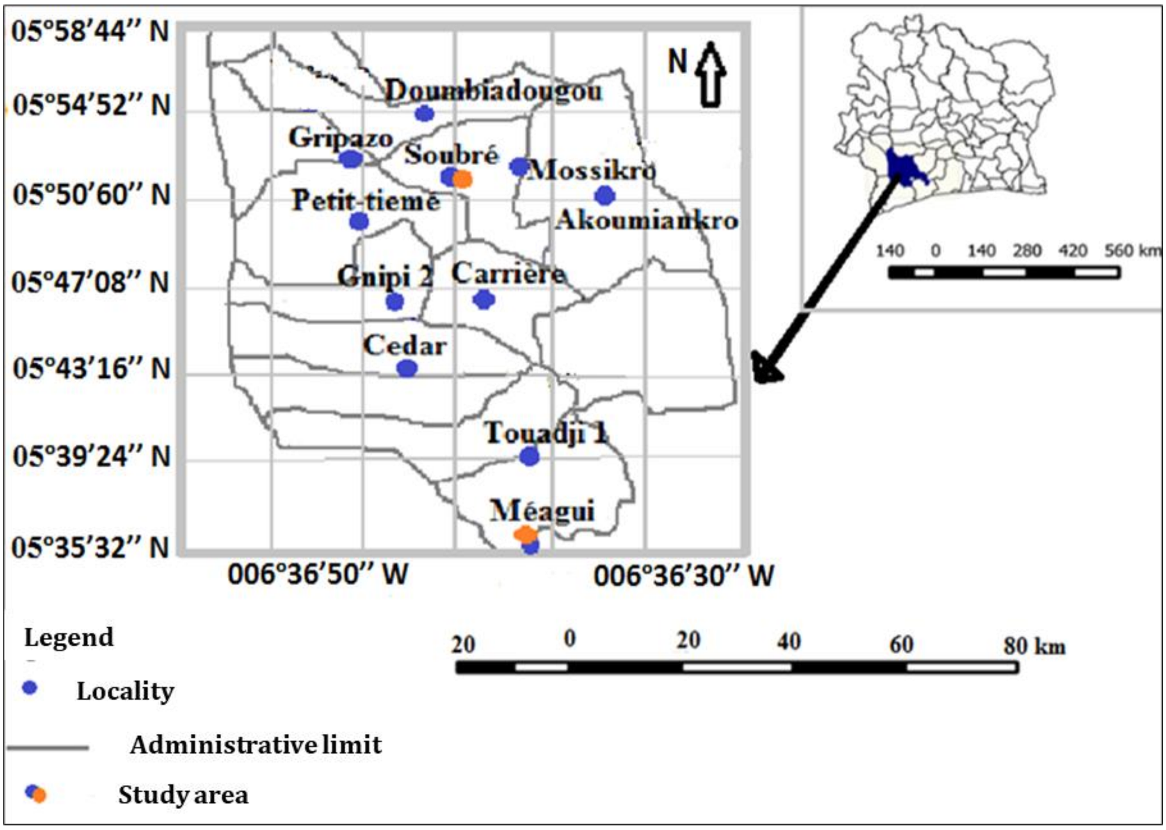

Figure 1 Study area map

2.2. Methods

2.2.1. Choice of villages and cocoa plantations

The study area was subdivided into three sectors:

- Soubré 1, with two villages (Gripazo and Doumbiadougou);
- Soubré 2, with three villages (Mossikro, Akoumiankro and Kedekouassikro);

- Méagui, with three villages (Touagui 1, Cedar and Petit tiémé).

A total of 27 cocoa farms in the three sectors were visited.

To assess the impact of cocoa-based agroforestry systems on soil chemical parameters, four criteria guided the choice of plots. These were:

- Topographical position; for this criterion, the mid-slope, the most cultivated topographical segment according to [12], was selected;
- The age of the cocoa farm; the 25 to 35 years age range, the age of the majority of cocoa farms visited, was selected;
- The use of fertilizers; unfertilized plots were selected; however, if fertilizers were used, the last application should be more than 3 years old, so that no residual effect would bias the expected results;
- Density of associated trees; for two cocoa farms meeting the above criteria, the one with the highest density of associated trees is selected.

On the basis of these four criteria, nine farms were selected, three in each sector, including two under shade and one without shade considered as the control (Table 1).

Table 1 Cocoa farms selected according to established criteria

Number	Locations	Age of cocoa plantation (year)	Cocoa farm management system	Topographical position of the cocoa plantation	Year of last fertilizer application	Associated tree densitiy
1	Soubré1	25	Under shade	HS ; MS	--	65
2	Soubré1	28	Under shade	MS ; BS	2008	37
3	Soubré1	25	Unshaded	MS	2010	0
4	Soubré2	35	Under shade	HS ; MS ; BS	--	43
5	Soubré2	27	Under shade	HS ; MS ; BS	2010	65
6	Soubré2	25	Unshaded	MS	2010	0
7	Méagui	29	Under shade	MS	--	36
8	Méagui	35	Under shade	HS ; MS ; BS	2008	44
9	Méagui	29	Unshaded	MS	--	0

HS : High Slope ; MS :Mid-Slop ; BS Bottom of Slope

2.2.2. Type of sampling and number of samples

The 0 - 20 cm horizon at mid-slope level was sampled. The method used for this work was regular square mesh sampling.

2.2.3. Principle

Systematic sampling is based on taking samples at predetermined, regular intervals **(Fig. 2)**.

These are defined using a regular grid, most often square, but sometimes triangular, rectangular, hexagonal or even rhombic, whose origin is placed either at random on the site, or in such a way as to optimize coverage of the area under investigation.

Samples can be taken at the nodes of the mesh or at the center of the geometric shapes thus determined. The main directions of the mesh can be arbitrary, but are generally oriented either according to the geometry of the site (boundaries, roads, waterways).

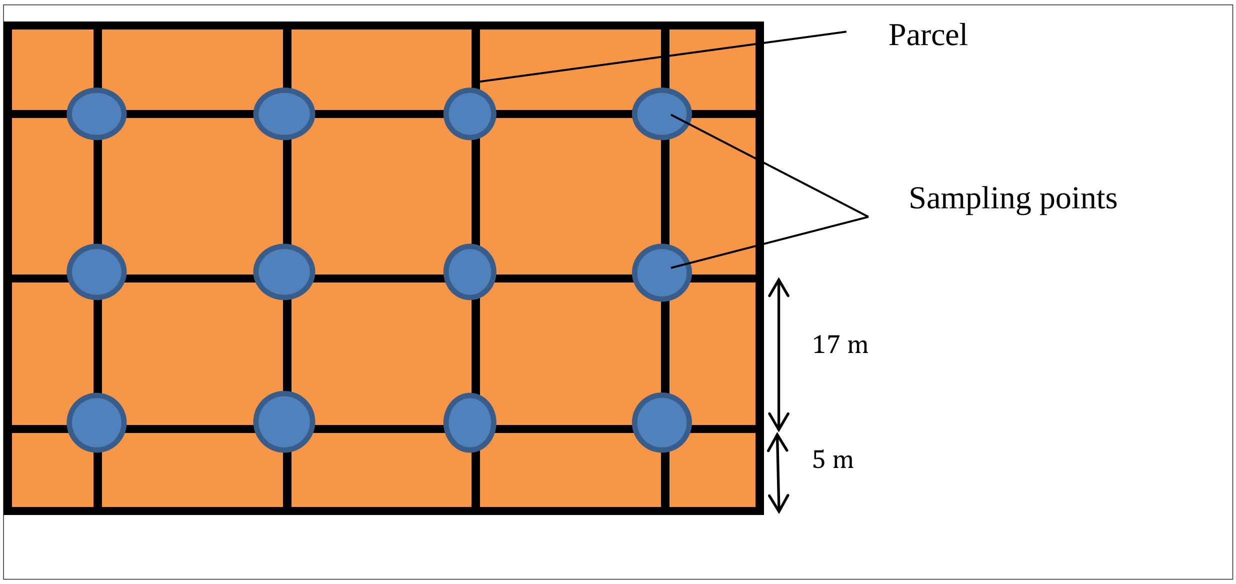

Figure 2 Regular square mesh sampling method (17 m X 17 m)

Samples were of the composite type. For each plot, we took 3 composite samples, that is to say 27 soil samples for all 9 plots in the 3 defined sectors.

2.2.4. Physico-chemical characterization

Physico-chemical characterization consisted in determining soil acidity, soil organic carbon (SOC) and matter (SOM), total nitrogen (Ntotal), available phosphorus, boron, zinc and exchangeable bases, cation exchange capacity and measuring soil carbon stock. In practice, soil acidity is determined through soil water pH, which is measured by direct reading using a glass electrode pH meter, at a soil/solution ratio of 1/2.5. Soil organic carbon (SOC) was determined using the [13] method, by oxidizing organic carbon with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulfuric acid, followed by titration of Cr^{3+} ions. Soil organic matter (SOM) content was deduced from organic carbon according to equation 1:

$$SOM = 1.724\, S_{OC} \qquad \text{(Equation 1)}$$

Total nitrogen (Ntotal) was determined using the Kjeldahl mineralization method, followed by nitrogen (NH^{4+}) determination using the Nessler reagent. Available phosphorus is extracted from soils using a solution of ammonium fluoride and hydrochloric acid based on the Olsen-Dabin method. Exchangeable bases are displaced from the adsorbent complex by a solution of silver ($AgNO_3$) and thiourea (H_2NCSNH_2), and determined by atomic absorption spectrometry (Ca^{2+} and Mg^{2+}) and flame emission spectrometry (Na^+ and K^+). Cation exchange capacity (CEC) is measured from the extracted solution of exchangeable bases. From these last two soil chemical characteristics, the exchangeable base saturation of the absorbent complex is deduced using equation 2:

$$V = \frac{S}{CEC} . 100 \qquad \text{(Equation 2)}$$

2.2.5. Statistical processing of collected data

The data collected were coded, then entered and cleared in EXCEL.

The effect of the association of cocoa trees with trees on soil chemical fertility was determined by a one-factor analysis of variance using the GLM procedure in SAS 9.4. Means whose variances were significant at the 5% level were separated using the Student-Newman-Keuls (SNK) test.

3. Results

3.1. Organic matter and mineralization

3.1.1. Organic matter and its mineralization as a function of cocoa farm exposure

SOM contents were more or less the same: 17.4 $g.kg^{-1}$ for full sun exposure and 17 $g.kg^{-1}$ b.w. for shaded exposure. The average was 17.1 $g.kg^{-1}$. C/N ratios ranged from 10.45 (unshaded) to 10.67 (shaded). The average was 10.6. (Table 2).

3.1.2. Organic matter and its mineralization as a function of exposure and location

There were no significant differences in SOM content according to location or exposure. Similarly, there were no significant differences between mean SOC/Ntotal values. SOM and mineralization remained virtually unchanged (Table 3).

Table 2 Organic matter and mineralization as a function of exposure

Exhibitions	**SOC/N_{total} ($g.kg^{-1}$)**	**SOM ($g.kg^{-1}$)**
Unshaded	10.45 **a**	17.40 **a**
Under shade	10.67 **a**	17.00 **a**
Means	10.60	17.10
C.V. (p.c.)	11.56	22.16

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

Table 3 Organic matter and its mineralization as a function of exposure and location

Exhibition	**SOM ($g.kg^{-1}$)**			**SOC/N_{total} ($g.kg^{-1}$)**		
	Soubré 1	Soubré 2	Méagui	Soubré 1	Soubré 2	Méagui
Unshaded	15.70 **a**	16.20 **a**	20.50 **a**	10.97 **a**	10.45 **a**	9.92 **a**
Under shade	15.80 **a**	17.40 **a**	17.80 **a**	10.27 **a**	10.90 **a**	10.84 **a**
Means	15.70	17.00	18.70	10.50	10.75	10.53
C.V. (p.c.)	24.78	22.27	20.13	16.85	7.19	10.38

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

3.2. Adsorbent complex and soil acidity

3.2.1. Adsorbent complex and soil acidity as a function of cocoa farm exposure

CECs ranged from 5.16 to 7.20 $cmol.kg^{-1}$ with an average of 5.84 $cmol.kg^{-1}$. Exchangeable base sums (S) ranged from 1.88 to 2.40 $cmol.kg^{-1}$. V values ranged from 32.41 to 37.56%, with an average of 35.84%. pH ranged from 5.80 to 5.83, with an average of 5.81 (Table 4).

Table 4 CEC, S, V and pH as a function of cocoa farm exposure

Exhibitions	**CEC ($cmol.kg^{-1}$)**	**S ($cmol.kg^{-1}$)**	**V (%)**	**pH**
Unshaded	7.20 **a**	2.40 **a**	32.41 **a**	5.83 **a**
Under shade	5.16 **a**	1.88 **a**	37.56 **a**	5.80 **a**
Means	5.84	2.05	35.84	5.81
C.V. (p.c.)	30.41	43.63	31.70	6.34

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

3.2.2. Adsorbent complex and soil acidity as a function of locality and exposure

The analysis showed that there was no significant difference between the mean values of each of the chemical parameters (CEC, pH, S and V) according to locality and exposure, with the exception of CEC in the Méagui locality, which varied significantly from exposure under shade (5.77 $cmol.kg^{-1}$) to exposure to full sun (8.48 $cmol.kg^{-1}$) (Table 5).

Table 5 CEC, S, V and pH as a function of location and exposure

	CEC ($cmol.kg^{-1}$)			**S ($cmol.kg^{-1}$)**		
Exhibitions	Soubré 1	Soubré 2	Méagui	Soubré 1	Soubré 2	Méagui
Unshaded	6.64 a	6.50 a	8.48 a	1.52 a	2.31 a	3.36 a
Under shade	5.06 a	4.65 a	5.77 b	1.53 a	1.77 a	2.33 a
Means	5.59	5.27	6.68	1.53	1.95	2.68
C.V. (p.c.)	28.29	43.48	20.88	35.6	54.55	24.34

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

Table 5 (continued)

	V (%)			**pH**		
Exhibitions	Soubré 1	Soubré 2	Méagui	Soubré 1	Soubré 2	Méagui
Unshaded	23.17 a	34.38 a	39.68 a	5.63 a	5.70 a	6.16 a
Under shade	34.93 a	37.32 a	40.44 a	5.90 a	5.48 a	6.01 a
Means	31.01	36.34	40.19	5.81	5.56	6.07
C.V. (p.c.)	55.01	20.9	15.46	6.33	6.04	2.89

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

3.3. Cocoa tree nutritional elements

3.3.1. Cocoa tree nutritional elements as a function of exposure

Depending on exposure (Table 6), it was found that only sodium levels differed significantly from one another. The sodium content observed in shaded exposures (0.06 $cmol.kg^{-1}$) was significantly higher than in unshaded exposures (0.02 $cmol.kg^{-1}$).

Table 6 Nutritional elements in $cmol.kg^{-1}$ as a function of cocoa farm exposure

Exhibition	**N ($g.kg^{-1}$)**	**P ($mg.kg^{-1}$)**	**K ($cmol.kg^{-1}$)**	**Ca ($cmol.kg^{-1}$)**	**Mg ($cmol.kg^{-1}$)**	**Na ($cmol.kg^{-1}$)**
Unshaded	0.92 **a**	112.44 **a**	0.05 **a**	1.77 **a**	0.54 **a**	0.302 **b**
Under shade	0.91**a**	130.33 **a**	0.05 **a**	1.34 **a**	0.41 **a**	0.06 **a**
Means	0.91	124.37	0.05	1.48	0.46	0.05
C.V. (p.c.)	29.08	41.61	47.98	48.12	44.96	77.94

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

3.3.2. Cocoa nutritional elements as a function of locality and exposure

The combination of localities and exposures showed that the nutritional elements each had concentrations that varied very little from one exposure to another in each locality. (Table 7)

Table 7 Nutritional elements as a function of locality and exposure

	N ($g.kg^{-1}$)			P ($mg.kg^{-1}$)			K ($cmol.kg^{-1}$)		
Exhibitions	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**
Unshaded	1.09 **a**	1.78 **a**	2.45 **a**	129.30 a	106.30 **b**	101.60 **a**	0.05 **a**	0.03 **a**	0.08 **a**
Under shade	1.05 **a**	1.27 **a**	1.70 **a**	113.30**a**	152.80 **a**	124.80 **a**	0.05 **a**	0.04 **a**	0.06 **a**
Means	1.07	1.45	1.95	118.67	137.33	117.11	0.06	0.04	0.07
C.V. (p.c.)	40.66	60.83	27.76	36.42	18.17	67.14	33.33	38.26	45.52

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

Table 7 (continued)

	Ca ($cmol.kg^{-1}$)			Mg ($cmol.kg^{-1}$)			Na ($cmol.kg^{-1}$)		
Exhibitions	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**
Unshaded	1.09 **a**	1.78**a**	2.45 **a**	0.36 **a**	0.47 **a**	0.78 **a**	0.02 **a**	0.02 **a**	0.05 **a**
Under shade	1.05 **a**	1.27**a**	1.70 **a**	0.36 **a**	0.38 **a**	0.51 **a**	0.06 **a**	0.07 **a**	0.04 **a**
Means	1.07	1.45	1.95	0.37	0.41	0.60	0.05	0.06	0.05
C.V. (p.c.)	40.66	60.83	27.76	28.01	53.12	34.08	98.86	93.85	37.34

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

3.4. Chemical balances of cocoa tree nutritional elements

3.4.1. Chemical balances as a function of cocoa farm exposure

Balances varied very little from one exposure to another. Values fluctuated around the averages. For calcium (71.32%), magnesium (22.78%), potassium (2.88%) and (S+6.15)/Ntotal (9.10%). (Table 8)

Table 8 Chemical equilibria as a function of exposure

Exhibitions	**Ca.100/S**	**Mg.100/S**	**K.100/S**	**(S+6,15)/N_{total}**
Unshaded	73.03 **a**	23.21 **a**	2.45 **a**	8.89 **a**
Under shade	70.47 **a**	22.56 **a**	3.09 **a**	9.21 **a**
Means	71.32	22.78	2.88	9.10
C.V. (p.c.)	8.87	22.81	44.63	31.68

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

3.4.2. Chemical equilibria as a function of locality and cocoa farm exposure

The results showed that chemical equilibria varied very little from one exposure to another in each locality. (Table 9)

Table 9 Chemical equilibria as a function of cocoa farm exposure

	Ca.100/S			Mg.100/S			K.100/S			(S+6,15)/N		
Exhibitions	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**	**Soubré 1**	**Soubré 2**	**Méagui**
Unshaded	71.61 **a**	74.17 **a**	73.31 **a**	23.66 **a**	23.09 **a**	22.89 **a**	3.21 **a**	1.59 **a**	2.54 **a**	9.23	9.42	8.0 **a**
Under shade	67.71 **a**	71.63 **a**	72.08 **a**	24.56 **a**	20.48 **a**	22.64 **a**	4.06 **a**	2.41 **a**	2.80 **a**	9.80 **a**	8.79 a	9.03 **a**
Means	69.0	72.4	72.4	24.2	21.3	22.7	3.78	2.14	2.71	9.61	9.00	8.70
C.V. (p.c.)	9.23	9.8	8.8.	23.4	20.1	27.2	45.0	22.7	35.1	46.7	14.0	30.3

Nb: Means followed by the same letters in a column are not significantly different at the 5 % threshold.

4. Discussion

The organic matter content in both production systems was identical. It was found to be low (ranging from 08.6 to 24.3 $g.kg^{-1}$). Indeed, cocoa trees require soils rich in organic matter, i.e. a minimum rate of 30 $g.kg^{-1}$ [14]. The rate determined by our work is significantly lower than that determined by Koko [6], in soils under non-degraded cocoa trees and forest in the departments of Méagui and San-pédro, which is 31 $g.kg^{-1}$. The low level of organic matter found in the soils of cocoa-based agroforestry systems, and their similarity to the soils of full-sun cocoa farms, would be due to the low density of trees and their spatial distribution. In fact, most of the trees associated with these systems are residual plantations, which means that they don't cover the entire cocoa plantation area. In addition to this, the type of sampling. In fact, the regular square mesh does not allow for systematic sampling in the space covered by the crown of the canopy of associated trees.

Mineralization of organic matter, characterized by the C/N ratio, was on the whole above 9 and below 15. These values confirm very good mineralization. This ratio indicates a balance between the mineralization and humification of organic matter (litter). Podwojewski [15] established limit values for the "normal" supply of nitrogen to plants. For a C/N ratio of less than 9, mineralization is too rapid (nitrogen loss), and when this ratio exceeds 15, mineralization is slow (nitrogen deficit). This observation regarding the proper mineralization of organic matter is confirmed by [16]. This author demonstrated that nitrogen was available in the soils of south-west Côte d'Ivoire. This would justify our results, which showed that there was no difference between production systems for this fertility index.

Exchangeable cations were disproportionately distributed in the three localities (Méagui, Soubré 1 and Soubré 2). The average value of the sum of exchangeable cations observed in the Méagui locality is 2.68 $cmol.kg^{-1}$, which would be normal for highly desaturated and acidic soils [17]. According to this author, the sum of exchangeable bases should be between 2 and 6 ($cmol.kg^{-1}$) for these soil types. In Soubré 1 and Soubré 2, the sum of exchangeable cations is below the threshold established for highly desaturated soils. Ferralsols are dominated by kaolinite-type clay. This clay has a reduced specific surface area (between 7 and 30 $m^2.g^{-1}$). As a result, fewer exchangeable cations will be present on its surface. This type of clay has a low cation exchange capacity due to its reduced specific surface area. This explains the low CEC values of soils in the study area. The saturation level of most of the soils studied was between 3.1 and 4 $cmol.kg^{-1}$. Soils under both cocoa-based cropping systems have unsaturated absorbent complexes. Indeed, the normal rate for cocoa cultivation is between 5 and 6 $cmol.kg^{-1}$ [18]. Ferrallitic soils (farralsols) are soils in which leaching is very pronounced. Exchangeable cations are eliminated from surface horizons. As a result, the specific surface area of clays is unsaturated. The soils studied have a sandy-clay surface texture, with a low clay content (10-20%); they are conducive to significant leaching of mineral elements, especially exchangeable cations.

The low saturation of exchangeable cations explains the relatively acidic pH in the study area. The pH values recorded ranged from 5.1 to 6.2. Average values showed that soils in the Soubré 2 locality were more acidic (pH= 5.5), which would be due to a low level of exchangeable cation saturation in the absorbent complex and significant leaching of exchangeable cations. Indeed, the soils in this part of the study area have a sandy-clay texture with a low clay content (5-10%). The rate of saturation influences soil acidity; high saturation leads to an increase in pH, which tends towards neutrality. This is indicated by the pH of the soil at Méagui, which was close to 7.

The low level of saturation of the absorbent complex in ferrallitic soils (ferralsols) and the good mineralization of organic matter explain the similarity in pH between the two types of cropping system. The acidity of the soils in both systems is suitable for cocoa farming, even though the ideal pH for cocoa cultivation is 7 [19, 20]. They confirmed that the plant could thrive on soils with acidic (pH 4.5-6) or slightly basic (pH 6.7-7.5) pH.

Available phosphorus, the second most important deficiency in ferrallitic soils after nitrogen according to Boyer [17], was above 100 $mg.kg^{-1}$ in 63% of the plots studied (determined by the Olsen-Dabin or modified Olsen methods, see method). This value constitutes the optimum for good cocoa tree nutrition [16]. Specifically, in the soils of shaded cocoa farms, 67% of plots had levels above this optimum. This result runs counter to the findings of Jadin and Snoeck [18], who indicated that all soils under cocoa trees in south-west Côte d'Ivoire were deficient in available phosphorus.

Cocoa growing systems under shade would therefore provide this major element in cocoa tree nutrition.

This link could be explained by the fact that large trees have roots that penetrate deep into the soil, enabling them to extract nutrients from the depths to the surface horizons[21]. These authors mentioned that, in addition to producing litter, the tree layer captures particles transported by wind and water, using mineral elements located deeper in the soil, and that this effect is amplified with tree age for the main nutrients, i.e. nitrogen, phosphorus and potassium. They even argued that the presence of trees increases nutrient availability by utilizing nutrients inaccessible to the lower stratum due to their depth in the soil.

According to Verlière [22], the chemical equilibria between the nutritional elements of cocoa trees were only as valuable as their presence (abundance) in the soil; their analysis seems relevant to this study.

The results showed that 74% of the soils studied had a ratio (Ca.100 / S) greater than 68%, the optimum for good Ca nutrition by the cocoa tree [23, 16]. These authors set the optimum chemical balance for calcium (Ca) at 68%, for magnesium (Mg) at 24% and for potassium (K) at 8%.

Specifically, 65% of cocoa farms under shade had reached this 68% threshold for calcium balance. It could therefore be said that calcium is not a limiting factor in the mineral nutrition of cocoa trees in shaded systems.

As for the Magnesium (Mg) balance, the results showed that 50% of cocoa farms under shade respected this balance.

Only the potassium balance was not achieved by all cocoa farms in the different cropping systems. In fact, potassium is a limiting factor. This imbalance could be due to the low capacity of colloids to bind a large number of exchangeable cations.

5. Conclusion

The study showed that agroforestry systems do not impoverish soils, even with associated trees. Soils under cocoa-based agroforestry systems met most of the chemical standards (pH, nitrogen, C/N, available phosphorus, chemical balances) indicated for cocoa farming.

However, the study was unable to highlight the role of cocoa-based agroforestry systems in providing organic matter.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to disclosed.

Statement of ethical approval

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

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