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Research Article
Palm Stalks Compost Input in the Fertility Restoration of Degraded Soils in Côte d'Ivoire

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Abstract

Background and Objective: The Grand-Lahou area in the Ivory Coast is characterized by intensive use of land for agriculture. It is a location submitted to a high land pressure with poor soil in organic matter. The main research objective of this study was to question how to efficiently restore soil fertility of severely degraded sandy soils in the Grand-Lahou area using palm stalks compost. **Materials and Methods:** A small-scale composting trial was set up for the production of composts from palm stalks and poultry manure. The characterisation of the mature composts made it possible to define the agronomic potential of this material. The trials were conducted over 2 years from 2018-2019 in a randomized complete block design. Four doses of compost on the soil were tested, including: $D_0 = 0$, $D_1 = 10$, $D_2 = 20$ and $D_3 = 40$ t ha^{-1}. **Results:** At the end of this study, the application of compost to the soil gave satisfactory results by increasing the value of the pH, the total carbon, the total nitrogen, mineral nitrogen, labile carbon and this increase depends on the dose of compost applied with higher values under the D_3 dose which was identified as the best one. **Conclusion:** Study suggested that the D_3 dose could be recommended to farmers to restore efficiently soil fertility and increase the yield of vegetables in their area conditions.

Key words: Compost, palm stalks, poultry manure, soil fertility, organic matter, crop productivity

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tropical soils are known for their fragility and their poverty in organic matter[1]. Indeed, due to their geographical position, these soils are exposed to harsh climate conditions where rainfall is an important agent of their degradation[2]. The consequence of this degradation is the loss of their fertility level[3]. The soils of Côte d'Ivoire belong to this group of tropical soils, including the south-west region, in particular, the locality of Grand-Lahou, which is under strong land pressure. This region is located in the forest zone and is home to vast industrial orchards of oil palm, rubber and cocoa. These orchards permanently occupy almost all of the arable land to the detriment of food crops relegated to marginal soils, unsuitable for agriculture[4-6]. These marginal soils, which are predominantly sandy and poor in organic matter are used for food crop production without the possibility of crop rotation and in the absence of mineral fertilizers. These essentially sandy soils are also hydromorphic in the shallows. They have a high proportion of sand on the surface and low clay content. Because of the high pressure on those lands, there is no possibility for implementing fallowing to restore soil fertility[7].

Yet, fallowing remains the main mechanism for natural soil fertility restoration. Therefore, this mechanism for soils fertility restoration can no longer be practised in the current context in this area. Consequently, this inappropriate farming practice on soils for food production in this area leads to permanent degradation of the soil organic matter, leading to the loss of crop productivity and nutritive elements essential to good plant growth.

It is hence necessary to adopt a good farming practice such as rotation with amendments and fertilization to restore and maintain the fertility level of these degraded soils to obtain better food crop yields. In the case of this paper, an amendment of sandy soils, poor in organic matter, with bad physical and chemical properties was performed using palm stalks compost.

The objective of the paper was to assess the conditions to restore the fertility of the severely degraded sandy ferralsols employing palm stalks compost to re-establish its food production function.

MATERIALS AND METHODS

Study area: The study was carried out in N'gorankro 1 a rural locality about 10 km away in the town of Grand-Lahou from 2018-2019. The geographical coordinates of the study site are 5°19'59'' north latitude and 5°1'39'' west longitude. According to, the zone is characterized by a humid equatorial climate and an average rainfall varying between 1500 and 2000 mm per year. The region is characterized by 4 alternating seasons (2 dry and 2 rainy). The trials took place on a site where cocoa, oil palm and cassava have been previously cultivated. The soils of the study site are generally ferralsols.

Study materials

Compost production: The material used in the study was compost made from the composting of palm stalks combined with poultry manure, both of which are available in the study area. The composting method consisted of making composting piles in an ambient environment as described by Gnimassoun *et al.*[5]. The composting process lasted 6 months (181 days). The mature product at the end of the composting process was applied during the trial for 2 years. The compost contained 21.3% carbon, 1.48% nitrogen, 0.63% phosphorus and 1.99% potassium.

Methodology

Application of compost in the trials: The elaborated compost was applied in 4 doses (D): control D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}. This corresponds to a multiplier coefficient of 2 per applied dose. The compost was applied to the ridges in the first 20 cm of depth (Fig. 1). These ridges were prepared for the cultivation of 2 vegetables that are pepper and eggplant. The compost doses were applied twice to the ridges at the beginning of each crop cycle. The evolution of the physical and chemical parameters of the soil was monitored. Soil samples were taken at the beginning of the experiment and again 4 months later at the end of the planned vegetable crop cycles. The purpose was to determine the chemical and physical characteristics of the soils before compost application and to monitor the level of nutrient evolution in the soil after the compost input. The monitoring of the evolution of the physico-chemical properties of the soils of the site aims to assess the process of restoration of the fertility of these soils.

Physico-chemical characterisation of the soils: Before and after installation of the experiment, soil samples were collected and the preparation operations consisted of open air-drying for 72 hrs and sieving on a 2 mm sieve for routine chemical analyses for the estimation of soil fertility. Thus, pH water and pHKCl were determined on an aqueous extract in a ratio of 1/2.5. The dosing of total carbon and total nitrogen by the CHN analyser was done in a laboratory. The method is based on the simultaneous determination of C_{total} and N_{total} by total dry combustion under Oxygen (O_2) with pure helium

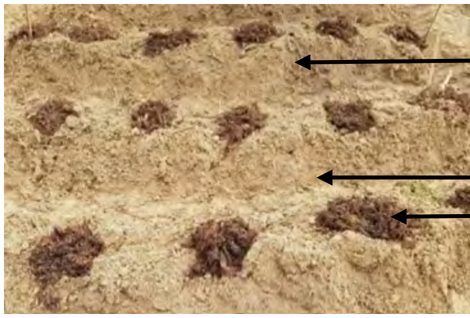

Fig. 1: View of compost sample applied on sandy ridges

as carrier gas. The labile carbon dosing was carried out by the potassium permanganate, a method called POxC (Permanganate Oxidizable Carbon) and the mineral nitrogen dosing by colourimetry on a continuous flow analyzer (SKALAR) using the Berthelot method for the dosing of $N\text{-}NH_4^+$ and the Griess and Ilossay method for the dosing of $N\text{-}NO_3^-$. The assimilable phosphorus dosing was done by OLSEN extraction. The extraction was performed by colourimetry after forming a phosphomolybdic complex associated with malachite green. The reaction was then fixed with Polyvinyl Alcohol (PVA) and the absorbance was measured at 630 nm. The ammonium acetate method at pH 7 was used to determine the levels of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+).

The CEC was determined by the cobalt hexamine method by measuring the cobalt cations present in a solution after filtration by spectrocolorimeter at the wavelength of 475 and 380 nm.

The organic matter (OM) content was calculated by multiplying the carbon content by a coefficient that is stable in cultivated soils:

$$OM = C \times 1.72$$

The plant usable reserve (AW) was obtained by subtracting the amount of water at the wilting point from the amount of water at field capacity according to the following formula[8]:

$$AW = \frac{FC\text{-}PWP}{RZ} \times 100$$

Where:

AW = Available water (in)
FC = Field capacity (%)
PWP = Permanent wilting point (%)
RZ = Depth of root zone (in)

Statistical analysis: Data collected were processed using R software version 3.6.1. Normality tests were used to perform parametric statistical tests. If normality was met, the variants studied were compared by a fixed-factor ANOVA.

Comparisons of averages were made at the p = 0.05 threshold using the Student-Newman-Keul test. In the case where normality is not respected, the non-parametric Kruskal-Wallis test was used to compare the variables.

RESULTS

Initial physico-chemical characterization of the soil of the site: The results of the analyses of the physical and chemical parameters of the soil at the study site were given in Table 1. The data obtained show that the soil has a grain size dominated by sand. The texture of the soil is sandy-silty with a content of over 77% sand and 13.30% silt. A low clay content (9.5%) was noted. The soil is strongly acidic characterised by a pH<4.5 (pH = 4.42). The total organic carbon and total nitrogen contents, respectively $\leq$1 and $\leq$0.1%, indicate very low contents. However, the C/N ratio that reflects the state of mineralisation of the organic matter is high (13.67) in this soil indicating a high risk of carbon loss in this sandy soil. The organic matter content of the soil is very low (1.38%). Assimilable phosphorus and total phosphorus contents, respectively <0.03 and <0.5%, indicate that the soil is very deficient in phosphorus. Exchangeable base contents (Ca^{2+}, Mg^{2+}, Na^+, K^+) are also very low in the soil. The CEC value is below 5 $cmol^+$/kg, which is low. Indeed, when the soil has a CEC<5 $cmol^+$/kg, it is considered very poor and when the CEC is between 5 and 10 $cmol^+$/kg, the soil is considered poor in exchangeable bases. Overall, this type of soil has a low level of fertility.

Effects of compost in improving soil fertility: The results of the evolution of the various chemical parameters (pH, carbon,

Table 1: Physico-chemical characteristics of the soil in the 0-20 cm horizon

Parameters	Values
Clay (%)	9.5
Silt (%)	13.3
Sand (%)	77.15
pH_{water}	4.42
pH_{KCl}	3.83
C_{tot} (mg kg^{-1})	8030.25
C_{lab} (mg kg^{-1})	508.83
N_{tot} (mg kg^{-1})	588.59
N_{min} (mg kg^{-1})	8.35
P_{tot} (mg kg^{-1})	9.81
P_{ass} (mg kg^{-1})	0.87
C/N	13.67
MO (%)	1.38
CEC (cmol$^+$/kg)	2.91
Ca^{2+} (cmol$^+$/kg)	0.52
Mg^{2+} (cmol$^+$/kg)	0.41
K^+ (cmol$^+$/kg)	0.06
Na^+ (cmol$^+$/kg)	0.07

nitrogen) obtained after soil amendment are described below. The result of Fig. 2 shows the evolution of pH in the soil according to the doses of compost applied. These trends were also observed with the different forms of carbon (Fig. 3) and nitrogen (Fig. 4). The analysis of these results shows that the compost inputs had a positive effect on soil fertility through the increase in soil nutrient levels.

Effect of composting on the evolution of soil pH: Compost inputs increased the pH of the soil (Fig. 2). The soils in the plot were described as strongly acidic. After 2 cropping seasons with a double organic amendment, the pH of the soil increased by an average of 1.81 pH units with the application of 3 doses. The soils changed from strongly acidic (pH<4.5) to medium or weakly acidic ($5.5 \leq pH \leq 6.5$). Despite the increase in pH, there was no significant difference between the doses applied at the threshold $\alpha = 0.05$.

Effect of compost on total carbon (C_{tot}) and total nitrogen (N_{tot}): The results obtained for the total carbon in year 1 indicate an increase in the contents ranging from 0.82% with D_1 and D_2 to and 1.02% with D_3 compared to the D_0 control. The same trend was obtained in year 2 with an increase ranging from 1.13, 1.15 and 1.21% of the contents with the same doses, respectively (Fig. 3). However, in any given year there was no significant difference between the treatments.

The total nitrogen contents show the same trend as the total carbon contents in both years under the different crops. Indeed, the results show an increase ranging from 573.10, 641.48 and 712.95 mg kg^{-1} with treatments D_1, D_2 and D_3, respectively compared to control D_0 (514.40 mg kg^{-1}) in year 1 and 756.25, 748.66 and 817.93 mg kg^{-1} with the same treatments in year 2 (Fig. 4). However, in any given year, no significant differences between the rates for total nitrogen were observed.

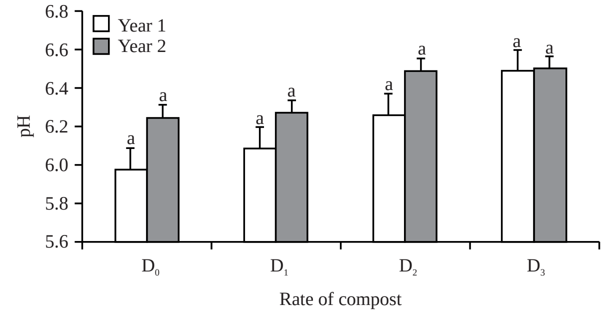

Fig. 2: Evolution of the pH of the soils after compost application in the experimental years (2018 and 2019) in the 0-20 cm horizon

D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}, data affected by the same letter do not differ significantly at the 5% level according to Newman-Keuls test

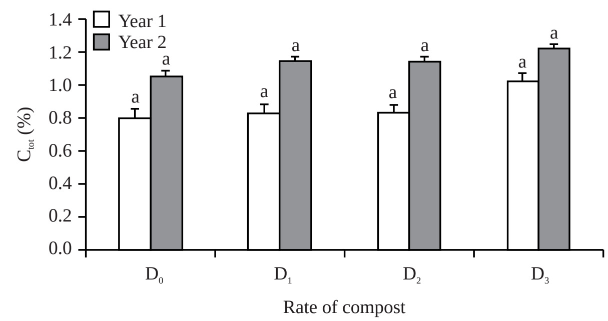

Fig. 3: Evolution of the total carbon in the soils during the 2 experimental years

D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}, data affected by the same letter do not differ significantly at the 5% level according to Newman-Keuls test

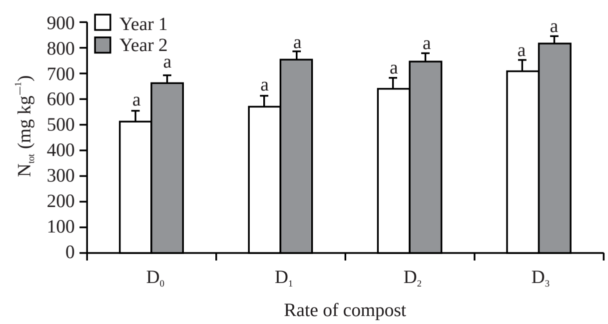

Fig. 4: Evolution of the total nitrogen in the soils during the 2 experimental years

D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}, data affected by the same letter do not differ significantly at the 5% level according to Newman-Keuls test

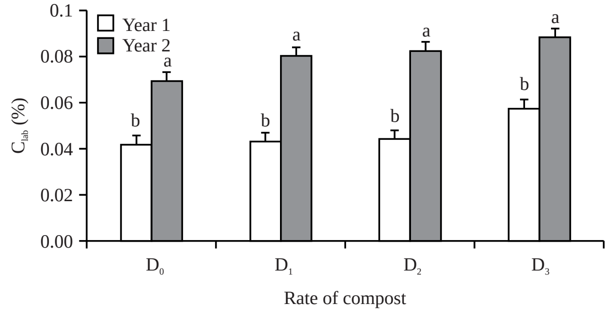

Fig. 5: Status of the labile carbon in the soil during the 2 experimental years

D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}, data affected by the same letter do not differ significantly at the 5% level according to Newman-Keuls test

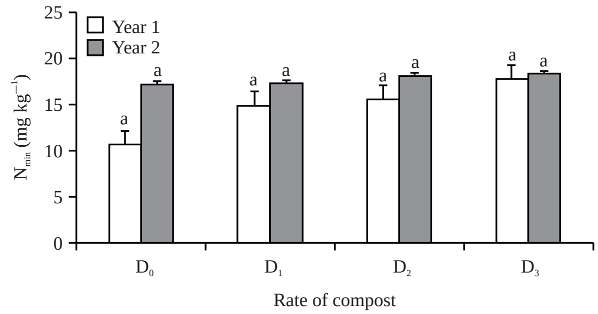

Fig. 6: Mineral nitrogen status in the soil during the 2 experimental years

D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}, data affected by the same letter do not differ significantly at the 5% level according to Newman-Keuls test

Table 2: Average values of the AW as a function of the compost doses in the 0-20 cm horizon

Treatments	AW (mm m^2)
D_0	1.00^a
D_1	0.84^a
D_2	0.71^a
D_3	0.70^a

D_0: 0, D_1: 10, D_2: 20 and D_3: 40 t ha^{-1}, data assigned the same letter on the same column does not differ significantly at the 5% threshold (Newman-Keuls test)

Effect of compost on labile carbon (C_{lab}) and mineral nitrogen N_{min}: The results obtained indicate that the addition of compost to the soil improved the labile carbon content with contents ranging from 0.04% with D_1 and D_2 and 0.06% with D_3 in year 1 and 0.08%, with treatments D_1, D_2 and 0.9% with D_3 in year 2 compared to the control D_0 (Fig. 5). There was a significant difference in year 1 between the labile carbon content obtained with D_3 compared to D_0, D_1 and D_2. However, in year 2, there was no significant difference between the treatments.

The results of the evolution of mineral nitrogen (N_{min}) in the soils during the 2 years are shown in Fig. 6. The results obtained for N_{min} indicate an increase of 14.99 mg kg^{-1} with D_1, 15.67 mg kg^{-1} with D_2 and 17.87 with D_3 in year 1. In year 2, an increase of 18.21 mg kg^{-1} and 18.41 mg kg^{-1} was observed with D_2 and D_3 compared to the D_0 control.

Effect of compost on the useful water reserve (AW) of the soils: The effect of compost on the soil water AW was presented in Table 2. The recorded values show that the D_0 dose has the highest value with 1.00 mm/m^2 of the depth of water available compared to the D_1, D_2 and D_3 doses with the lowest value obtained with the dose D_3 (0.70 mm/m^2). Nonetheless, no significant difference was observed between the doses.

DISCUSSION

The result of the study helps to evaluate the efficiency of palm stalks compost in the process of restoring the fertility of sandy ferralsols poor in organic matter. The soil of the experimental site before the amendment was qualified as strongly acid soil with a pH = 4.4. While it is accepted that most plants grow well at pH values between 5.5 and 8.5[9,10], the work of Brady and Weil[11] places the pH water range from 5.5-6.5 for good agricultural soils. Nevertheless, the current pH of the soil at the experimental site cannot ensure the good production of the crops. The pH of the soil is described as highly acidic. Then the soil needs to be amended to bring the pH back to the appropriate proportions to allow it to function properly. In fact, according to Brady and Weil[11], the pH is an important parameter that conditions a large number of chemical and microbiological reactions in the soil. The low pH values in soils limit plant growth by decreasing the bacterial activity especially that of nitrification and the slowing down of the mineralisation of organic matter, the phosphorus deficiency, the aluminic and manganic toxicity, the excessive increase in heavy metal availability, the deficiency of essential elements (Ca, K, N, Mg, Mo, P, S)[12]. It could present risks of aluminium toxicity for vegetable crops. Organic amendment in the form of palm stalks compost combined with poultry droppings led to an effect on the pH of the soil. It resulted in an increase in the initial pH of the soil from strongly acidic soil to medium or weakly acidic with the D_1, D_2 and D_3 doses during both crop years. The increase in soil pH in the amended soils is thought to be due mainly to the initial pH of the compost, which was 8.83.

After 2 years of cultivation, although no statistically significant differences were found between the doses for the elements analyzed, variations were observed between the different doses. Compared to the initial soil nutrient values, the overall trend shows an increase for the majority of the measured chemical elements such as C and N which could be attributed to the incorporation of the compost into the soil.

Before the application of the compost, the soil chemical results indicated a highly acidic soil, poor in nutrients and organic matter, not efficient for good agricultural production. These results are in line with those[12,13], who showed that the compost input to the soil increases the soil nitrogen, potassium, phosphorus, carbon and exchangeable base levels.

The useful water reserve of the soils is an important parameter for the water nutrition of the plants. The Available Water (AW) of a soil, often referred to as "useful reserve", represents the maximum amount of water that the soil can hold and return to the roots of plant life.

The AW value depends on several characteristics of the soil such as texture. The AW of a clay soil horizon is about 1.7 mm cm^2 of soil, that of a clay-silt soil horizon about 2 mm cm^{-1} of soil and that of a sandy soil about 0.7 mm cm^{-1} of soil[8,14]. In the case of this study, the results of the laboratory analysis of these soils parameter showed that the doses gave the same AW with values between 0.70 and 1.00 mm/m^2. This AW of the site soil is consistent with the values found in previous studies. The compost used in the present study improved the useful reserve of the soil. However, according to the statistical analysis, these compost rates do not conserve water in the soil compared to the D_0 control. It appears that the rates used did not improve the water holding capacity of the soil. Indeed[15], who used urban compost also obtained insignificant results based on the low quantity of compost applied. According to Tan[16], the soil texture has a direct influence on moisture levels because sandy soils have low water retention capacities and soils with a high proportion of fine particles (silts and clays) store more water. Nonetheless, Carvalho *et al.*[17], point out that green manures improve the soil structure and increase water infiltration into the soil. As for the work of Widowati *et al.*[18], they showed that for sandy and clay soils, compost has a very important effect in improving water retention, especially in sandy soils. And that this was probably related to the fact that the physico-chemical conditions (aeration, permeability) of the sandy soil are more favourable for the humification of organic matter (compost). In his study, Yu *et al.*[19] demonstrated that organic matter significantly increases the retention capacity of the soil and subsequently its useful reserve. Furthermore, he shows that the increase in soil water retention with organic matter content is greater at field capacity than at the wilting point. Also, Foley and Cooperband[20] showed that the intensity of the effect of the compost on this water retention depends on the dose applied to the soil and its degree of humification. This means that the retention capacity increases with the applied dose. This result was confirmed by the studies of previous research[20,21] that demonstrated that to obtain an effect, it was necessary to apply high proportions of compost enriched with chicken droppings to observe significant effects on the improvement of the physico-chemical properties of the soil. In the present study, the water retention capacity was almost non-existent. This could be related to the insufficient doses of compost applied and which shows the importance of these high proportions in the rapid improvement of the fertility of the sandy soils of the site.

CONCLUSION

The present study was initiated to assess the effect of palm stalks compost on the improvement of sandy soil fertility in Grand-Lahou. The trial consisted of the application of 4 doses of compost in the restoration process of the physico-chemical fertility of sandy soils. The use of palm stalks compost on sandy soils improved the pH, carbon and nitrogen contents of the soil and the use of available water. The fertilised treatments with the dose D_3 significantly increased the levels of soil organic matter compared to the other treatments and the unfertilised control. Under the conditions of this trial, palm stalks compost has a high potential to improve soils nutrient availability and can provide the necessary nutrients to the crop. Still, to maintain the soil nutrients in the sandy-textured soil, mulching of the mounds or seedbed ridges should be considered early in the planting cycle to avoid exposure of soil and leaching by water erosion.

SIGNIFICANCE STATEMENT

The study shows that the compost-based palm stalks combined with poultry manure contributed to the restoration of the chemical fertility of the soil in a proportional way to the doses brought by the improvement of the pH, the increase of the carbon contents and nitrogen. Thus, the recycling of these organic matter must be encouraged for use as an amendment for poor soils because this practice could be an alternative to synthetic fertilizers which, due to their high cost are not accessible to producers.

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