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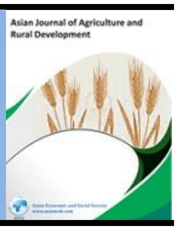

Restoration of the potentialities of a degraded ferralsol using cocoa bean teguments in Ahoue (South East, Côte d'ivoire)

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ABSTRACT

This study consists of using the cocoa bean teguments as a means of sustainable production growth and environmental preservation. It aims to characterize the effects of the teguments on the chemical properties of a Ferralsol in Ahoué (Côte d'Ivoire). In an experimental block design of Fisher, three treatments of Cocoa bean teguments: T1 (10 $t.ha^{-1}$), T2 (15 $t.ha^{-1}$), T3 (20 $t.ha^{-1}$) and one Control T0 have been set up with four repetitions. The main results show that the contribution of cocoa bean teguments has a positive effect on all the characteristics studied. The values obtained of the pH of the T0 and the T1, T2, T3 indicates, respectively 4.2; 5.4; 5.5 and 5.8. As regards the contents of the CEC, the values obtained give: 2.32; 7.2; 11.44 and 12.5 $cmol.kg^{-1}$, respectively, for T0, T1, T2 and T3 treatments. As for the organic matter, the contents obtained indicate the following values: T0 = 12.56 $g.kg^{-1}$; T1 = 26.49 $g.kg^{-1}$; T2 = 35.09 $g.kg^{-1}$ and T3 = 38.08 $g.kg^{-1}$. The data corresponding to the sum of the captions oscillated between 4.5 and 10.5 $cmol.kg^{-1}$ according to the treatments.

Contribution/ Originality
Unlike synthetic fertilizers that have a number of disadvantages on the soil, this study focused on restoring the agronomic potential of degraded soils through the use of cocoa by-products. The study shows that cocoa beans teguments, used as an organic fertilizer, constitute both an amendment and a food supply for the plant. The contribution of cocoa bean teguments is one of the solutions for restoring the fertility of degraded soils and improving crop yields.

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1. INTRODUCTION

The predominant role played by agriculture in Côte d'Ivoire's economy forces farmers to practice intensive farming because of the heavy pressure on land, due to the growing needs generated by population growth, and lack of arable land (N'Goran *et al*., 1997). The nutrients exported during crops are not adequately replaced (FAO, 2003). The consequence of this pressure is the reduction of fallow duration, leading to soil degradation and low crop yields (Yemefack and Nounamo, 2000). The managing natural resources in a rational way to ensure sustainable production are the challenge for producers in South-East Côte d'Ivoire. Soil, the main base of agricultural production (Duchaufour, 1995), is particularly affected by the loss of its many potentialities, in particular by the reduction of fallow land without compensatory fertilization and intense erosion. These factors led to a gradual disappearance of vegetation and significant chemical and physical degradation of cultivated soils. The direct consequence is lower crop yields and a dramatic drop in production. The use of fertilization is the most appropriate way to provide cultivated plants the indispensable complement to the soil. The fertilization, giving priority to mineral fertilizers at the expense of organic manure, certainly increases the immediate yield, but gradually destroys the soil (Cattan *et al*., 2001). Its exclusive use leads to an increase in acidity, a deterioration of physical status and a decrease in soil organic matter (Boli and Roose, 2000). In view of the disadvantages caused by chemical fertilizers, the search for new production methods that improve productivity and preserve the environment is essential (Rajot *et al*., 2002). The work of Ayanlaja and Sanwo (1991) has shown that the decomposition of plant residues considerably improves the level of nutrients and soil organic matter. The organic fertilization could therefore play an important role on various soil properties.

It is in this perspective that experiments are carried out in the South-East of Côte d'Ivoire with the cocoa bean teguments used as organic fertilizers to restore the fertility of degraded soils.

The objective of this study is to characterize the effects of manure from cocoa bean teguments on the chemical fertility of Ferralsol and the vigor index of cassava plants in Ahoué (South-East Côte d'Ivoire).

1. MATERIAL AND METHODS

2.1. Material

2.1.1. Site description

Located in the South-East of Côte d'Ivoire, the study area (Ahoué) is delimited by the coordinates 05°30'43"N and 03°56'31"W (Figure 1). The climate of Ahoué is the subequatorial regime. It is characterized by four seasons (Kouakou *et al*., 2016). The rainfall is about 1200 mm per year. The average temperature of the area is 26 °C.

The area belongs to the rainy area of the Guinean domain, characterized by dense evergreen forest. The area belongs to the ombrophilic area of the Guinean domain, characterized by the humid dense forest. The relief is presented as a model in half-orange. This area is characterized by a relief consisting of vast plains and low plateaus traversed by a succession of undulations.

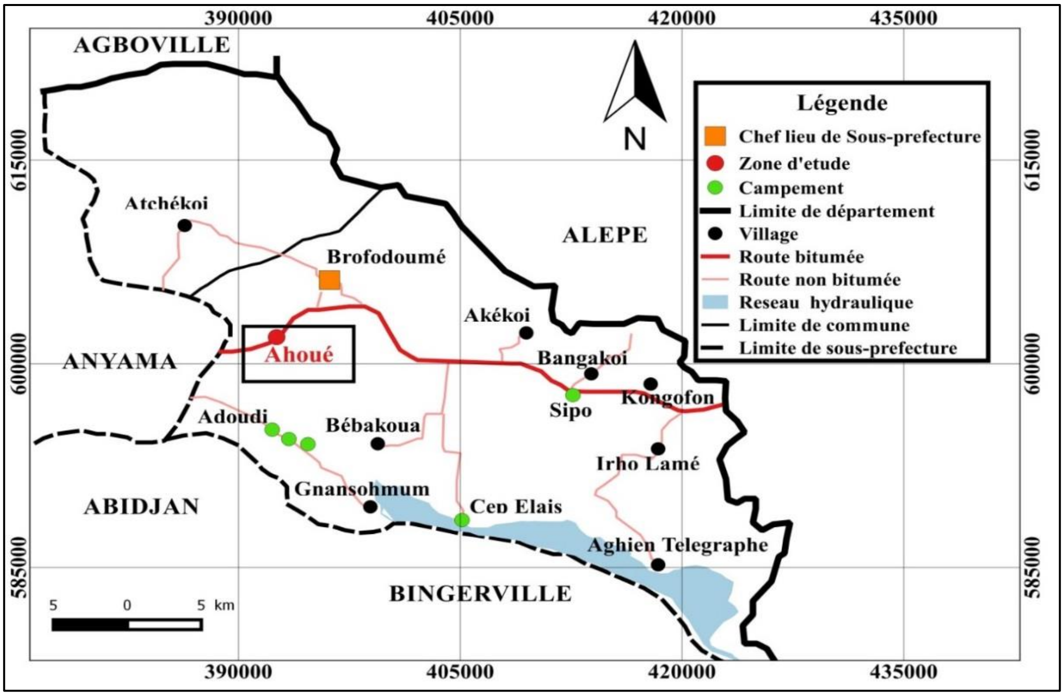

Figure 1: Location of the experimental site

2.1.2. Plant material

The experimental trial focuses on cassava, a tuberous root plant. The cassava variety (*Manihot esculenta Crantz*) used for this study is Improved African Cassava (commonly called yacé) (Figure 2). It is a resistant variety, commonly grown and consumed by the Ivorian population in different forms (cassava paste, flour, starch, bread, cake, etc.).

Figure 2: **Cassava cuttings (**Improved African Cassava***)***

2.1.3. Organic material fertilizer

The organic manure used consists of cocoa bean teguments (Figure 3). This fertilizing organic material came from a dump, place of trade of the cocoa bean teguments composted in the municipality of Abobo (Abidjan, Côte d'Ivoire).

Figure 3: **Cocoa bean teguments**

2.2. Methods

2.2.1. Experimental design

The experiments were carried according to a random block or "Fisher" block device with four repetitions (Figure 4). The subplots of 9 m^2 (3mx3m) are numbered from T0 to T3. In the case of this experiment carried out in the field, the blocks constitute a set of neighboring parcels very similar to each other. The distribution of objects within the different blocks is completely random and independently of one block to another. The cocoa bean teguments constitute the factor studied at four (4) levels: T1 (10 $t.ha^{-1}$), T2 (15 $t.ha^{-1}$), T3 (20 $t.ha^{-1}$) and T0 (0 $t.ha^{-1}$). The blocks are separated by 2 m and the sub-plots are separated from each other by 1 m. These different doses (treatments) are added during the preparation of the soil or during the planting.

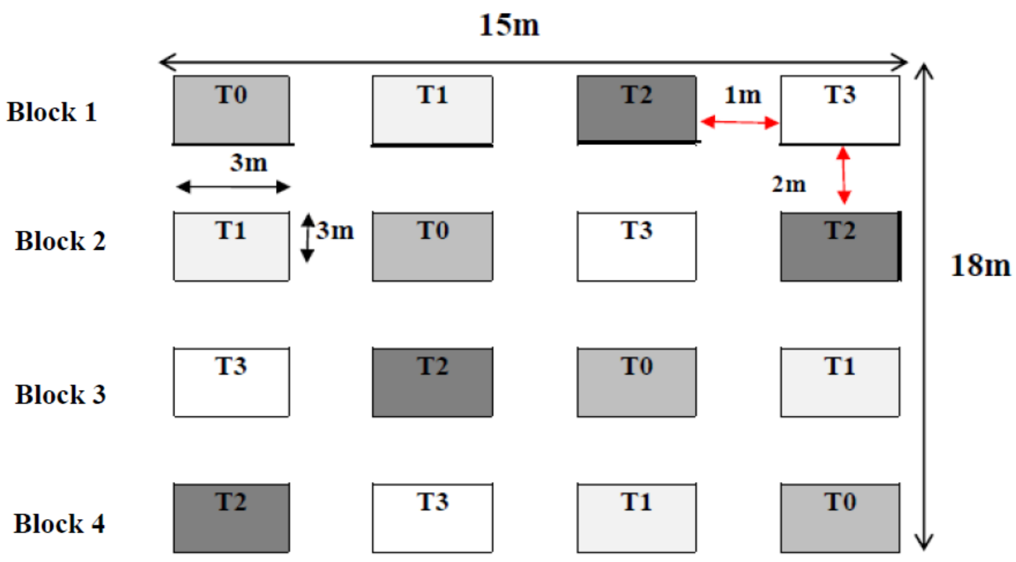

Figure 4: Experimental design

2.3. Agronomic trial

2.3.1. Soil preparation and application of fertilizing organic material

The preparation of the soil was done mechanically. The teguments were weighed and then applied on a thin regular layer according to the different doses on each of the sub-plots concerned, according to the experimental device.

2.3.2. Culturing

The planting mode is the one used by the directorates of research programs and development support and information systems CNRA (N'zué *et al*., 2005). The cuttings 20 to 30 cm long (4 to 6 knots) were collected from healthy stems at least 6 months old. The planting density is 10 000 plants per hectare (1 m between rows and 1 m between plants on the same line), or 16 cassava cuttings were placed on each sub plot of 9 m^2.

2.4. Collecting samples of Cocoa bean teguments and soil

2.4.1. Samples of Cocoa bean teguments

The cocoa bean teguments, obtained in a dump in Abobo (Abidjan), were dried, crushed and sieved (ø <2 mm) before being spread (Figure 5).

Figure 5: **Powder of cocoa bean teguments**

2.4.2. Germination rate

This dormancy is manifested by the appearance of germs. The end of dormancy is the growth of the plant with leaf development (Ettien, 2004). The raised feet were counted on each sub-parcel per block. Observations began 2 weeks after planting. After the second observation, a third occurred during the fourth week to identify the germinating plantlets (Bakayoko *et al*., 2013).

2.4.3. Vigor index

The vigor index (X), an important characteristic of plant development (Berchoux and Lecoustre, 1986), was determined two months after planting, according to the following formula:
$X = \log [(C^2 \times H) / 4\pi)]$ (01); C = circumference, H = height (H and C are expressed in centimeters).

2.4.4. Soil samples

The sampling took place in the 0-30 cm layer because of rooting depth of cassava (Hauser *et al*., 2013) and also some past work (Akanza and Yao-Kouamé, 2011). Within each elementary parcel, a random sample of soil was made at five different points, following the two main diagonals. The first, before the addition of the cocoa bean teguments, was aimed at determining the gross potential of the soil in nutrients and the second, after the harvest.

2.5. Chemical analysis of cocoa bean teguments and soil

The pH H2O measurements, to assess soil acidity, were performed in a soil suspension in water using a pH meter in a 1/2.5 ratio. The 1 M ammonium acetate method at pH 7 (Anderson *et al.*, 1993) was used to determine Cation Exchange Capacity (CEC) and exchangeable base contents (Ca^{2+}, Mg^{2+}, K^{+}). Total organic carbon was determined by the method of Walkley-Black (1934). The determination of total nitrogen (N) soil levels was done by the Kjeldahl method of Rittember (Bremner and Mulvaney, 1982) and the quantities of total phosphorus and assimilable, respectively, by colorimetry in the presence of ammonium molybdate and ascorbic acid after extraction by attack with perchloric acid (Olsen and Sommers, 1982), and by colorimetry after extraction with an alkaline solution of sodium bicarbonate(NH4F 0.5 N^{+} NaHCO3 0,5 N, pH 8.5) (Dabin, 1967).

2.6. Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) using SAS software. The Newman-Keuls test was used for comparison of averages when significant differences between treatments were revealed at the 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Chemical composition of cocoa bean teguments

The analysis of the cocoa bean teguments shows that the chemical composition, determined from the dry matter, indicates high levels of total carbon (320 $g.kg^{-1}$), total nitrogen (18 $g.kg^{-1}$), in total phosphorus (7600 $mg.kg^{-1}$), potassium (797.95 $Cmol.kg^{-1}$), calcium (19.21 $cmol.kg^{-1}$) and magnesium (234.47 $cmol.kg^{-1}$) (Table 1).

Table 1: **Chemical characteristics of cocoa bean teguments**

Chemical characteristics	Cocoa bean teguments
C ($g.kg^{-1}$)	320
N ($g.kg^{-1}$)	18
C/N	17.78
total phosphorus ($mg.kg^{-1}$)	7600
Ca ($Cmol.kg^{-1}$)	19.21
Mg ($Cmol.kg^{-1}$)	234.47
K ($Cmol.kg^{-1}$)	797.95
Na ($Cmol.kg^{-1}$)	8.69

3.1.2. Fertilizer elements provided by manure of cocoa bean teguments

An intake of 10 $t.ha^{-1}$ manure of cocoa bean teguments has provided the soil with the following quantities of organic elements: 180 kg of total nitrogen and 320 kg of total carbon (Table 2). The various fertilizer elements, both major and secondary, are released into the soil by the manure of cocoa bean teguments. These are phosphorus pentoxide (P_2O_5), potassium oxide (K_2O), calcium oxide (CaO) and magnesium oxide (MgO). The amounts of nutrients of the soil provided by 10 $t.ha^{-1}$ of organic fertilizer are: 76 fertilizer units of P_2O_5; 3120 fertilizer units of K_2O; 27 fertilizer units of CaO and 570 units MgO fertilizers (Table 2). A precise indication of the mass of organic elements and fertilizing minerals provided by the different quantities of manure of cocoa bean teguments is given in Table 2.

Table 2: Organic elements and fertilizer equivalents supplied by manure

Organic elements and minerals brought to the soil	Quantity of manure applied cocoa bean teguments ($t.ha^{-1}$)			
	0	10	15	20
	(fertilizing units.ha^{-1})			
C	0	320	4800	6400
N	0	180	270	360
P_2O_5	0	76	114	152
K_2O	0	3120	4680	6240
CaO	0	27	39.5	52
MgO	0	570	855	1140

3.1.3. Soil chemical characteristics before the tests

The chemical characteristics of the soil of the site before the tests are determined (Table 3).

These values indicate a low fertility in view of the low levels of organic elements (N = 0.3 $g.kg^{-1}$ and C = 7.3 $g.kg^{-1}$) poorly decomposed (C / N = 24.33). The nutrient binding and exchange potential of the clay-humic complex remains low, the sum of exchangeable bases (S = 0.23 cmol.kg-1) and base saturation (V = 9) , 91%), bear witness to this. Its cation exchange capacity also remains low (CEC = 3.10 $cmol.kg^{-1}$) as well as its assimilable phosphorus content (85 $mg.kg^{-1}$).

Table 3: **Soil chemical characteristics before the tests**

pH H_2O	N	C	C/N	Pass.	Ca	Mg	K	Na	CEC	S	V
	($g.kg^{-1}$)			($mg.kg^{-1}$)			($cmol.kg^{-1}$)				(%)
4.2	0.3	7.3	24.33	85	0.064	0.135	0.013	0.018	2.32	0.23	9.91

Pass. = assimilable phosphorus; S = sum of exchangeable bases; V = base saturation rate

3.1.4. Effects of cocoa bean teguments on soil chemical parameters

The soil pH H2O data varied from 4.2 to 5.8 depending on the treatments. The values significantly varied under the influence of different amounts of the cocoa bean teguments (Table 4). The soil pH H_2O increased from 4.2 to 5.8. The improvement rates passed from 22.22 to 27.59 %, respectively, for 10 and 20 $t.ha^{-1}$ of cocoa bean teguments manure. The optimum pH H_2O is 5.8, obtained at the dose of 20 $t.ha^{-1}$. Under the influence of organic fertilizer, soil organic matter levels varied from 26.49 to 38.08 $g.kg^{-1}$, with manure quantities (Table 4). The corresponding improvement rates fluctuated between 52.59 and 66.94 % compared to the T0 treatment, whose organic matter content is estimated at 12.56 $g.kg^{-1}$. The organic fertilizer had a significant influence on calcium, magnesium, potassium, sodium, the sum of the cations and the saturation rate in the bases of the adsorbent complex. Manure doses increased exchangeable calcium levels in the soil from 4.81 to 6.98 $cmol.kg^{-1}$, magnesium levels from 2.36 to 3.20 $cmol.kg^{-1}$, and potassium levels from 0.62 to .96 $cmol.kg^{-1}$ and Na contents of 0.14 to 0.23 $cmol.kg-^{1}$. The residual effects of the treatments caused an increase in the amount of assimilable phosphorus in the soil ranging 85 to 125 $mg.kg^{-1}$. With 10 $t.ha^{-1}$ of manure, an amount of 95.75 $mg.kg^{-1}$ is acquired, against 85 $mg.kg^{-1}$ for the T0 treatment. In addition, inputs of 15 and 20 $t.ha^{-1}$ manure allow access, respectively, 112.05 and 125.2 $mg.kg^{-1}$ (Table 4). The data corresponding to the sum of the cations varied between 4.5 and 10.5 cmol.kg-1 according to the treatments (Table 4). The rates of increase in the sum of the cations, relative to T0, passed from 94.88 to 97.81%, respectively, for manure quantities of between 0 and 20 t.ha-1. The base saturation rate values of the clay-humic soil complex fluctuated between 62.5 and 84% depending on the treatments (Table 4). The organic fertilizers had a significant effect on base saturation of the adsorbent complex.

Table 4: Effects of cocoa bean teguments on soil chemical parameters

Doses ($t.ha^{-1}$)	pH H_2O	MO (g.kg-1)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	Pass. (mg.kg-1)	CEC ($cmol.kg^{-1}$)	S (Cmol.kg-1)	V (%)
T1	5.4	26.49	4.81	2.36	0.62	0.14	95.75	7.2	4.5	62.5
T2	5.5	35.09	4.93	2.47	0.75	0.20	112.05	11.44	7.3	63.8
T3	5.8	38.08	6.98	3.20	0.96	0.23	125.2	12.5	10.5	84
Pr>F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

MO = Organic matter; Pass. = assimilable Phosphorus; S = sum of exchangeable bases; V = base saturation rate

3.2. Effects of cocoa bean teguments on germination rate and vigor index of cassava plants

3.2.1. Germination rate of cassava plants

After 14 days of planting, it is found that the germination rate in each sub-plot amended with the organic fertilizer is greater than 50%. However, there is a slight improvement in the germination rate (59.75%) in sub-plots treated with T1 treatment. This germination rate after 21 and 28 days of planting varies markedly for each treatment, but with a slight improvement in subplots T2 and T3 (82.8 to 87.5%) (Table 5).

Table 5: Germination rate of cassava plants

Treatments	Germination Rate			Average
	14 days	21 days	28 days	
T0	51.563a	71.875a	75.000a	66.146a
T1	59.75a	79.688a	81.250a	73.438a
T2	56.250a	82.813a	84.375a	74.479a
T3	54.688 a	82.813a	87.500a	75.000a
CV (%)	19.10515	9.449914	10.54809	20.78308
Pr> F	0.7714	0.1837	0.2593	0.4449

Values with the same letter are not significantly different at the 5% threshold

3.2.2. Vigor index of cassava plants

The table 6 presents the mean values of the vigor index for the different treatments. The table 6 also shows that the smallest vigor index was obtained with T0. As for the largest vigor index, it was obtained with T3 treatment. The plots fertilized with the treatments have a growth rate ranging from 12.65 to 14.59% from the first to the third week of observation.

Table 6: Vigor index of cassava plants

Treatments	vigor index			Average
	64 days	71 days	78 days	
T0	1.81b	1.99c	2.127b	1.97c
T1	1.99a	2.09bc	2.33a	2.14b
T2	2.05a	2.25ab	2.37a	2.23ab
T3	2.14a	2.38a	2.45a	2.32a
CV (%)	18.1879	17.1426	16.2217	18.0857
Pr> F	0.0007	<1.0001	0.0017	<0.0001

Values with the same letter are not significantly different at the 5% threshold

4. DISCUSSION

The chemical characterization of the soil before the application of organic fertilizers and the implantation of the cassava cuttings, revealed a soil very poor in organic matter (C = 7.3 g / kg and N = 0.3 g / kg), and poorly decomposed (C / N = 24.3). These properties show a very low potential for binding and exchange of elements (S = 0.23 Cmol / kg) and saturation rate (V = 9.91%). It is a very acidic soil (pH H2O = 4.2) and belongs to the subclass of Ferralsols (Akanza and Yao-Kouamé, 2011). The continuous exploitation of Ahoué soils with natural fallow as the only means of restoration causes sharp decreases in crop yields of around 30 to 75% (Kouadio, 2012). The mineral elements such as calcium and magnesium available in soils are exported by crops and by runoff or seepage, thus making the pH acidic (Green and Kowal, 1960). The drop in pH is accompanied by the appearance of toxic elements such as manganese or aluminum (Merelle, 1998). The analysis of the cocoa bean teguments indicates high amounts of total carbon (320 $g.kg^{-1}$), total nitrogen (18 $g.kg^{-1}$), total phosphorus (7600 $mg.kg^{-1}$), potassium (797.95 $Cmol.kg^{-1}$), in Calcium (19.21 $Cmol.kg^{-1}$) and in Magnesium (234.47 $Cmol.kg^{-1}$). The soil supply of the manure of teguments shows a clear improvement of the chemical fertility of the soil. The evolution of the pH, the organic matter, the CEC and the sum of the cations testifies to it. The increase of each of the characteristics is all the more marked as the dose of teguments is strong. The cocoa bean teguments are rich in total carbon, total nitrogen, exchangeable calcium, magnesium and exchangeable potassium. The manure of the teguments brought significant effects on the chemical parameters of the degraded soils of Ahoué by the improvement of the CEC, the organic matter, the sums of the exchangeable bases, the saturation rate in bases and the pH H_2O of amended soils, especially, with T3 treatment. Indeed, with their decomposition in the soil, the integuments ensure a high availability of nutrients for the cassava plants. These results are in agreement with those of Useni *et al.* (2013), Djeké *et al.* (2011) and Moyin-Jesu (2007) who showed, respectively, that the decomposition of plant residues has raised the pH and nutrient levels of the soil. The increase in soil pH observed in treated plots reflects a decrease in soil acidity. With the T3 treatment, the acidity of the soil ranging from 4.2 to 5.8, would be linked to the Ca^{2+} and Mg^{2+} ions, which, despite their uptake by the plants, are in sufficient quantities to neutralize the ions responsible for the acidity of the soil. The increase in CEC, following the introduction of manure from cocoa bean teguments, could be explained by the fact that these fertilizers have affected the phenomena of fixation of exchangeable cations on the soil-absorbing complex (Abobi *et al.*, 2014). According to the works of Djeké *et al*. (2011), since the pH makes it possible to define the state of the adsorbent complex, in particular, the saturation rate in bases (Duchaufour, 1997), its improvement by the addition of cacao bean teguments also reflects that of the saturation rate in bases. The results, thus obtained, are perfectly concordant to authenticate the hypothesis according to which the organic matter, in the form of cocoa bean teguments, is one of the real engines of the improvement of the chemical fertility of the soil. It is used in high doses (Adden, 2004). The data analysis establishes that the T3 treatment seems to have the best result. This observation confirms that the addition of high-dose organic fertilizer is essential to maintain or jointly increase total carbon and soil nutrient stores (Thuriès *et al*., 2000). The improvement of the vigor index of cassava plants on fertilized plots shows that the supply of cocoa bean teguments has a positive effect on the different chemical parameters of the soil. By providing nutrients by mineralization and neutralizing the acidity of the soil, the cocoa bean teguments have a very strong influence on the vigor index of the cassava plants. Thus, the cocoa bean teguments improve the physical chemical properties of the soil, make available elements such as Calcium, Magnesium, Phosphorus (Bado, 2002), and provide nutrients by mineralization. This leads to an improvement in the vigor index of the crop plants. The organic matter is one of the main regulators of soil productivity. The results provided by the tests are very satisfactory and generally consistent.

5. CONCLUSION

This study, conducted on Ferralsols in Ahoué, South-East of Côte d'Ivoire, showed that the use of cocoa bean teguments as an organic fertilizer is one of the solutions for restoring the fertility of degraded soils. The use of the cocoa bean teguments had a beneficial effect on the chemical fertility and vigor index of the cassava plants. The addition of 20 $t.ha^{-1}$ of teguments achieves the best compromise between the soil chemical parameters and the vigor index of the cassava plants. The addition or restitution of organic matter to the soil is both an amendment and a food contribution for the plant. The organic matter, once incorporated into the soil, undergoes a series of transformations which, under the action of microorganisms and under the influence of the environment, break it down into humus and mineralize it. These transformations are very beneficial for the soil, the organic matter inputs should be realized, in principle, every year, for farmers concerned with the preservation of their soil capital.

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