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Evaluation of the Effectiveness of an Organic Fertilizer Based on Cocoa Hulls and Moringa Leaves on N'Drowa Eggplant (*Solanum aethiopicum*)

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Abstract

Organic fertilizers generally come from agricultural co-products. Their valuation is therefore a major issue for sustainable development. The main objective of this study aims to develop an organic fertilizer derived from moringa leaves and cocoa pod husks that can improve soil quality and plant growth. The experimental design consisted of completely randomized blocks in three repetitions. The experiment was carried out in five treatments: T0: no fertilization, T1: 100% cocoa pods, T2: 75% cocoa pods + 25% Moringa leaves; T3: 50% cocoa pods + 50% Moringa leaves; T4: 25% cocoa pods + 75% Moringa leaves; T5: 100% Moringa leaves. Three doses were applied: 1; 2; 4 kg/m^2. The trial took place over three growing cycles. The results of the soil analysis compared to the control revealed a significant improvement in physicochemical parameters. Variation of pH from (6.1 to 7.2), calcium from (1.4 to 4.13), magnesium from (0.450 to 0.870), potassium from (0.096 to 0.365) cmol+/kg. Carbon and nitrogen were recorded (1.02% to 2.77%) and (0.12% to 2.56%) respectively. The CEC (cation exchange capacity) saw a clear improvement (4.2 to 9.03) cmol+/kg. Concerning the growth parameters, the control plants recorded an average height of (31.19 cm) while those that benefited from the treatments oscillated between (55.51 to 105.57 cm). In terms of production, the best yields are attributed to treatments T3 and T4 with (37.66 t/ha) and (51.176 t/ha) respectively. The T3 and T4 formulations could help improve the fertility of agricultural soils and the yield of market garden products such as eggplant.

Keywords

Solanum aethiopicum Gilo, Organic Fertilize, Cocoa, Moringa, Nutrients

1. Introduction

One of the main constraints on agriculture in Africa south of the Sahara is the constant fall in the level of soil fertility, resulting in lower levels of crop productivity [1]. The prohibitive cost of fertilizers and chemical amendments as well as their unavailability in rural areas place producers in a situation of great pressure and economic vulnerability. In addition, the continuous and exclusive use of land leads to a drop in productivity [2], notably jeopardizing agricultural yield [3] and environmental stability. Thus, the implementation of strategies favoring the use of organic fertilizers to improve soil fertility should be encouraged.

Organic fertilizers are increasingly used in sustainable agriculture for their low environmental and health impact [4]. Recent studies involving the use of organic amendments as soil fertilizer have revealed positive results in terms of improved yields which would be comparable to chemical fertilization [5].

However, the ability of organic fertilizers to provide nutrients to crops depends on the plant type, organic matter and prevailing agro-climatic conditions in the field for subsequent decomposition, which limits the generalizability of the results [6]. The local, inexpensive, durable, ecological and easily available material could be used to sustainably manage soil quality in agro-ecosystems.

Ivory Coast is the leading cocoa producing country in the world with around 2.2 million tonnes of cocoa beans in 2022. The intensification of cocoa production has become a major issue for the entire cocoa sector. From production to processing. The Toumbokro agro-industrial plantation, in the Yamoussoukro district (central Ivory Coast), generates a large quantity of four types of co-products: cocoa pod shell (CPM), placenta, cocoa mucilage and cocoa bean hulls (CS). CPM, which makes up about 70 - 75% of the whole fruit, is used locally as an organic fertilizer. This green manure is a source of macro and micronutrients necessary to improve plant productivity, but it is relatively poor in nitrogen [7]. Unfortunately, the relatively high contents of fibrous materials, including lignin, cellulose, hemicellulose and pectin, can delay its decomposition [8]. This situation is detrimental to the restoration of soil fertility and constitutes a significant challenge.

Moringa (*Moringa oliefera*) is an Asian plant that lives in the tropics and is widespread on the Ivory Coast. More recently, there has been growing interest in the use of Moringa leaves in tropical agricultural systems. The liquid extracted from Moringa leaves has been used in agriculture to improve the growth and productivity of several crops. The effectiveness of Moringa leaf extract is attributed to its content of minerals, proteins, nitrogen and numerous plant growth hormones

[9]. Thus, the formulation of an organic fertilizer from these two substrates could improve the state of fertility of agricultural soils. Well adapted to tropical climates, eggplant is grown throughout the Ivory Coast but prefers light soils that are rich in organic matter and well drained. The fruits of the African eggplant are widely consumed in West Africa due to its mild taste, its high yield, the length of the harvest and storage season as well as its resistance to mites [10]. These low-calorie vegetables participate in the human diet due to their remarkable abundance of minerals and fiber as well as their high potential in antioxidant compounds [11] [12]. Market supplies are mainly ensured by producers who use improved cultivars of African eggplant without fertilization or phytosanitary treatments in small spaces [13].

The main objective of this study is to evaluate the level of restoration of agricultural soils degraded by the use of combined organic fertilizers. To achieve these objectives, it specifically involves:

Formulate an organic fertilizer (cocoa pods/moringa leaves) and evaluate the effect of this combined fertilizer on improving the physical and chemical parameters of the soil and the yield of eggplant N'Drowa, (*Solanum aethiopicum* Gilo).

2. Material and Methods

2.1. Hardware

2.1.1. Description of the Study Site

The experiment was carried out in Yamoussoukro (6˚821N, 5˚277W and 214 m altitude), during the period from February 2019 to October 2021, the capital of Ivory Coast. It is located in the south-central part of the country, on the edge of the savannah and the forest, 216 km from Abidjan, the economic capital. The average annual rainfall in the area is 1098 mm with a bimodal regime of two rainy seasons from April to June and August to October, and two dry seasons, one in July and the other in November. to March. The average daily temperature varies between 35 and 31˚C during the day and between 23 and 19˚C at night. The average sunshine is 12.3 h day-1 [14]. The tests were carried out on a plot whose GPS coordinates were determined. Crop residues were collected and placed outside the field. No fertilizer was applied during the two years of the crop cycles.

2.1.2. The Ground

The soil has a low organic carbon content (TOC = 1.02%) with a low ratio (C/N = 10.2).

A pH of 6.1, a cation exchange capacity of 4.2 cmol kg^{-1} and a sandy-clay texture (8.83% clay); essentially reworked modal ferality soils.

2.1.3. Fertilizer Preparation

These are cocoa pod husks (Theobroma cacao), available on the Ivory Coast, and they constitute a significant source of agricultural waste left in the fields after harvest. Cocoa pods and moringa leaves air-dried for 7 days were used. They were crushed separately in a grinder (Retsch Masch. Nr. 68261 types BB1) and passed through a 2 mm sieve. They were mixed in volumetric proportions and then spread on the ground.

2.1.4. Cultivar

The experiment used the hybrid eggplant cultivar (*Solanum aethiopicum* Gilo) N'Drowa developed by the CNRA (National Center for Agronomic Research), referenced Aub 21/06 Du "N'Drowa" Average yield 24 (t/ha).

2.1.5. Experimental Device

The completely randomized block experimental design with six treatments and three repetitions. The block (20 m × 39 m) includes three elementary plots, each plot measuring 20 m × 13 m, comprising a total of 18 elementary plots (**Figure 1**). A 1 m driveway separates two adjacent blocks, while the inter-plot driveway is 1 m wide. The aisle is 1 m wide.

The treatments compared were:

-T0: Control without fertilizer application.

-T1: Exclusive contribution of crushed cocoa shells mixed with the grinding.

-T2: Contribution of 75% crushed cocoa hulls and 25% crushed Moringa leaves mixed with soil.

-T3: Contribution of 50% crushed cocoa hulls and 50% crushed Moringa leaves mixed with soil.

-T4: Contribution of 25% crushed cocoa hulls and 75% crushed Moringa leaves mixed with soil.

-T5: Exclusive contribution of crushed Moringa leaf mixed with earth.

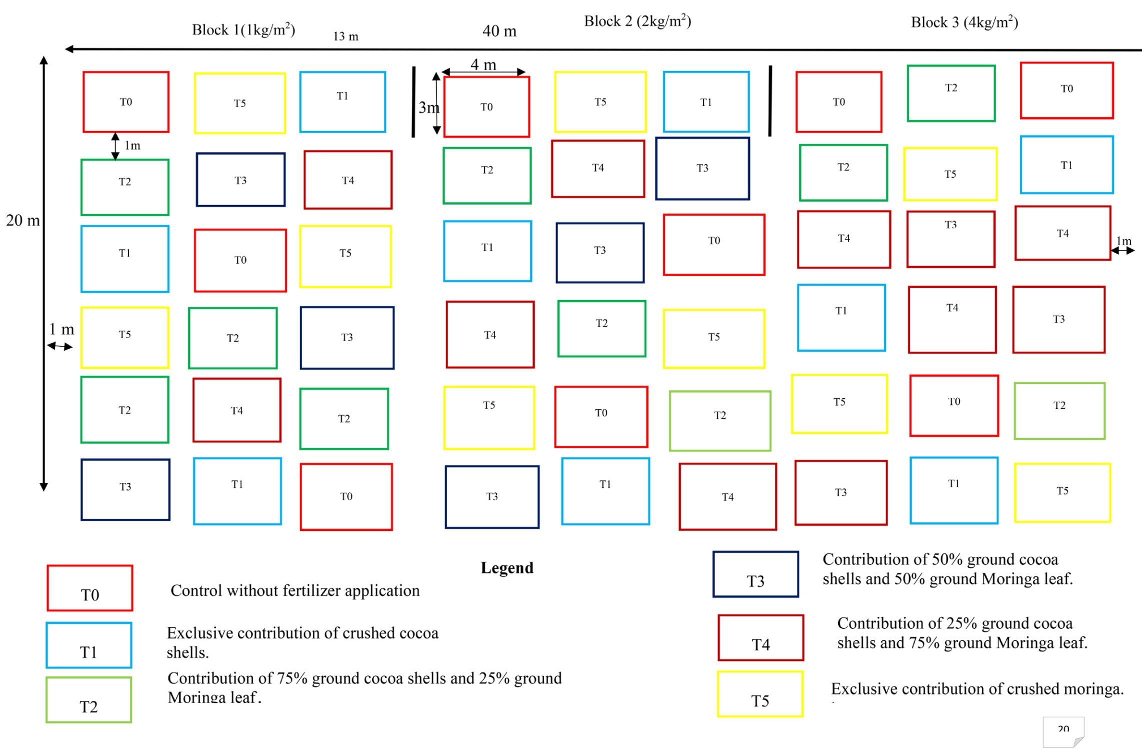


Figure 1. Experimental setup of the plot.

2.2. Methods

2.2.1. Soil Parameters Analyzed

The chemical parameters were determined on soil samples dried and passed through a 2 mm diameter sieve. The main analyzes focused on pH, total organic carbon (TOC), total nitrogen (Nt), assimilable phosphorus (P. assi), cation exchange capacity (CEC), exchangeable cation content and the texture.

2.2.2. pH

The pH was measured in accordance with the international standard ISO 10390 (1994), using the electrometric method which consists of preparing a soil-water suspension in a weight ratio of 1:2.5 (20 g of soil for 50 ml of water distilled), shake it for five minutes and let it sit for at least thirty minutes. The pH is then measured using a JENWAY 3520 pH meter.

2.2.3. Total Organic Carbon (TOC)

Total organic carbon was determined according to the Walkley and Black method **(1934)**, the principle of which consists of oxidizing the material with a powerful oxidant (potassium dichromate) at high temperature and in the presence of sulfuric acid. The excess of dichromate is determined using a standard solution of Mohr's salt (ferrous II sulfate and ammonium sulfate), in the presence of a colored indicator (diphenylamine). The organic matter content is obtained by the following formula:

$$\mathbf{MO\ (\%) = Carbon\ (\%) \times 1.72}.$$

2.2.4. Determination of Total Nitrogen Content

The nitrogen content was determined according to the Kjeldahl method (AOAC, 2007), with some modifications. The mineralization of 1g of product sample was carried out in a P SELECTA mineralizer in the presence of a catalyst composed of copper sulfate ($CuSO_4$), potassium sulfate (K_2SO_4) and selenium, using a mineralizing digester, for 2 h 30 min. The distillation is then carried out using a VELP SCIENTIFICA UDK 129 distillation unit, after adding 25 ml of 40% caustic soda solution (NaOH) to the mineralization. The distillate is collected in a 0.1 N buffer solution of sulfuric acid (H_2SO_4) in the presence of a colored bromocresol green and methyl red indicator. The distillate is titrated with a 0.1 N NaOH solution. The total nitrogen content is determined by the following formula:

$$\text{Total nitrogen (\%)} = ((\text{Vb} - \text{Vv}) \times 14 \times \text{N} \times 100)/\text{P} \tag{2}$$

V Volume of NaOH;

N Normality of NaOH;

0.014 Coefficient attributed to the concentration of the normal nitrogen solution (14/1000);

P Sample mass.

2.2.5. CEC and Exchangeable Bases

Extraction of exchangeable bases with ammonium acetate at pH7, determination by atomic absorption spectrophotometer; washing the base with alcohol.

The determination of the cation exchange capacity (CEC or T) was carried out using a special modified method developed by (Orsine and Rémy (1976)), the principle of which is based on the bringing into contact of the alcohol-washed soil sample with sodium chloride [NaCl] solution of known concentration. The Na+ ions displace the cations of the adsorbent complex and attach to them. In the solution collected during saturation, we find the exchangeable cations and the ions obtained by the difference between the quantity of ions in the initial solution and that remaining after contact with the ground. Exchangeable cations were determined in the same extract as the cation exchange capacity. As the extraction solution is not buffered, the exchange pH is close to that of the soil in place. The extract is distilled with Kjeldahl then titrated with hydrochloric acid [Hcl]. The results are expressed in cmol*kg^{-1} of soil.

2.2.6. Particle Size

(Robinson pipette method (1922)) in accordance with standards NEN 5357 and ISO/DIS 11277. Its aim is to know the quantitative distribution for each dimensional class of the elementary particles constituting the sample. This method is based on the difference in sedimentation speed between light particles and larger ones. The method used is based on the law of STOCKES. Different preliminary chemical treatments are used to obtain good dispersion of elementary particles. A first treatment ensures the destruction of the organic matter with hydrogen peroxide, a second ensures the destruction of the limestone with Hcl, then long agitation in water is sufficient in the presence of a dispersing salt (sodium pyrophosphate).

After free sedimentation under the action of gravity, the particles fall with constant speeds, the greater the larger they are. Thus, the fine fraction (clay: 0 - 2 µm and fine silts: 2 - 20 µm) was taken by the ROBINSON pipette and the coarse fraction (coarse sand: 200 - 2000 µm, fine sand: 50 - 200 µm, coarse silt: 20 - 50 µm) was obtained by successive sieving.

2.2.7. Assimilable Phosphorus

The determination of assimilable phosphorus is carried out according to the modified Olsen-Dabin method (Bray-Dabin, 1979). It consists of extracting the ortho phosphates using a solution of ammonium fluorine (NH4F) at 0.03 M in the presence of sodium bicarbonate ($NaHCO_3$) at 0.5 M in a soil/solution ratio. The phosphorus dosage is carried out by colorimetry based on the formation and reduction of a phosphomolybdic complex. Phosphorus is thus determined using a spectrophotometer using molybdenum blue at 820 nm.

3. Conduct of Tests

There are 6 treatments/3 doses/ and 5 formulations. Likewise, 5 formulations + controls = 6 treatments.

The doses of organic fertilizers were added manually in the form of manure with burial in the soil at approximately 10 cm.

The allocation of the eighteen treatments resulting from the interaction of three doses of cocoa husk (C) and Moringa leaf (M) fertilizers and five fertilizer formulations was done in a random manner with three repetitions. Doses D1 (1 $Kg \cdot m^{-2}$ of cultivated soil), D2 (2 $Kg \cdot m^{-2}$ of cultivated soil) and D3 (4 $Kg \cdot m^{-2}$ of cultivated soil) were studied comparatively to control without fertilizer addition during the experiment. One week after the application of fertilizers, direct sowing was carried out.

3.1. Maintenance Work

On the experimental plot, we used two types of maintenance operations which are: weeding and the addition of nutrients. Watering and weeding were done on demand and at the daba.

3.2. Data Collection and Analysis

Data collection was carried out on a sample of 108 plants at a rate of 6 plants per elementary plot, for a total of 324 samples over the three blocks. The data collected at plant level focused on the average height and diameter at the collar of the plants. Regarding production, the weight was determined at each harvest.

All these growth parameters were evaluated at the first harvest at 120 days after sowing (DAS).

The parameters measured in the field were analyzed with Statistica software, version 7.1. Multiple analysis of variance (ANOVA) was used to study the overall effect of organic fertilizers and their interaction on growth and yield parameters. When the ANOVA revealed a significant positive influence of several factors or their interactions on a group of dependent variables, these were selected. The factors thus retained were the subject of an analysis of variance (ANOVA) in order to study their individual or combined effect on the parameters studied. When a significant difference is noted between the factors for a given variable, multiple comparisons are carried out by performing the test for the smallest significant difference (ppds) by comparing the least squares means two by two. The significance of the test is determined by comparing the probability (P) associated with the test statistic to the theoretical value $\alpha = 0.05$. Thus, when $P \geq 0.05$, we deduce that there is no difference between the means. On the other hand, when $P < 0.05$, there is a significant difference. Duncan's method was used to separate means at the 5% level.

4. Results and Discussions

4.1. Results

4.1.1. Chemical Composition of the Fertilizer

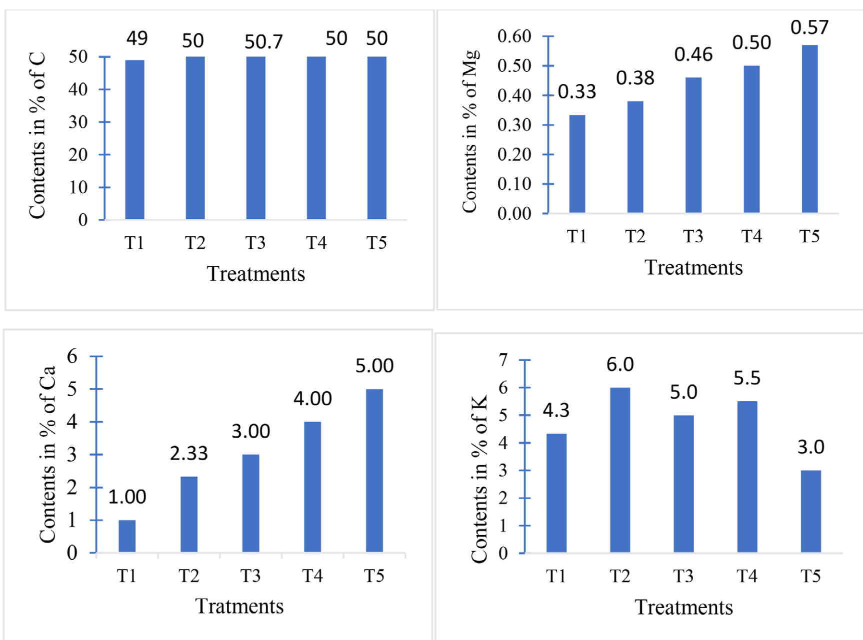
The chemical characterization studies carried out show variability in the composition of mixed fertilizers of crushed cocoa shell and crushed Moringa leaves (Table 1). Element contents are given as a percentage of dry matter (DM). Theobroma T1 cocoa shell grind (100% C) recorded satisfactory nutrient contents, namely potassium (4.33%), magnesium (0.33%), carbon (49%) and organic matter. (85.61%) and phosphorus (0.26%), respectively have a low rate of nitrogen and calcium (1.32%

and 1%). The crushed leaf of Moringa oleifera (T5 (100% M) consists respectively of (3%) potassium, (5%) calcium and (0.57%) magnesium, carbon and organic matter (50% and 86%), nitrogen (3%) The increase in the incorporation rate of Moringa oleifera leaves led to an enrichment of the nutrients of the composite organic fertilizers T2, T3 and T4 differ significantly from T2 by the relative proportion of their nitrogen, phosphorus, potassium, calcium and magnesium content illustrated by the corresponding graphs (Appendix 1). The organic matter induced by the combination of the two substrates is significantly increased (87.72%), the carbon rate is (51%). (21.43% and 27.09%) would be best indicated for good mineralization. Figure 2 represents the improvement of the different parameters.

Table 1. Chemical characteristics of fertilizer powder.

Treatments	C	N	P	K	Ca	Mg	M.O	C/N
T1	**49.0 ±** 1.00a	**1.32 ±** 0.02^{a}	**0.26 ±** 0.01^{b}	**4.33 ±** 1.53^{ab}	**1.00 ±** 0.50^{a}	**0.33 ±** 0.02^{a}	**85.61 ±** 1.19^{a}	**37.21 ±** 0.58^{e}
T2	**50.0 ±** 1.00^{a}	**1.50 ±** 0.13^{a}	**0.27 ±** $0{,}01^{b}$	**6.00 ±** 1.00^{c}	**2.33 ±** 0.67^{b}	**0.38 ±** 0.02^{b}	**86.00 ±** 1.72^{a}	**33.55 ±** 3.74^{d}
T3	**50.7 ±** 1.53^{a}	**1.87 ±** 0.13^{b}	**0.23 ±** 0.01^{a}	**5.00 ±** 0.50^{bc}	**3.00 ±** 0.50^{b}	**0.46 ±** 0.01^{c}	**87.15 ±** 2.63^{a}	**27.09 ±** 1.01^{c}
T4	**51.0 ±** 1.00^{a}	**2.38 ±** 0.02^{c}	**0.28 ±** 0.02^{b}	**5.50 ±** 0.50^{bc}	**4.00 ±** 0.50^{c}	**0.50 ±** 0.01^{d}	**87.72 ±** 1.72^{a}	**21.43 ±** 0.59^{b}
T5	**50.0 ±** 1.00^{a}	**3.00 ±** 0.35^{d}	**0.35 ±** 0.02^{c}	**3.00 ±** 0.50^{a}	**5.00 ±** 0.50^{d}	**0.57 ±** 0.01^{e}	**86.00 ±** 1.72^{a}	**16.79 ±** 1.56^{a}
					P-value			
Cycle (*C*)	0.30	<0.001	<0.001	<0.02	<0.001	<0.001	0.61	<0.001

The nutrient levels recorded illustrate the differences for each treatment.



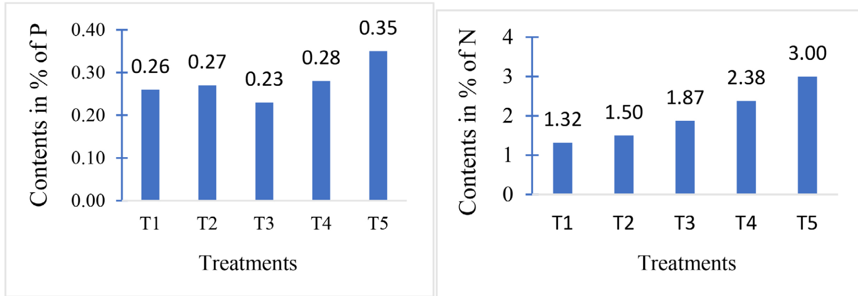


Figure 2. Levels of nutrients contained in formulations.

4.1.2. Evolution of Soil Characteristics before Sowing and at the End of the Cycles

The characteristics of the initial soil analyzed before cultivation and at the end of the cycles show that there has been a physical and chemical modification of the blocks. In **Table 2** Variation in soil pH (6.1 to 7.2). Mineral contents were increased compared to the control, namely calcium increased from 1,354 to 4,132; magnesium from 0.450 to 0.870; potassium from 0.096 to 0.365 cmol+/kg. Carbon and nitrogen recorded a significant increase from 1.02% to 2.77% and 0.12% to 0.26%, respectively. The C/N ratio is 10.65 indicating good mineralization. A variation in the cation exchange capacity (CEC) from 4.88 to 9.03 cmol+/kg and the sum of exchangeable bases from 2.05 to 5.48. Variation from sandy-clayey texture to sandy-clayey-silty texture. These analyzes showed that soil parameters such as pH, organic carbon, nitrogen, exchangeable bases and CEC recorded a significant increase where biofertilizer was added compared to controls. Improvement in soil parameters ground supported by **Figure 3**.

Table 2. Physical and chemical characterization of the soil before sowing and at the end of the cycles.

			Average values of analyzed soil parameters							
Analytics	Settings	F test (P-value)	Initial		Cycle 1		Cycle 2		Cycle 3	
Chemicals	C	0.000	**1.0**	±0.0	**2.87**	±0.0	**2.79**	±0.0	**2.77**	±0.0
	Nt	0.397	**0.13**	±0.0	**0.32**	±0.01	**0.29**	±0.0	**0.23**	±1.1
	Pass	0.000	**50.7**	±0.5	**70.0**	±0.6	**66.0**	±1.0	**64.0**	±1.0
	CEC	0.000	**4.20**	±0.1	**9.65**	±0.0	**9.13**	±0.0	**9.03**	±0.0
	Ca^{2+}	0.000	**1.4**	±0.1	**4.62**	±0.0	**4.35**	±0.0	**4.13**	±0.0
	Mg^{2+}	0.000	**0.45**	±0.0	**0.89**	±0.0	**0.88**	±0.0	**0.87**	±0.0
	K	0.000	**0.10**	±0.0	**0.40**	±0.0	**0.39**	±0.0	**0.37**	±0.0
	Na	0.006	**0.10**	±0.0	**0.11**	±0.0	**0.11**	±0.0	**0.11**	±0.0
Particle size	A	0.000	**8.83**	±0.0	**10.0**	±0.1	**10.0**	±0.0	**10.0**	±0.0
	Lf	0.000	**5.50**	±0.2	**22.1**	±0.4	**22.5**	±0.0^{c}	**22.5**	±0.0
	Lg	0.000	**5.77**	±0.1	**15.1**	±0.0	**15.0**	±0.0	**15.0**	±0.0
	Sf	0.065	**45.3**	±0.8	**46.0**	±0.10	**46.2**	±0.0	**46.2**	±0.0
	Sg	0.000	**33.2**	±0.0	**33.4**	±0.03	**33.1**	±0.0	**33.1**	±0.0

4.2. Growth Parameters

Overall, the blocks which benefited from the fertilizer application had good vegetation compared to the controls. The plants in the control blocks remained stunted with accentuated yellowing of the leaves.

4.2.1. Effect of Dose on Height as a Function of Cycle

Figure 4 shows the heights for each treatment depending on the cycle and fertilizer dose. In the first cycle, the average height (71.98 cm) recorded is significantly different between cycles (2 and 3) respectively (63.8 cm) and (64.02 cm). On the other hand, the heights obtained in the first cycle were very significantly ($P < 0.001$) higher than those in the second and third cycles. Same observation with the control (To) sees (Table 3)

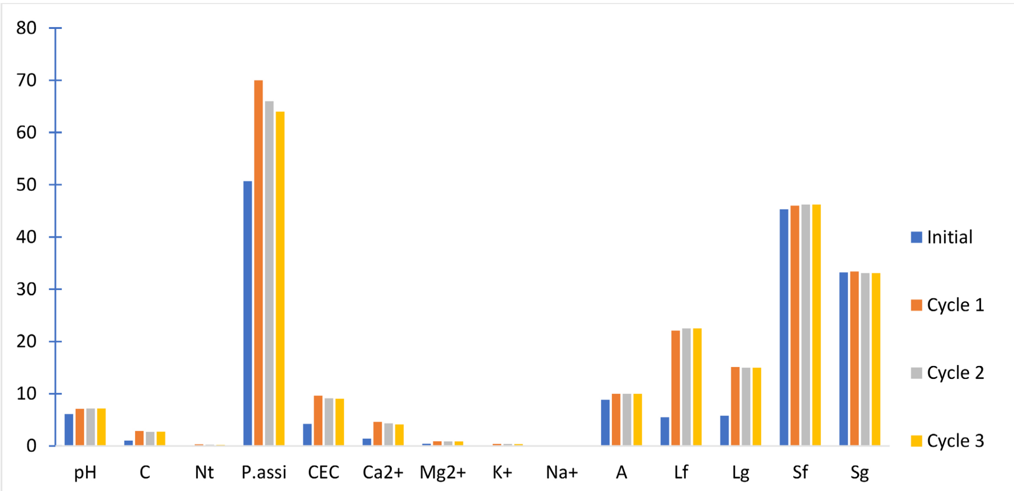


Figure 3. Variation of initial soil parameters depending on the cycles.

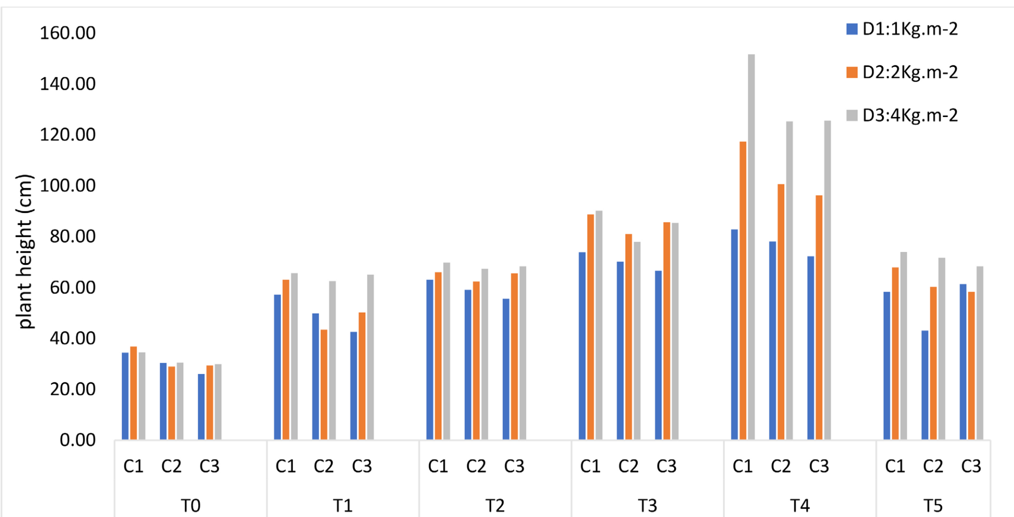


Figure 4. Effect of dose on plant height depending on cycle. T: treatment, C: cycle. Dose D1: 1 $Kg \cdot m^{-2}$ of fertilizer to the cultivated soil, D2: 2 $Kg \cdot m^{-2}$ of fertilizer to the cultivated soil and D3: 4 $Kg \cdot m^{-2}$ of fertilizer to the cultivated soil.

Table 3. Values of growth parameters according to treatments, and cycles.

Treatment	Yield (t/ha)	Height (cm) at end of cycle	Diameter (cm) at end of cycle
Cycle			
C1	25.981 a	71.98 b	3.23 c
C2	24.087 a	63.48 a	2.74 b
C3	23.540 a	64.02 a	2.51 a
Dose			
1 kg	10.400 a	56.92 a	2.31 a
2 kg	19.525 b	66.78 b	3.00 b
4 kg	43.683 c	75.77 c	3.16 c
Treatment			
T0	8.050 a	31.19 a	1.52 a
T1	14.465b	55.51b	2.11b
T2	17.697 c	64.14 c	2.83 d
T3	37.665 d	90.20 d	3.29 e
T4	51.176e	151.67e	4.73f
T5	18.163 c	62.58 c	2.47 c
P-value			
Cycle (*C*)	0.050	<0.001	<0.001
Dose (*D*)	<0.001	<0.001	<0.001
Treatment (*T*)	<0.001	<0.001	<0.001
$C \times D$	0.040	0.046	<0.001
$C \times T$	0.031	<0.001	<0.001
$D \times T$	<0.001	<0.001	<0.001
$C \times D \times T$	0.08	<0.001	<0.001

4.2.2. Effect of Dose on Diameter as a Function of Cycle Plant Diameters

Figure 5 shows the different diameters at the collar of the plants. At the cycle level, significant differences were observed (P > 0.001). The average diameter at the collar of plants from cycle 1 (3.23 cm) is significantly greater than the diameters of plants from cycle 2 (2.74 cm) and cycle 3 (2.51 cm).

4.2.3. Effect of Dose on Performance Depending on Cycle

Figure 6 shows the yields for each treatment depending on the cycle and the fertilizer dose. Regarding the cycle, no significant difference was observed in yield. On the other hand, the yields obtained at the dose of 4 kg (51.18 t/ha) were very highly significant (P < 0.001) than the doses (D2 (19.525 t/ha) and D1 (10,400 t/ha) and the control (Do) (Table 3) At the treatment level, significant differences were observed. The highest yields were obtained with the T4 treatment (51.176). t/ha) followed by treatment T3 (37.665 t/ha) Treatments T5 (18.163 t/ha) and T2

(17.697 t/ha) are not significantly different from each other. Treatment T1 (14.465 t/ha) is. followed by T0 (8,050 t/ha) which recorded the lowest yield.

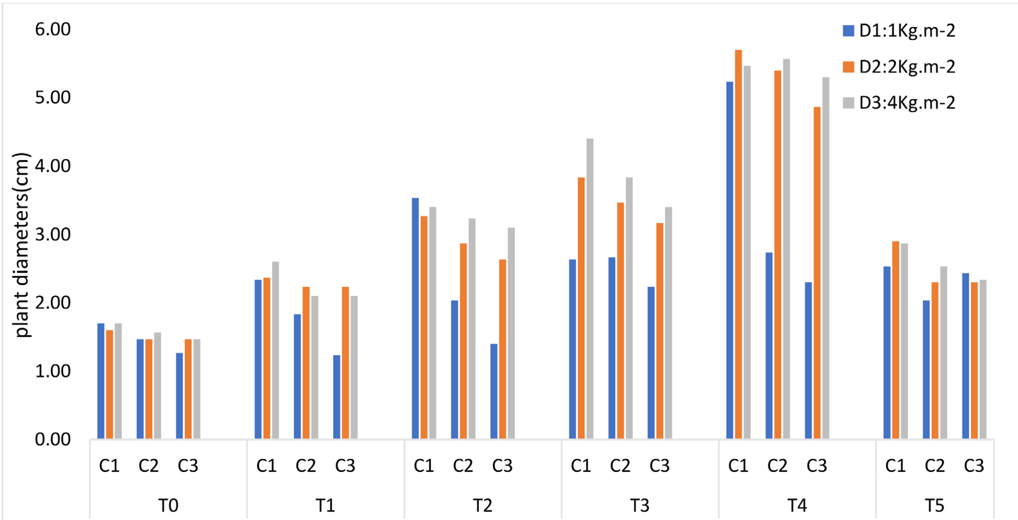


Figure 5. Effect of dose on plant diameter as a function of cycle. T: treatment, C: cycle. Dose D1: 1 Kg·m^{-2} of fertilizer to the cultivated soil, D2: 2 Kg·m^{-2} of fertilizer to the cultivated soil and D3: 4 Kg·m^{-2} of fertilizer to the cultivated soil.

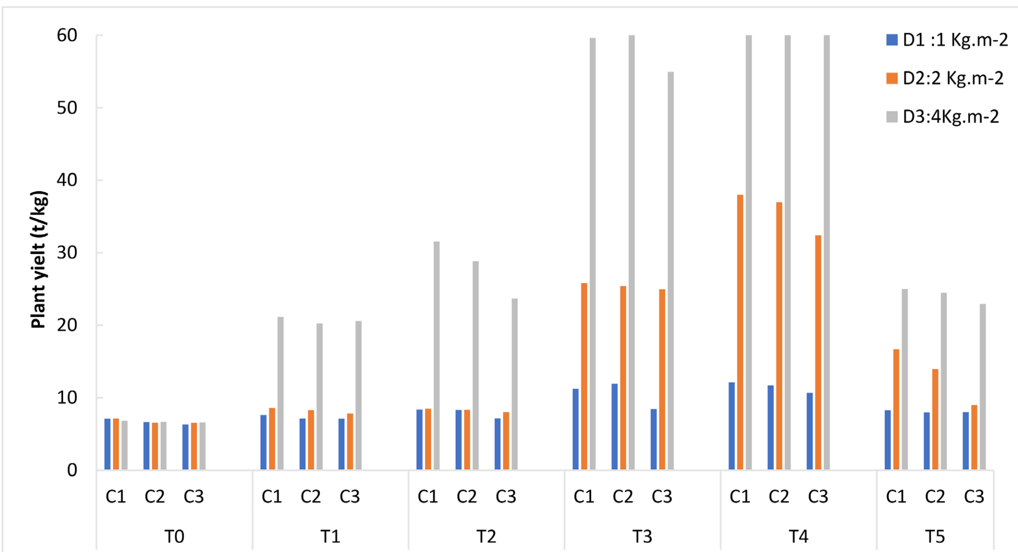


Figure 6. Effect of dose on plant yield as a function of cycle. T: treatment, C: cycle. Dose D1: 1 Kg·m^{-2} of fertilizer to the cultivated soil, D2: 2 Kg·m^{-2} of fertilizer to the cultivated soil and D3: 4 Kg·m^{-2} of fertilizer to the cultivated soil.

4.2.4. Comparison of the Yields Obtained with the Yield in the CNRA Technical Sheet

(Figure 7) the experiment used the hybrid eggplant cultivar (*Solanum aethiopicum* Gilo) N'Drowa developed by the CNRA (National Center for Agronomic Research), referenced Aub 21/06 Du "N'Drowa" Average yield 24 (t/ha). With the use of synthetic fertilizer (10-18-18).

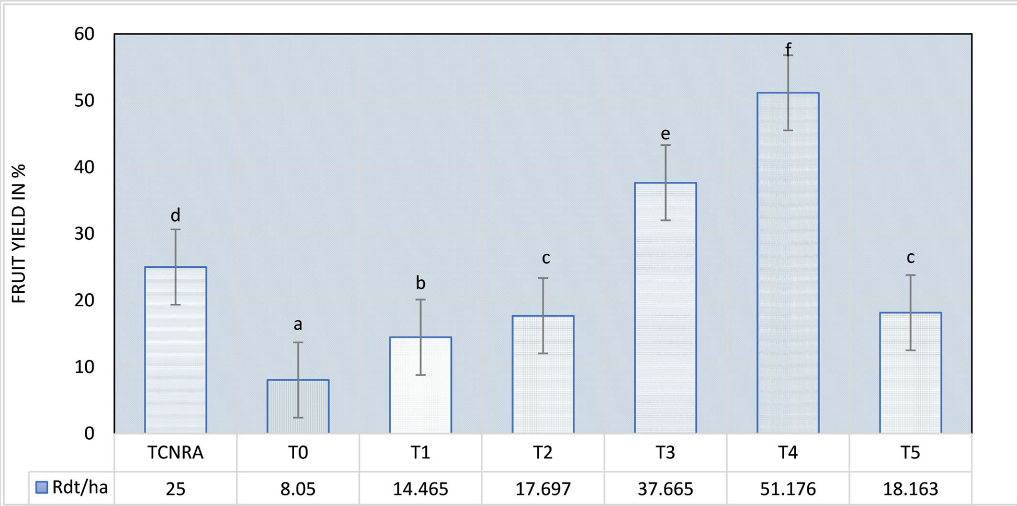


Figure 7. Comparison of the yields obtained with the yield per hectare of CNRA.

Specifically, cocoa husk substrates associated with moringa leaves rich in nitrogen, phosphorus and potassium stimulated the growth of plants giving better yields. However, comparing the yield of 24 t/ha indicated by the CNRA eggplant production technical sheet. We note that T3 (37,665 t/ha) and T4 (51,176 t/ha) have yields well above that of the CNRA and the control T0 (8,050 t/ha).

5. Discussion

The chemical characterization of the different formulations showed that the manures are rich in mineral elements and organic matter. However, fertilizers T3 (50% Coques/50% Moringa) and T4 (25% Coques/75% Moringa) recorded significantly better results than the other formulations. The respective C/N ratios (27.09 and 21.43) are in accordance with the theoretical ratios of between 20 and 30. Environment favorable to microorganisms which participate in the decomposition of the nutrient-rich substrate. Bacteria benefiting from a favorable aerobic environment could accelerate the decomposition of lignin [15]. The greatest improvement in the determined nutrients was achieved with T3 (50% C/50% M) and T4 (25% Coque/75% Moringa), rich in nitrogen and minerals characterized by a C/N ratio = 27.05 and C/N = 21.43. A C/N ratio between 20 and 30 is partly synonymous with good kinetics of decomposition of organic matter and therefore good mineralization of the substrate and good quality humus [16]. This finding is supported by studies by Muhammad Saleem [17]. The soil microbiome is a vital reservoir of microbial traits potentially relevant to plant growth and health. If properly managed, the soil microbiome can enable strong, resilient plant growth while reducing the need for agrochemicals. The high C/N ratios obtained by treatments T1 (37.70) and T2 (33.33) are outside the reference interval due to the large proportion of cocoa pods. In fact, the cocoa pod is rich in lignin, poor in nitrogen, and forms a rigid complex with proteins that are difficult for micro-organisms to degrade. Which then has the consequence of negatively affecting the availability of nutrients for the plant. Adding substances that promote decomposition will lower this ratio. Moringa leaves are rich in nitrogen and contain Zeatin, a growth-activating plant hormone that also facilitates the proper mineralization of substrates by micro-organisms. Thus, the moringa leaves, by decomposing quickly, will promote the decomposition of the cocoa pods, allowing the substrate to mature well. By digesting the substrate, the micro-organisms make available to the soil all the elements they contain, including the nitrogen released into the environment, promoting good decomposition of the carbonaceous material contained in the cocoa pods which are difficult to degrade. Thus, moringa leaves would have a dual action, facilitating the decomposition of cocoa pod husks and enriching the soil. These results are in the same direction as Fadeyi's [18]. Study where moringa leaves improved nitrogen, phosphorus and potassium (N, P, K).

A C/N ratio that is too low, less than 20, as is the case with T5 (16.66), leads to too rapid decomposition, allowing nitrogen to escape, which is therefore not available in the long term for the plant. Cocoa shells rich in carbon (51%), potassium (6%) and phosphorus (0.26 mg/kg) have a low nitrogen content (1.32%). The more the proportion of cocoa shell substrate increases, the more the C/N ratio is very high (37) there is a phenomenon of bulkiness of the substrate. As a result, decomposers do not find there all the elements necessary for their growth as well as sufficient humidity. The combination of moringa leaves and cocoa hulls improves nitrogen levels, facilitating the digestion of these substrates (in a ratio of 1/2 C to 1/2 M and 1/4 C to 3/4 M). Thus, the manure rich in organic matter would provide the microorganisms with nitrogen and carbon. These results are in accordance with Alexandre's studies which stipulate that exposure of organic matter to microorganisms accelerates mineralization [19]. In general, a nitrogen deficit involves a slow degradation process and an excess of nitrogen or a lack of carbon leads to significant losses of nitrogen C/N < 17.

Note also that the C/N ratio does not exclusively imply a slow or rapid degradation effect. When nitrogen is not limiting, it is more the biochemical characteristics of the residue which control its decomposition. The composite elements of organic matter do not decompose at the same rate. According to [20] the degradation of plants follows an order: protein > carbohydrates > cellulose > hemicellulose > lignin. Indeed, it is the biochemical structure of the molecules considered which determines the speed of decomposition and also the favorable environmental conditions (temperature, the presence of oxygen, presence of activator molecules, etc.). Moreover, cocoa shells made up of lignin and proteins form a rigid complex that is difficult to degrade by microorganisms. Which then has the consequence of negatively affecting the availability of nutrients for the plant. The incorporation of moringa leaves rich in nitrogen and zeatin, a growth-activating plant substance, facilitated the good mineralization of the substrates. Moreover, cocoa shells made up of lignin and proteins form a rigid complex that is difficult to degrade by microorganisms. Which then has the consequence of negatively affecting the availability of nutrients for the plant. The incorporation of moringa leaves rich in nitrogen and zeatin, a growth-activating plant substance, facilitated the good mineralization of the substrates [21]. The organic fertilizer made up in the soil degrades naturally. The decomposition of organic matter through which organic raw materials, such as crop residues (agricultural co-products) are digested by microorganisms. The fertilizer produced would be a means of recycling and restoring organic matter in the soil. This observation is in line with the studies of [22]. Indeed, soil organic matter plays an important role in the sustainability of fertility, and therefore for sustainable agricultural production [23]. In addition to being a source of nutrients for crops, it improves the biological properties of the soil. The results of analyzes of the state of the soil before and at the end of the study essentially took into account the absolute value of the different parameters, and the state of equilibrium of the clay-humic complex. Concerning, for example, organic carbon, the deficiency threshold retained after comparison with data from certain authors, was 1%, in reference to Boyer (1982).

The incorporation of organic fertilizer changed the chemical characteristics of the soil. The different doses had a significant influence on the chemical properties of the soil. The pH (6.1) before sowing experienced a variation at the end of the study, pH (7.2). The fertilizer rich in calcium induces the alkalizing environment, hence the variation in the pH of the neutral soil solution. The results obtained are in accordance with the studies carried out by [24]. It highlights the effect of the addition of different types of organic fertilizers on soil fertility and carrot production. The calcium-rich biofertilizer induced the alkalizing environment, hence the variation in the pH of the neutral soil solution. This observation confirms the observations made by [25] after the application of different types of compost for the cultivation of cabbage and amaranth. The neutral pH (7.2) is an asset for better root absorption of nutrients [26]. The saturation rate (V) of the exchange complex and the relationships between the exchangeable bases fixed there, influencing both the pH and by extension the biological and mineral functioning of the soil. The alkaline pH promotes the release of trace elements (Fe, Zn, etc.), facilitating the absorption of secondary elements by the plant, on the other hand an acidic soil causes a cessation of these elements. Respective threshold values of 5 - 8 cmol, kg^1 and 1.5 - 3 cmol+.kg^{-1}. The discussion was made on the basis of the relationships with the level of organic matter input by the fertilizer. The carbon rate provided by the biofertilizer is around (51%) by extension rich in organic matter (88%) or (M.O = %C × 1.72). The results of soil carbon analyze before fertilization were low (1.02%) and after application of the fertilizer at the end of the study the carbon rate was highly improved (2.77%), *i.e.* a gain of 63.18% carbon. The fertilizer raised the nitrogen content of the soil because before the implementation of the test its content was low (0.10%). After the application of the fertilizer the nitrogen recorded is (0.26%) or a gain of 61.53%. The carbon/nitrogen (C/N) ratio conditions the processes of mineralization or, on the contrary, reorganization of nitrogen in the soil. The organic matter/(clay + fine silt) ratio determines the relative richness of the soil in organic matter. A ratio lower than 7, in principle, reflects an increased sensitivity of the soil to erosion and by extension its poverty in organic matter, the main factor in the physical stability of the soil. In view of the above, the organic matter/(clay + fine silt) ratio is greater than 7 or even 14.86, confirming that our plot is abundantly supplied with humus to allow the plants to develop well. Organic matter would be the central element of the fertility state of a soil. Our results are consistent with the studies of [27]. These authors showed that organic matter largely controls the physical, chemical and biochemical properties of the soil and consequently influences the functional properties of the soil, such as the stabilization of aggregates. The organic matter added led to a structural reorganization of the soil. The silty clay complex, before (20.1%) and at the end of cultivation (47.04%), significantly improved, allowing significant immobilization of minerals. It improved the coherence of the structural elements and promoted the retention of useful water. The saturation rate of the CEC (cation exchange capacity) was calculated by excluding sodium, that is to say it was equal to: (Ca^{2+} + Mg^{2+} +K^{+}) * 100/CEC. In this way, it concerned the contribution of major nutrient elements to the saturation of the absorbent complex. The N PK element contents of organic fertilizers in the soil solution are in the N form; P_2O_5; K_2O complies with French Standards NFU 44,051 applied to organic amendments. According to this Standard, products whose content of each of the element's N; P_2O_5; K_2O (2.77%; 0.01%; 0.04%) is less than 3% and the sum of these elements is 2.82% less than 7% would be classified as organic amendments. This is justified by the reorganization soil chemistry and physics. The C/N ratio of the T3 and T4 formulations would be the ideal fertilizers because these substrates provide the soil with the nutrients necessary for soil balance. These two formulations open up a field of investigation into the state of decomposition of cocoa pods. These results would provide a solution to the decomposition of the cocoa pod which is rich in lignin and would delay its mineralization. The carbon obtained by the addition of fertilizers is generally around 50%, making it possible to modify the structure of the soil. Soil structure maintains its physical properties such as permeability, porosity and water retention capacity [28]. The aggregate structure is the most favorable because the ions are in the form of complexes, linked to clay and humus, thus preventing their leaching towards the deeper layers, making them available to plants this phenomenon is essentially favored by the richness of the plot in organic matter which can retain mineral elements in the surface layers and moisten the soil [29]. The conclusions drawn are in close conformity with the results obtained by [30]. These results reveal that adding organic matter to the soil would allow the plant to resist water deficit conditions. This result can be explained by the fact that organic fertilizers would correct the structure and acidity of the soil by providing nutrients such as calcium cations (Ca^{++}) and magnesium (Mg^{++}) to the plants. Thus, our manure has improved the organic characteristics of the soil and their fertility, while representing a sustainable path. The soil before the addition of the organic fertilizer has a clay-sandy texture devoid of organic matter, reduces the value of the contact angle of the sandy particles and increases the circulation of water carrying nutrients. This causes structural destabilization. The addition of manure changed the texture of the soil making it clayey-sandy. This modification is due to the carbon levels satisfying (2.77%) by extension the very high organic matter content (4.76%). Thus, the minerals incorporated into the organic matter under the action of decomposition of microorganisms form a complex of aggregates and clods. This transformation process favored by microorganisms immobilized the nutrients, allowing for the richness of the soil. Humic colloids increase the exchange capacity of the soil. This property makes organic matter (OM) in certain environments such as sandy soils, the main reserve of available bases (K^+ and Ca^{2+}) [31]. Calcium increases with the increase in the dose of organic matter provided by moringa (1.354 to 4.132 cmol/kg). This is justified by the fact that moringa is rich in calcium. A significant effect of the application of biofertilizer on the vegetative growth of plants. The height averages of the plants at flowering and at the end of harvest varied from (60 to 151.67 cm) compared to the controls (30 to 40 cm). There is a correlation between height, collar diameter and yield. The plants in the control blocks are stunted with accentuated yellowing of the leaves. In theory, yellowing of the blade is induced by an absolute or relative deficiency of either nitrogen or phosphorus, the difference being linked to the arrangement of the yellow streaks. On these control blocks the C/N ratio is low (8.5) associated with a carbon rate less than or barely equal to unity (1%). In this case, the yellowing could be caused by a nitrogen deficit. Overall, the test blocks had more or less a satisfactory level of nitrogen which would be the basis of green vegetation. We also note that there is an interaction between the richness of the soil in nutrients and the morphology of the plants, by extension the fruits. Attractive vegetation originates from the existence of good biological activity in the soil and is appreciated through the level of organic matter whose decomposition produces humus. Nitrogen thus promotes the use of carbohydrates, stimulates root development and activity, facilitating the export of mineral elements and plant growth [20]. The results obtained from the agro morphological tests indicate that there was a significant difference between the cycles affecting the height and diameter of the collar. This is explained by the fact that the nutrients immobilized in the first cycle were largely used by the plants. So, the available stock has decreased. Having no more supply after the harvest this had a progressive exhaustion effect on the two cycles to such an extent that the height and diameter at the collar were reduced. However, there was no significant difference between the returns of each cycle. On the other hand, regarding the treatments and doses, the results obtained showed a significant effect in terms of agronomic parameters. Treatments T3 and T4 had the best effects on eggplant growth parameters. In particular, the height and the diameter of the collar are important. This observation is due to the fact that the fertilizer contains nutrients directly assimilated by the plant which would have favored the growth and vigor of the recorded plants. Concretely, the cocoa shell substrates associated with moringa leaves rich in nitrogen, phosphorus and potassium stimulated the growth of plants giving better yields.

While at the level of treatments T1 and T2 the analyzes indicate a low yield due to the slow decomposition of the formulations produced due to the high percentage of lignin in the cocoa shell substrate. This means that the plants are not well supplied with nutrients. T1 and T2 formulations low in nitrogen release nutrients under the action of micro-organisms over a long period. The T5 treatment consisting solely of moringa leaf substrate quickly decomposed, leading to the rapid depletion of nutrients and even nitrogen. The application of organic fertilizer allowed an increase in the yield of the T4 plot compared to the control without fertilizer. This result is probably due to the direct accessibility of the nutrients N, P and K provided to the soil by the fertilizer. It is therefore very likely that the increases recorded for treatments T4 (51,176 t/ha) and T3 (37,665 t/ha) are due to the combined effects of the three elements N, P and K. Similar results were found. obtained in Ivory Coast on cassava [32]. These results showed that the highest yields were recorded by the additions of N, P and K. Furthermore, [33] reported that potassium contributes to the improvement of sizes, while a deficiency in K would result in a greater proportion of small calibers. The results of the T3 treatment are approximately equal to the T4 treatment. However, the fair proportion of substrates used makes the T3 treatment the ideal fertilizer for crops with a long production period. This formulation gradually releases, under the action of microorganisms, the nutrients assimilated into the soil solution which is used directly by the eggplant plants. Mixed formulations are presented as amendments for the structural reorganization of the soil. The yields recorded by T3 (37.66 t/ha) and T4 (51.176 t/ha) are significantly higher than the yields proposed by the CNRA technical sheet (24 t/ha). With the use of synthetic fertilizer (10-18-18). These results confirm that the use of organic fertilizer promotes the improvement of physicochemical parameters of the soil and environmental balance. These results were corroborated by those of Sorgog [34]. This author through these writings has encouraged the development of management strategies that support agricultural production while maintaining the conservation of biodiversity.

6. Conclusion

The results of the tests carried out during this study showed that the application of fertilizer had significant effects on the chemical parameters of the soil. Variation in level; soil pH (6.1 to 7.2), organic matter (1.75% to 4.76%), cation exchange capacity (4.2 to 9.03 cmol/kg), exchangeable bases (2.05 to 5.48 cmol/kg). Furthermore, this richness acquired by the soil had a considerable impact on the vegetative growth parameters of the plants, unlike the T0 control. Formulations T3 and T4 recorded the best mineralization allowing significant immobilization of nutrients. We recorded a considerable impact on the yield of harvested eggplant. The formulations made up are all rich in carbon and by extension in organic matter. However, the T3 formulation would be best indicated for long-term cultivation before entering production because mineralization occurs gradually. The T3 formulation could be the appropriate solution to solve the problem of decomposition of cocoa pods. Organic fertilizer would be one of the chemical soil improvement solutions proposed to compensate for nutrient losses and nutritional deficiencies observed in production systems.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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