Asian Journal of Multidisciplinary Studies

ISSN: 2321-8819 (Online)
2348-7186 (Print)
Impact Factor: 1.498
Vol. 5, Issue 2, February 2017

Comparative Evolution of Soils under Cocoa Trees in Monoculture and Association of Forest Trees in the Forest-savannah Transition Zone of Côte D'ivoire.

Gala Bi Trazie Jeremie[1], Bohoussou N'Dri Yves[2], Yoboue Kouadio Emile[3] and Yao-Kouame Albert[4]

[1]Department of Soil Science –
Formation and Research Unit of Earth Sciences and Mineral Resources –
Félix Houphouet-Boigny University, Cocody - Abidjan, Côte d'Ivoire.
[2]Department of Soil Science –
Formation and Research Unit of Earth Sciences and Mineral Resources –
Félix Houphouet-Boigny University, Cocody - Abidjan, Côte d'Ivoire.
[3]Department of Soil Science –
Formation and Research Unit of Earth Sciences and Mineral Resources –
Félix Houphouet-Boigny University, Cocody - Abidjan, Côte d'Ivoire.
[4]Department of Soil Science –
Formation and Research Unit of Earth Sciences and Mineral Resources –
Félix Houphouet-Boigny University, Cocody - Abidjan, Côte d'Ivoire.

ABSTRACT: For sustainable soil management in cocoa farming in marginal areas such as the forest-savanna transition zone of southern center of Côte d'Ivoire, an agro-pedological characterization study of cocoa plantations was carried out, in the cocoa exploitations of Agricultural Society of Bandama (SAB), in M'Brimbo locality. It covered various cocoa cropping systems, mainly monoculture and association of forest trees to cocoa plantation, with differents densities, and their impacts on soil potential fertility. The observations of soil was done through soil pits and laboratory analyzes on soil samples taken. The results showed that the cocoa culture systems under the associated trees' shading, have improved the soil organic matter content and the balance between mineral elements. However, only the densities of associated trees providing a medium and high shading, lead to a content of organic matter higher than the minimum threshold in cocoa culture. But, the higher densities of associated trees, providing a higher shading, have a limiting factor in cation exchange capacity of soil. So, The cocoa farm system associating trees, according to a density providing a medium shading, has, therefore, been identified as the most viable for sustainable soil management in cocoa growing systems.

Keywords: cocoa farming, medium shading, sustainable soil management, forest-savanna transition, Côte d'Ivoire.

1. INTRODUCTION

Côte d'Ivoire, the world's largest cocoa producer, achieved this performance, mainly by extending cocoa plantations in forest zone, with a deforestation rate of 6%, among the highest in the world (Yedmel, 2004). The Ivorian forest cover has today sharply reduced (Maurice *et al.*, 2014). This reality has even led to the annexation of protected forest areas, for the extension of agricultural activities (Eblin and Amani, 2015); But this could not prosper, given the environmental protection measures (MINEF, 2014). Faced with this land blockage, the southern center of Côte d'Ivoire, a forest-savannah transition zone, part of the former cocoa loop, is increasingly returning to cocoa farming. Indeed, this zone, qualified as a marginal zone, , not suitable for cocoa farming, had been abandoned in favor of the forests of the Southwest. Thus, this return to cocoa farming should be accompanied by studies enabling the removal of the possible constraints for a sustainable cocoa farming. To this end, various cultivation techniques exist. These include:

- cocoa monoculture, which, like other crops, would be a kind of intensification of culture (Freud *et al.*, 2000; Clough *et al.*, 2009);

- the association of banana trees with cocoa trees, to serve as shade for young plants, which can disappear from mature cocoa plantations (Ruf and Schroth, 2013), or subsist with cocoa trees (Traoré *et al.*, 2009);

- the association of fruit trees with cocoa trees, with the aim of obtaining additional income (Kouadio *et al.*, 2016);

- the association of forest trees species with cocoa trees; these trees, being in fact only residual trees of preexisting vegetation; Their existence in plots depends on their use (medicinal, cultural, etc.), or on the difficulty of slaughter linked to the means used for clearing in the stage of creation of cocoa plantations;

- mixed systems, resulting from the combination of at least two or above of the mentioned techniques.

From this diversity, cocoa monoculture and association of forest species in different modalities are applied to the farms of the Agricultural Society of Bandama (SAB), located in the forest-savanna transition zone in the south-central of Côte d'Ivoire.

This study aims sustainable management of soil, by contributing to the establishment of the impact of these cocoa cultivation techniques on the soil, for a sustainable farming of cocoa in this zone.

2. MATERIALS AND METHODS

Study zone

The study took place in the locality of M'Brimbo, in the department of Tiassale, located in the South Center of Côte d'Ivoire. the Universal Transverse Mercator (UTM) coordinates are included in the 30 N spindle, between 283 000 mE and 293 000 mE for longitude then 667 000 mN and 671 000 mN for latitude (Figure 1). This area is in the north-west of Abidjan, at about 120 Kilometers. (Ouattara and Koffi, 2014).

The climate is the hot and rainy equatorial type. The average annual rainfall is approximately 1200 mm. As for the average temperature, it oscillates around 28 ° C and the mean humidity of air is between 54 and 71% (Dabin and Leneuf, 1960).

Classification of cocoa farming systems used

Two approaches have been made, namely the density of trees associated with cocoa trees that provide different degrees of shading.

Depending on the degree of shading, the cocoa farming systems were classified into 4 types (Bohoussou, 2016), as shown in Table 1.

Morpho-pedological characterization and soil sampling

In each type of cocoa farming system, a pedological pits was opened on the representative soil of this type of system.

Also, a pedological pit has been opened under and outside the canopy of certain forest trees with high-impact on cocoa trees, such as, *Spathodea campanulata* (Bohoussou, 2016), which does not tolerate cocoa trees under its canopy. the soil morphological characterization was carried out through observation of these pits, in order to determine the impact of the forest trees associated to cocoa trees, on the physical and chemical characteristics and fertility of cultivated soil.

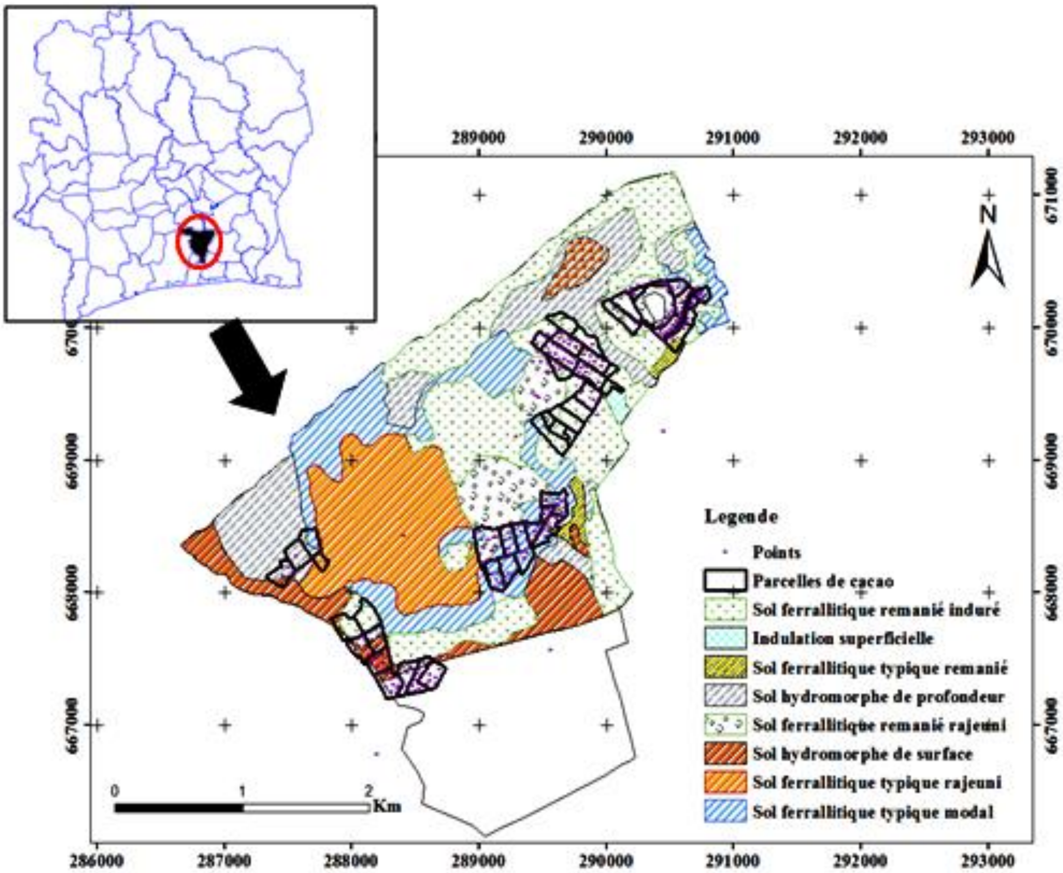


Figure 1: Location map of the study area and soils according to the CPCS classification (source: SAB in N'Douba, 2016).

Table 1: Correspondence between the density of forest trees associated in cocoa farm and the degree of shading.

Density of forest trees associated in cocoa farm (arbres/ha)	Degree of shading
0	No shading or full sun
]0 ; 20]	Low
]20 ; 50]	Midle
]50 ; 100]	Dense

Source : Bohoussou (2016)

Thus, the soils were described and then sampled for bulk density and other laboratory analyzes. The description was based on observations of color, organic matter content, soil depth and horizon thickness, texture, coarse material content, drainage class and possible constraints for cocoa cultivation.

Concerning the bulk density (Da), the calculation was as follows:

$$\mathbf{Da}(g.cm^{-3}) = Ms/V \quad (1)$$

Ms being the mass of dried soil sample (g) and V its volume (cm3).

The water reserve (Re) was also determined according to the formula;

$$\mathbf{Re\ (mm)} = Da * Z * (Mh-Ms)/Ms \quad (2)$$

Mh being the mass of wet soil sample in gram (g), and Z the depth in millimeter (mm).

The granulometric analysis was carried out using the Robinson-Köln pipette method (Fournier *et al.*, 2012). It made it possible to determine the contents of clay (0 to 2 μm), fine (2 to 20 μm) and coarse (20 to 50 μm), fine (50 -200 μm) and coarse (200-2000 μm) .

The soil pH measurements were carried out by the electrometric method, in a sol / water ratio of 1: 2.5 and in triplicates (Mathieu and Pieltain, 2003).

Total organic carbon was determined according to the Walkley-Black method (Nelson and Sommer, 1982). The total nitrogen content was obtained by the Kjeldahl method (Bremner and Mulvaney, 1982),

The exchangeable bases (Ca2 +, Mg2 +, K +) were determined by extraction with ammonium acetate buffered to pH 7, followed by saturation with NaCl for the determination of the cation exchange capacity (CEC).

Statistical analysis

The different results obtained were analyzed statistically using Assistat software version 7.7 and SAS 9.0 and XLSTAT 2016 version, for the comparison of the mean on the one hand and on the other hand for the observation of the correlations and regressions between the variables.

3. RESULTS

General morphological characteristics of the soils of cocoa farming systems

The general morphological features of the soils under the different types of cocoa plantations are given in Table 2.

These soils, generally, have a fragmentary structure on the surface and subangular polyhedral in the depth. However, the depth horizons of soil of cocoa trees under dense shading, revealed a massive structure.

The characteristics grouped in Table 2 made it possible to give the following nomenclature to the soils according to the World Reference Base Classification (figure 2) :

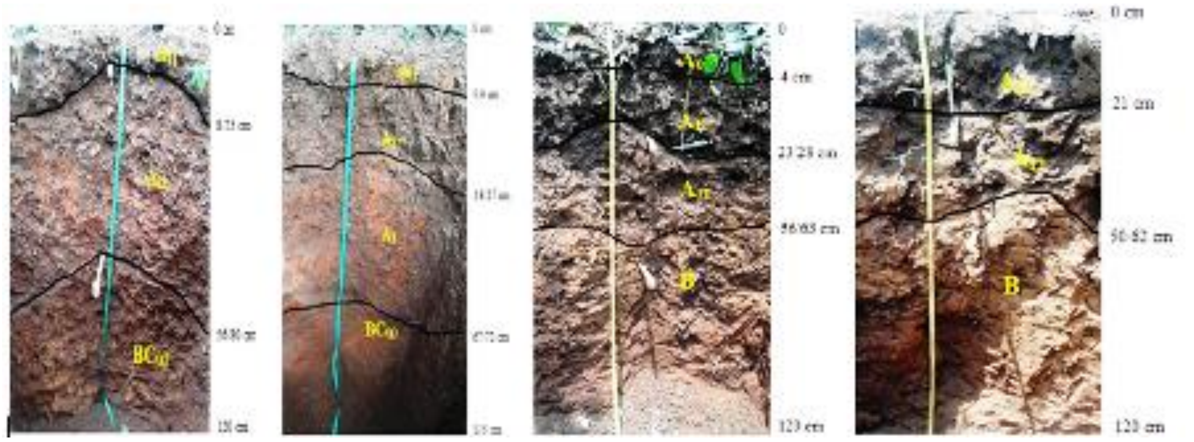
- Endopseudogleyic Plinthic Cambisol, which is characterized by hydromorphic spots appearing beyond 50 cm deep and limited by induration between 115 and 120 cm deep; It has been observed in the cocoa system under dense and medium shade;

- Clayic Ferralic Cambisol, characterized by a high level of clay at depth, a deep profile (more than 120 cm) and well differentiated; It has been observed in cocoa farming systems under full sun and low shade.

Table 2: General morphological characteristics of the soils of the different cocoa farming systems at M'Brimbo.

Cocoa Farming system	Depth (cm)	Color	Texture	Structure	Coarse element (concretions and nodules)	Drainage
under dense shading	120	Very dark red (10R3/4) at surface to reddish yellow (7,5YR6/8) in the deep,and red sopt (2,5YR4/8)	Sandy loam at surface to sandy clay in the deep	Fragmentary in topsoil to massive in the deep	25% in topsoil, 60% in gravel front and 25% in the deep	Good to moderately bad

Cocoa Farming system	Depth (cm)	Color	Texture	Structure	Coarse element (concretions and nodules)	Drainage
nder medium shading	115	Dark red (2,5YR3/6) at surface to red (10R4/6) with yellowish brown spot (10YR4/6)in the deep	Sandy loam at surface to sandy clay in the deep	Fragmentary	30% in topsoil, 50% in gravel front and 15% in the deep	Good to moderately bad
under low shading	120	Dark reddish brown (5YR3/4)at surface to yellowish red (5YR4/6) in the deep	Sandy loam at surface to clay in the deep	Fragmentary	None	Good
under full sun	120	Yellowish red (5YR4/6)at the surface to red (2,5YR4/6) in the deep	Clay loam at surface to clay in the deep	Fragmentary	none	Good



A. Endopseudogleyic Plinthic Cambisol. under dense shading.

B. Endopseudogleyic Plinthic Cambisol. under medium shading

C. Clayic Ferralic Cambisol. under low shading

D. Clayic Ferralic Cambisol. under full sun

Figure 2: Soil profiles under the different cocoa farming systems

Soil Depth and Soil Drainage Class

The soils of cocoa trees under dense and medium shading are characterized by induration around 115 to 120 cm deep. This level of induration is underlying a horizon with poor drainage, so that the bedrock experiences a deterioration phase.

Evolution of soil color

The two to three first horizons of the soil, show a reversal of the soil color range under dense and medium shade. Indeed, under dense shade, the soil color starts from 10R 3/4 in the surface horizon to 2.5YR 3/6 in the underlying horizon, while under the medium shading, it starts from 2,5YR 3 / 6 to 10R 4/6. As for cocoa soils under low shading, for the two to three surface horizons, the soil color varied from 5YR 3/4 to 5YR 4/6, whereas, under full sun, the color of the soil started from 5YR4 / 6 to 5YR 4/8. In sum, from the system of cocoa culture under dense shading to the system under full sun, the color of the soil surface horizons becomes less and less dark.

Coarse elements in the soil horizons

According to the data in table 3, indicating the coarse element content in the different profiles of soil, the soils of cocoa farming systems under dense and medium shading, are the only ones with coarse elements. These profiles start with a surface horizon containing 25 to 30% of coarse elements. This horizon is followed by a gravel front, with coarse element content between 50 and 60%. These coarse elements are dominated by concretions and nodules in the cocoa farming system under medium shading, whereas under dense shading, the quartz coarse elements and those of concretionary and nodular nature, are approximately equal in proportion. The gravel front rests on an alteration horizon whose coarse elements are essentially fragments of schist, which constitute the bedrock.

Table 3: content of coarse elements in soils under the different cocoa farming systems

Cocoa Farming system	Thickness of soil horizons (cm)	Nature and content of coarse elements (%)			
		Quartz	Concretions and nodules	Schist fragment	Total
under dense shading	0-8/23	11	14	0	25
	8/23-56/80	33	27	0	60
	56/80-120	13	12	0	25
under medium shading	0-5/9	1	29	0	30
	5/9-18/27	2	32	16	50
	18/27-67/72	2	43	0	45
	67/72-115	0	0	15	15
under low shading	0-4	0	0	0	0
	4-23/28	0	0	0	0
	23/28-52/63	0	0	0	0
	52/63-120	0	0	0	0
under full sun	0-21	0	0	0	0
	21-50/62	0	0	0	0
	50/62-120	0	0	0	0

Impact of associated trees to cocoa plantation on soil characteristics

Bulk density.

The average of bulk density of the different cocoa farming systems soils, showed a significant difference. The higher values was observed for soils under medium and dense shading, with respectively 1.59 and 1.43 gcm-3. the soils of the systems under Low shading and shadingless, have shown the lowest averages of bulk density value, with respectively, 1.35 and 1.31 gcm-3 (Table 4).

Considering the profiles of the soils, horizon by horizon, from the surface, with thicknesses of 10 cm, the soil's bulk densities have shown some similarities and some differences. Thus, the bulk density values decline in the first 40 cm of the soil profiles, except in the system under medium shading, where these value increase in from from 1.60 to 1.70 gcm-3, within the first 30 centimeters before dropping to 1.53 gcm-3, at 40 cm depth (Figure 3). After the first 40 centimeters of soil profile, the bulk density values remained stable overall, except for the low shade system soil, where a peak (1.32 gcm-3) was observed at 50 centimeters in soil profile.

Table 4: Average values of bulk densities of soils under the different cocoa farming systems

Cocoa farming system	Bulk density (gcm^{-3})
Under dense shading	1.43 b
Under medium shading	1.59 a
Under low shading	1.35 b
Under full sun	1.31 b

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

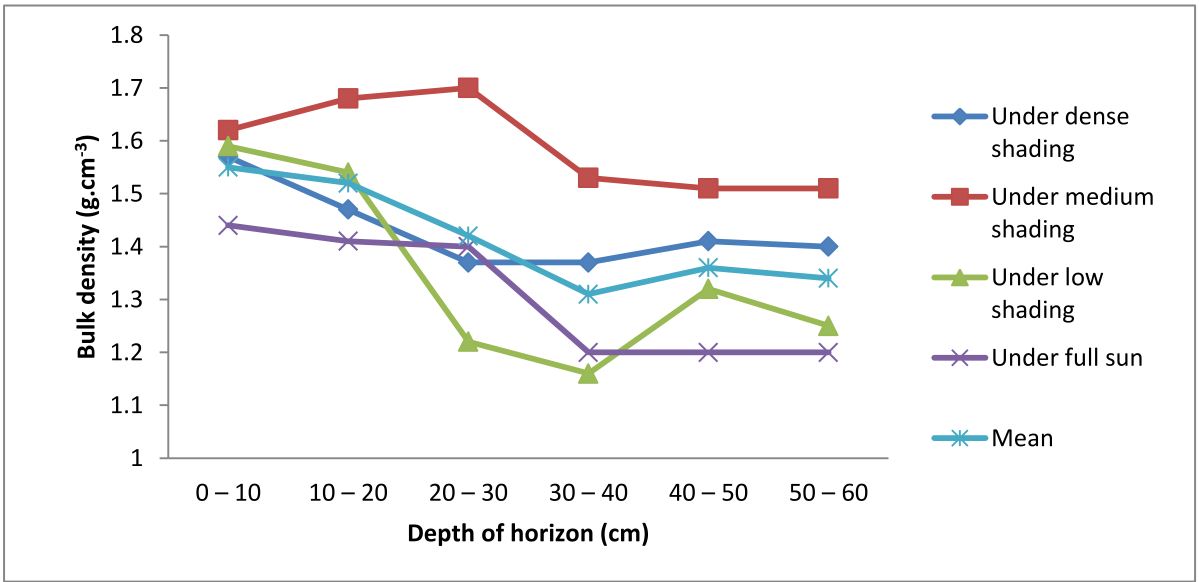


Figure 3: Evolution of soil bulk density under the different cocoa farming systems

Soil water Reserve

The overall average of water reserves by soil under different systems, have shown a significant difference. The systems under medium and dense shading had lower water reserves (9.86 and 13.32 millimeters respectively) than those under low shading and full sun, which have respectively 15,80 and 19,12 millimeters of water (Table 5).

Table 5: General averages of the soil water reserve by cocoa farming system

Cocoa farming system	Soil water reserve (millimeter)
Under dense shading	13.32 b
Under medium shading	9.86 c
Under low shading	15.80 b
Under full sun	19.12 a

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

The evolution of the water content in the profile of soil have shown a tendency to increase with the depth of the soil, while in the system under full sun the water content varies very littlely in the profile (Figure 4).

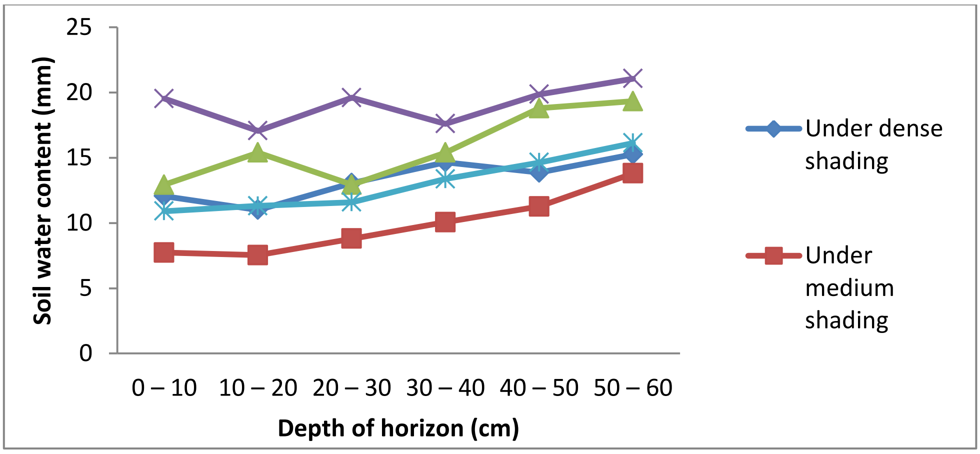


Figure 4: Average values of the soil water reserve under different cocoa farming system

Special case of the forest species Spathodea campanulata

The results of statistical analyzes applied to the overall average of bulk density and water reserve of soils, reveal no significant difference between the soil under influence of *Spathodea campanulata* and soil out of the canopy of this tree. However, it was observed a relative superiority of the water content of the soil out of the impact of *S. campanulata* canopy, Ie, 10.34 millimeters against 9.85 millimeters of water (Table 6).

Table 6: Average values of bulk density and water reserve of soil according to the position in relation to *Spathodea campanulata*

position in relation to ***Spathodea campanulata***	**Bulk density (gcm^{-3})**	**Water reserve (mm)**
Under canopy	1,34 a	9,85 a
Out of canopy	1,31 a	10,34 a

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

Granulometry and texture of soil surface horizons

The first 20 centimeters of soils are dominated by sand fraction, except the soil of the cocoa farming system under full sun, where the clay and sandy fraction are approximately at the same rate, ie 28.5 and 30.55 %. At this level, the silt fractions, with a cumulative rate of fine and coarse silt of 40.95%, constitute the dominant fraction. This makes it possible to have a clay loam texture in the system under full sun and sandy loam in other systems. The underlying horizon (20-40 cm) is characterized, on the one hand, by a reduction in the clay content, except the soil of cocoa farming system under medium shading, on the other hand, by the dominance of the silt fraction in cocoa farming systems under full sun, dense and low shading. These give them a loamy-sand texture whereas the soil of the system under medium shading have sandy-clay texture (Table 7).

Table 7: Granulometry and texture of soil surface horizons of the different cocoa farmingsystems

Cocoa farming system	Depth (cm)	Granulometry (%)					Texture
		Clay	Coarse silt	Fine silt	Coarse sand	Fine sand	
Under dense shading	0-20	11.00	15.10	14.50	23.70	35.70	Sandy loam
	20-40	6.50	2.85	56.50	10.00	24.15	Silty loam
Under medium shading	0-20	12.00	12.30	11.00	22.40	42.30	Sandy loam
	20-40	18.00	6.70	25.15	17.50	32.65	Sandy loam
Under low shading	0-20	10.00	8.15	16.50	25.60	39.75	Sandy-loam
	20-40	9.50	6.35	48.00	16.15	20.00	Silty loam
Under full sun	0-20	28.50	10.95	30.00	9.30	21.25	Clay loam
	20-40	17.00	7.00	44.00	10.10	21.90	Silty loam

Acidity, organic matter and rate of mineralization in soil surface horizons

Some parameters of soil chemical fertility are given in Table 8.

The differences between the pH values of the soil under these different systems are reduced (of the order 1 / 10e). Thus, under the system with dense shading, It have been observed the higher value of pH, with 6.5. This content decreases proportionally to the reduction of shading degree, reaching 6.3 in the system under low shading.

The content of organic matter are higher in cocoa plantation under shading than cocoa plantation under full sun. The values decrease according to the degree of shading, ie 39.3 gkg-1 in the system under dense shading to 27.2 gkg-1 for the system under full sun.

However, the rate of mineralization of this organic matter is high according to the values of the C / N ratio, which are between 6 and 8.

Table 8: Acidity and organic matter in the top 20 centimeters of soil under the different cocoa systems.

Cocoa farming system	pH	Organique carbon (gkg^{-1})	Total Nitrogen (gkg^{-1})	Organic matter (gkg^{-1})	C/N Ratio
Under dense shading	6.5	22.8	0.31	39.3	7.00
Under medium shading	6.4	19.7	0.25	34.0	8.00
Under low shading	6.3	17.1	0.27	29.5	6.00
Under full sun	6.4	15.8	0.21	27.2	8.00

Exchangeable Bases and Cationic Exchange Capacity (CEC)

The values of all components of the exchangeable bases are below the standards required for cocoa production. However, the values of cation exchange capacity of the soils of cocoa farming systems are greater than 21 cmolkg-1 (cocoa production standard), except the system under dense shading, with a value of 20 cmolkg-1 (Table 9).

Table 9: Cation exchange capacity (CEC) and exchangeable base content of the 0-20 cm soil horizon.

Cocoa farming system	K^+ ($cmolkg^{-1}$)	Ca^{2+}($cmolkg^{-1}$)	Mg^{2+}($cmolkg^{-1}$)	CEC
Under dense shading	0.37	4.50	1.21	20.00
Under medium shading	0.16	2.71	0.71	33.80
Under low shading	0.25	3.01	1.15	52.00
Under full sun	0.33	1.29	0.82	37.20
Standart value for cocoa	**0.7**	**11**	**2.45**	**21**

For the ratios between the exchangeable bases, namely, Ca / Mg, Mg / K and (Ca + Mg) / K, the system under full sun has the following values, 1.58, 2.45 and 11, 5. All of these values are below of the cocoa production standard. The cocoa farming system under shading are all higher than standards, except of the low shading system, where Ca / Mg ratio (2.62) observed is less than the standarts required for cocoa production. For the other two systems under shading, the one under dense shading has some values, on the one hand lower than those of the system under medium shading and, on the other hand, relatively closer to the threshold value of cocoa production (Table 10).

Table 10: Chemical balance between exchangeable bases in the surface horizon (0-20 cm) of soils

Cocoa farming system	Ca/Mg	Mg/K	(Ca+Mg)/K
Under dense shading	3.730	3.240	15.29
Under medium shading	3.810	4.340	20.85
Under low shading	2.620	4.690	16.97
Under full sun	1.580	2.450	6.33
Standart value for cocoa	**2.8**	**3**	**11.5**

Linear correlation between physical and chemical parameters

System under shading

Table 11 shows the correlation between physical parameters (sand, clay and silt) and chemical parameters in the soil surface horizon. Only coarse silt is correlated with certain chemical parameters. In fact, silt is significantly correlated with all parameters of organic matter: carbon (C), with a correlation coefficient (R) equal to 0.991, nitrogen (N), with a correlation coefficient (R) equal to 0.984 and mineralization rate (C / N ratio), with R = 0.941.

Table 11: Correlation between physical and chemical parameters in the surface horizon of soils of cocoa farming system under shading

Parameter	Clay		Silt				Sand			
			Coarse silt		Fine silt		Coarse sand		Fine sand	
	R	P>IrI	R	P>IrI	R	P>IrI	R	P>IrI	R	P>IrI
Ph	-0,123	0,876	0,709	0,290	-0,395	0,604	0,569	0,430	0,176	0,823
CEC	0,193	0,806	-0,669	0,330	0,331	0,669	-0,513	0,486	-0,119	0,881
MO	0,056	0,943	**0,991**	**0,008**	-0,848	0,151	0,935	0,064	0,801	0,198
C	0,056	0,943	**0,991**	**0,008**	-0,848	0,151	0,935	0,064	0,8017	0,198
N	0,052	0,947	**0,984**	**0,015**	-0,806	0,193	0,913	0,086	0,710	0,290
C/N	0,157	0,842	**0,941**	**0,058**	-0,909	0,090	0,939	0,060	0,937	0,062
Ca	0,221	0,778	0,924	0,075	-0,769	0,230	0,875	0,125	0,579	0,420
Mg	0,192	0,807	0,845	0,154	-0,659	0,340	0,780	0,219	0,431	0,568
K	-0,466	0,533	0,362	0,637	0,049	0,950	0,157	0,842	-0,236	0,763

The values in bold are significant

System under full sun

Soils in cocoa plantation under full sun show a large number of correlations between physico-chemical parameters. Indeed, clay has a significant correlation with organic matter (MO), with R = 0.966, carbon (C), with R = 0.966 and C / N ratio, with R = 0.999. Also, coarse silt shows a significant correlation with Ca (P = 0.959 and R = 0.040) and Mg (P = 0.033 and R = 0.966). Finally, coarse sand is only significantly correlated with C / N (P = 0.015 and R = -0.984) (Table 12).

Nonlinear correlation between some soil parameters

pH and organic matter

A nonlinear correlation was observed between these two parameters. The relation can be simulated by a polynomial curve of degree 2 (R^2 = 0.984), showing that the values Of pH increases with the content of organic matter (Figure 5).

Table 12: Correlation between physical and chemical parameters in the surface horizon of soil of cocoa farming system under full sun

Para-meter	Clay		Silt				Sand			
			Coarse silt		Fine silt		Coarse sand		Fine sand	
	R	P>IrI	R	P>IrI	R	P>IrI	R	P>IrI	R	P>IrI
pHeau	-0,035	0,964	0,886	0,114	-0,595	0,404	0,205	0,794	0,457	0,542
CEC	0,028	0,971	-0,202	0,797	0,511	0,488	-0,068	0,931	-0,778	0,221
MO	**0,966**	**0,033**	-0,107	0,892	-0,622	0,377	-0,905	0,094	-0,119	0,880
C	**0,966**	**0,033**	-0,107	0,892	-0,622	0,377	-0,905	0,094	-0,119	0,880
N	0,885	0,115	0,128	0,871	-0,800	0,199	-0,784	0,215	0,130	0,869
C/N	**0,999**	**0,0005**	-0,357	0,642	-0,452	0,547	**-0,984**	**0,015**	-0,281	0,718
Ca	-0,361	0,638	**0,959**	**0,040**	-0,643	0,356	0,520	0,479	0,917	0,082
Mg	-0,102	0,897	**0,966**	**0,033**	-0,724	0,275	0,282	0,717	0,711	0,288
K	0,292	0,707	0,495	0,504	-0,910	0,089	-0,168	0,831	0,843	0,156

The values in bold are significant

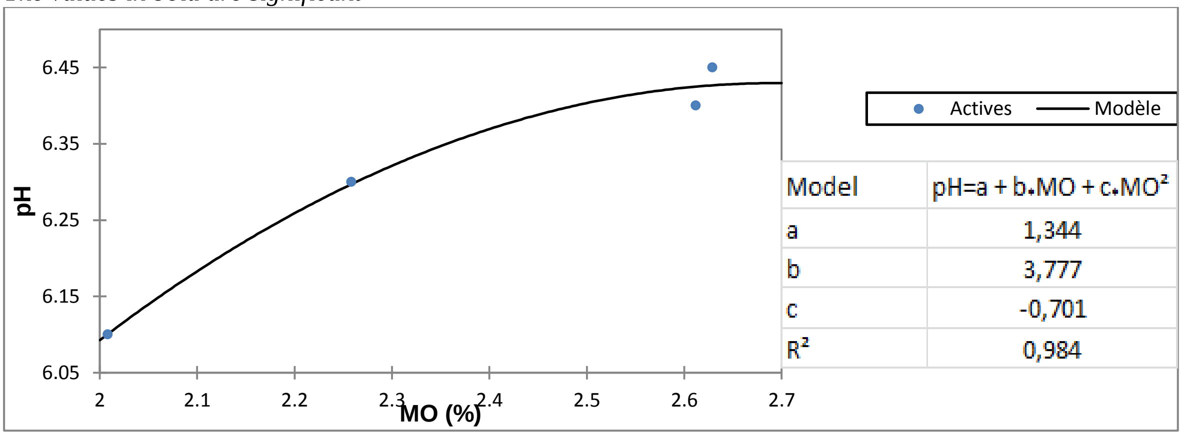


Figure 5: Evolution of the pH in function of the organic matter content of the 0-20 cm soil horizon

There was also a nonlinear relationship which can be modeling by a polynomial curve of second degree between pH and total nitrogen content. The regression coefficient (R^2) is 0.930 (Figure 6).

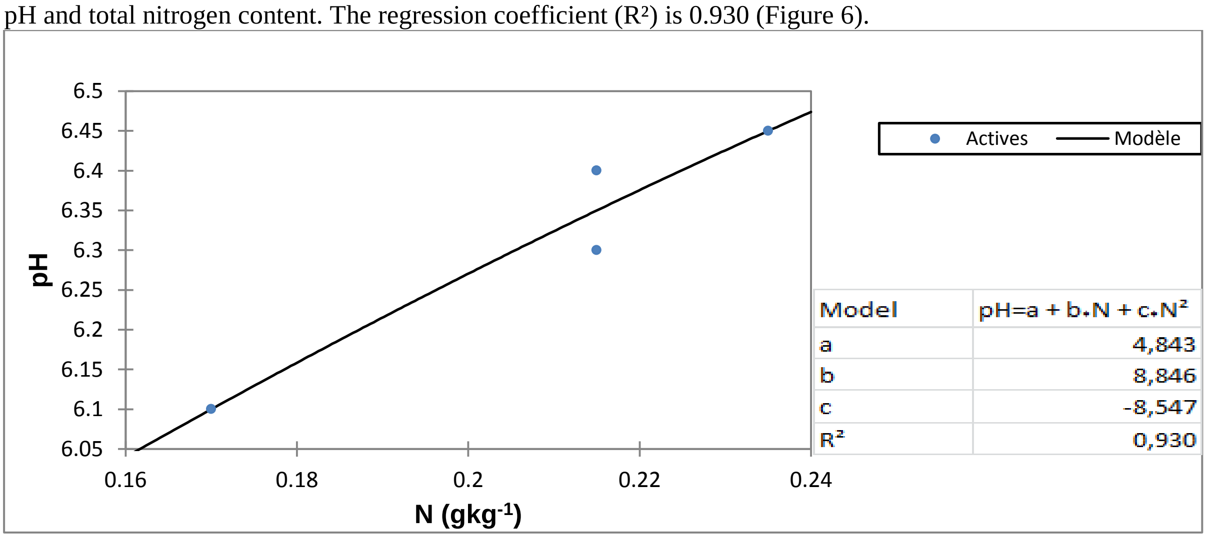


Figure 6: Evolution of pH in function of the total nitrogen content of the 0-20 cm soil horizon

pH and exchangeable bases

The component of the exchangeable bases that best determines pH evolution is magnesium (Mg ++). The relationship between these two parameters is a polynomial curve of degree 2, with a coefficient of determination of $R^2 = 0.985$. It indicates that pH increases with increasing of magnesium content. However, ph could drop with higher values of magnesium values (Figure 7).

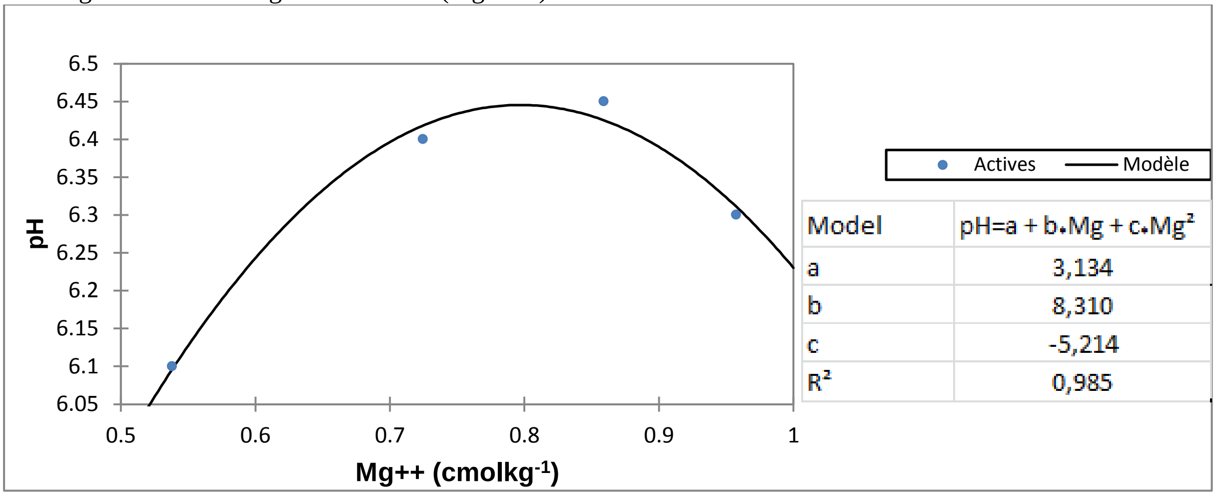


Figure 7: Evolution of the pH in function of the magnesium content of the horizon 0-20 cm

4. DISCUSSION

Bulk Density

The bulk density of the studied soils had the values in the same order as those of similar texture observed by Bruand *et al.* (2002).

The higher values of bulk density in cocoa farming systems under dense and medium shading in comparison to cocoa farming system under full sun and low shading would be partly, due to tillage, whose intensity would be decreasing with the increasing of density of the forest trees associated to cocoa trees (Thebaud, 2012). However, the higher values of bulk density of the soil in cocoa farming system under medium shading compared to cocoa farming system under dense shading, would be due to the nature of some associated trees, as noted, with the forest species *Spathodea Campanulata*. Indeed, according to Segalen (1963), certain secretions of living organisms could promote this. Moreover, the bulk density profile along the depth of the soil shows a discontinuity in the soil profile observed between 20 and 30 cm from the soil surface. This horizon corresponds to the level of the gravel front, which is followed by underlying horizons with lower coarse element content. This could also justify the relatively low values of bulk density at depth. However, similarly bulk density profiles observed in non-gravelly soils show that coarse elements and texture are not the only factors influencing the bulk density of soil.

As consequence of compaction of the soil, the water storage capacityof soil is reduced, causing a water deficit in the dry period (PROSENSOLS, 2011). The availability of water for plants will therefore decline sharply (Sadras *et al.*, 2005).

Soil water reserve

Soil moisture in the influence zone of *Spathodea Campanulata*, which is low compared to the area out of the impact of this tree, reflects the low soil water reserves observed in cocoa farming systems under associated trees shading. This would pose the problem of the choice of forest trees associated in cocoa plantation. Indeed, some trees, due to their abundant lateral roots, would reduced the soil water available to the cultivated plant. This is the case of some species found in the study area, such as *Alstonia boonei*, *Ceiba pentadra*, *Triplochiton scleroxylon* etc. these trees develop many thin lateral roots (Mapongmetsem *et al.*, 1999). This assertion is supported by Bidzanga *et al.* (2009), who argue that species with a shallow root system "dry out" the soil and therefore disturbe the normal development of associated crops. The lack of water in the soil leads to a low mobility of mineral elements in the soil (Lipiec and Stepniewski, 1995).

Physico-chemical characteristics

Water pH values, between 6 and 7, in the different cocoa systems studied, favor cocoa (Assiri *et al.*, 2015). However, organic matter contents in systems under low shading and under full sun, below 30 gkg-1 (threshold according to Snoek *et al.*, (2016)), respectively 29.5 and 27.2 gkg-1, constitute a limiting factor for the good development of cocoa trees. These organic matter contents are improved in cocoa farming systems under dense and medium shading, with respectively 39.3 and 34.0 gkg-1, thus providing better conditions for cocoa trees. The organic matter content observed in soil of cocoa farming systems under shading, compared to soils of the system under full sunlight is due to the falling of plant debris (dead leaves, branches, fruits, etc.) coming from the forest species associated to cocoa trees (Jackson And Ash, 1998). This confirms the results of Kouadio *et al.* (2016), who found higher organic matter contents in cocoa farming under shading of associated trees, compared to the system under full sun. The high levels of organic matter will allow the soils under cocoa trees to have a stable structure (ASB, 2000), for a better development of the cocoa trees. However, the C / N ratio on all plots is low. This value indicates a rapid decomposition of the organic matter.

For exchangeable bases, of course, none of the systems meet the threshold required by Snoek *et al.* (2016). However, all systems under shade have a satisfactory balance between mineral elements, unlike the soil of system under full sun, which does not respect any equilibrium. Also, among the systems under shading, only the soils of cocoa trees under dense shading do not reach the threshold of 21 cmolkg-1 for the cation exchange capacity.

Relationship between physical and chemical soil parameters

The silts, mineral particles with a size between 2 and 50 microns, can be inserted into the pores of the soil, generating a massive structure, thus reducing the infiltration of water in soil (Masson, 2012) . Thus, drainage difficulties, characterized by the pseudogleyic pattern of soils with high silt content, in cocoa trees under dense and medium shading are therefore justified. However, the observed correlation between silt and organic matter shows that fractions of similar size to those of silt exist in these soils and can form complexes with organic matter. Herbillon *et al.* (1966) describe them as pseudo-silts, composed of clay particles coated with free iron. The red color range of the soils under the different cocoa farming systems would confirm this phenomenon. These pseudo-silts could come into contact with organic matter through iron or clay (Cambier and Picot, 1988). The resulting argilo-humic complex could raise the values of the Cationic Exchange Capacity (Huber and Schaub, 2011), as observed in the soil of cocoa farming system under low and medium shading, where clay contents were relatively low. Also, the relationships between soil chemical parameters show that organic matter, nitrogen and magnesium are pH value determining parameters. However, the drop in pH value when the magnesium content exceeds about 8 cmolkg-1, could be the reflect, among other things, of the alteration of the parent rock.

5. CONCLUSION AND RECOMMANDATION

The results obtained show that the forest-savanna transition zone of Côte d'Ivoire, through M'Brimbo locality, has a strong natural diversity which requires an adequate use so that all of these potentialities allow a good development of the cocoa trees.

Cocoa farming system under shading of forest trees associated to cocoa plantations, contribute to directing agricultural practices towards an increased sustainability of agroecosystems, due to the improvement of the rate of organic matter and the preservation of the balances between the mineral elements.

However, the limiting factor law applied to all these systems makes it possible to identify the cocoa farming system under medium shading, as the best model.

6. ACKNOWLEDGMENTS

Our sincere thanks to the Agricultural Society of Bandama (SAB), whose exploitations served as the framework for this study.

7. REFERENCES

1. ASB., 2000. Alternatives to slash-and-burn: Summary report and synthesis of phase II in Cameroon. ASB Coordination Office, ICRAF-Nairobi, 35p.
2. Assiri A.A., Konan A., N'Guessan K.F., Kébé B.I., Kassin K.E., Couloud J.Y., Yapo A.R., Yoro G.R. and Yao-Kouamé A., 2015. Comparaison de deux techniques de replantation cacaoyère sur antécédents culturaux non-forestiers en côte d'ivoire. african crop science journal, vol. 23, no. 4, pp. 365 – 378.
3. Bidzanga N., Fotsing B., Agoume V., Birang M., Awana N.O and Zapfack L, 2009. Mycotrophie et connaissances paysannes des essences fertilitaires dans les agroforêts à base de cacaoyers du sud Cameroun. Cameroon Journal of Experimental Biology. Vol. 05 N° 02, pp. 79-86.
4. Bohoussou N. Y., 2016. Type d'exploitation et qualité de la production cacaoyère en zone forestière semi-décidue de Côte d'Ivoire : cas de M'Brimbo. Mémoire de Master des Sciences de la Terre. Université FHB, Abidjan, Côte d'Ivoire. 60 p.
5. Bremner J. and Mulvaney C., 1982. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Madison: ASA, SSSA. Nitrogen Total and Total P, Agronomy 9 Second edition. pp. 403-430.
6. Bruand A., Pérez Fernández P., Duval O., Quétin P., Nicoullaud B., Gaillard H., Raison L., Pessaud J.-F. and Prud'Homme L., 2002. Estimation des propriétés de rétention en eau des sols: Utilisation de classes de pédotransfert après stratifications texturale et texturo-structurale. Étude et Gestion des Sols. Volume 9, 2. pp. 105 – 125.

7. Cambier P. and Picot C., 1988. Nature des liaisons Kaolinite-oxyde de fer au sein des microagrégats d'un sol ferrallitique. Sciences du sol. volume 28 n°4, pp. 223-238.
8. Clough Y., Faust H. and Tscharntke T., 2009. Cacao boom and bust: sustainability of agroforests and opportunities for biodiversity conservation. Conservation letters. volume 2, issue 5, pp. 197-205.
9. Dabin B. and Leneuf N., 1960. Les sols de bananeraies de la Côte d'Ivoire. Fruits. volume 15 n°1. pp. 3-27.
10. Eblin M.O. and Amani Y.C., 2015. Déforestation et politique de reboisement dans les forêts classées : cas de la forêt de la Téné (centre-ouest de la Côte d'Ivoire). European Scientific Journal. volume.11, No.26, pp. 110-121.
11. Freud E. H., Petithuguenin P. and Richard J., 2000. Les champs de cacao. Un défi de compétitivité Afrique Asie. Editions KARTHALA CIRAD. 207 p.
12. Fournier J., Bonnot-Courtois C., Paris R., Voldoire O. and Le Vot M., 2012. Analyses granulométriques, principes et méthodes. CNRS, Dinard. 99 p.
13. Herbillon A.J., Pecrot A. and Vielvoye L., 1966. Apperçu de la minéralogie des fractions fines de quelques grands groupes de sols du Vietnam. Pédologie. XVI,I, pp. 5-16.
14. Huber G. and Schaub C., 2011. La fertilité des sols : L'i²mportance de la matière organique. Agricultures et Territoires, Chambre d'Agriculture Bas-Rhin. 42 p.
15. Jackson, J. and Ash, A.J., 1998. Tree-grass relationships in open eucalypt woodlands of northeastern Australia: influence of trees on pasture productivity, forage quality and species distribution. Agrofores. Syst 40: 159–176.
16. Kouadio K.H., Gala B.T.J., Assiri A.A. and Yao-Kouamé A., 2016. Characterization of traditional agroforestry systems of cocoa and their impact on some physical fertility parameters of soil in southwestern of Côte d'Ivoire. International Journal of Multidisciplinary Research and Development. Volume 3; Issue 10; pp. 145-152
17. Lipiec J and Stepniewski W., 1995. Effects of soil compaction and tillage systems on uptake and losses of nutrients. Soil and Tillage Research 35: pp. 37-52.
18. Mapongmetsem P.M, Duguma B, Nkongmeneck B.A and Selegny E., 1999 Germination des essences, développement et croissance de quelques essences locales en zone forestière. pp. 175-179.
19. Mathieu C. and Pieltain F., 2003. Analyse chimique des sols méthodes choisies. Lavoisier ed, Paris. 387 p.
20. Maurice J., Bouyer O. and Le Crom M., 2014. Évaluer les avantages et inconvénients des différentes définitions de la forêt en Côte d'Ivoire : État de l'art des bonnes pratiques et expériences internationales en matière de système de suivi des forêts. SalvaTerra, Paris, France. 71 p.
21. MINEF., 2014. Le nouveau code forestier Ivoirien – Loi n° 2014-427 du 14 juillet 2014 portant sur le Code Forestier. République de Côte d'Ivoire.
22. N'Douba E. M., 2016. Caractérisation des paramètres physiques, chimiques et hydrodynamiques d'optimisation de l'alimentation hydrique du cacaoyer sur sol dérivé de schiste, avec intrusion gabbroµïque : cas de M'Brimbo 'Centre-Sud de la Côte d'Ivoire). Mémoire de Master en Sciences de la Terre. Université Félix Houphouet-Boignyn Abidjan. 60 p.
23. Nelson D.W. and. Sommer L.E., 1982. Total carbon, organic carbon, and organic matter. In A.L. Page (ed.) Methods of Soil Analysis. 2nd Ed. ASA Monogr. 9(2). Amer. Soc. Agron. Madison, WI. pp. 539-579.
24. Ouattara G.and Koffi B.G., 2014. Typologie des granitoïdes de la région de Tiassalé (Sud de la Côte d'Ivoire - Afrique de l'Ouest) : Structurologie et Relations Génétiques. Institut National Polytechnique Félix Houphouët-Boigny de Yamoussoukro. Département des Sciences de la Terre et des Ressources Minières (STeRMi), Afrique SCIENCE. 10(2), pp. 258 - 276
25. PROSENSOLS., 2011. Le tassement des sols agricoles : Prévenir et remédier. 32p.
26. Ruf F. and Schroth G., 2013. Cultures pérennes tropicales: enjeux économique et écologiques de la diversification. Editions Quae, Versailles, France. 312 p.
27. Sadras V.O., O'Leary G.J. and Roget D.K., 2005 Crop responses to compacted soil : capture and efficiency in the use of water and radiation. Field Crops Res. 91: pp. 131-148.
28. Snoeck D., Koko L., Joffre J., Bastide P., Jagoret P., 2016. Cacao Nutrition and Fertilisation. In: Sustainable Agriculture Reviews, Vol. 19, Chapter 4. E. Lichtfouse (Ed.). Cham, Springer International Publishing. pp. 155-202.
29. Thebaud M.V., 2012. Effets des contraintes mécaniques du sol sur la limitation des rendements du tournesol. Institut National Polytechnique de Toulouse (INP Toulouse), Masson, Paris. 282 p.
30. Traoré S., Kobenan K., Kouassi K.S. and Gnonhouri G., 2009. Systèmes de culture du bananier plantain et méthodes de lutte contre les parasites et ravageurs en milieu paysan en Côte d'Ivoire. Journal of Applied Biosciences. volume 19, pp. 1094 – 1101.
31. Yedmel S. C., 2004. Contribution à l'amélioration de la culture du Teck (*Tectona grandis*, Verbenaceae) en Côte d'Ivoire par l'évaluation d'un essai de descendance et par la reproduction végétative de clones, Mémoire DEA, Université Félix Houphouet-Boigny, Abidjan. 40 p.