



Integrated Soil Fertility Management for Small Holder Cocoa Farms: Using Combination of Cocoa Pod Husk Based Compost and Mineral Fertilizers

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Authors' contributions

This work was carried out in collaboration between both authors. Author SBO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author MOO monitored and supervised the study, managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Nutrients are being removed through pod harvest without replacement in the form of fertilizer application leaving the soil impoverished and the nutrients grossly inadequate for optimum cocoa yield. To address this issue, a randomised complete block designed study was carried out to examine the effects of readily available source of organic fertilizer like cocoa pod husks compost combined with mineral fertilizers on the yield of cocoa. The treatments with three replications consisted of Compost (100%), Compost (75%) + NPK (25%), Compost (50%) + NPK (50%), NPK (100%) and Control (no fertilizer). Results indicated that cocoa yield obtained with the compost plus NPK fertilization was significantly higher than with sole compost, NPK applications, and control in all locations. Percentage dry cocoa bean yield gain was 72.4% with the compost plus NPK fertilization, while sole compost or NPK alone was 36.4% compared to the control. Additionally, compost plus NPK fertilization significantly reduced black pod losses compared to sole compost, NPK, or control with percentage loss rate ranging from 9.9 to 13.4%, 21.6 to 23.1, 19.6 to 22.3,

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32.2 to 35.5, respectively, in all locations. The use of CPH-based compost plus NPK fertilization has the potential to provide efficient integrated soil fertility restoration scheme that incorporated good agricultural practices and addressed disease management.

Keywords: Compost; cocoa pod husks; soil fertility; NPK; fertilization.

1. INTRODUCTION

Cocoa production is the main source of income to millions of smallholder farmers in Africa [1]. However, in the past 3 decades, cocoa production has witnessed a downward trend because of pests and diseases, ageing trees, climate change [2,3] and most importantly, falling soil fertility.

Nutrients are being 'mined' through pod harvest without replacement in the form of fertilizer application. For instance, harvest of 1000 kg dry cocoa beans removed 20 kg nitrogen, 4 kg phosphorus and 10 kg potassium from the soil [4] leaving the soil impoverished and the nutrients grossly inadequate for optimum cocoa yield.

Furthermore, there is a dearth of virgin forest land to be opened up for expansion. Hence the need to fertilize the soil for improve production. The first option available to farmers is inorganic fertilizers. However, the continuous application of inorganic fertilizers like NPK leads to decrease in the soil pH through acidification [5], causes formation, accumulation and concentration of mineral salts which leads to soil compaction in the long-term, decrease in soil porosity due to high compaction, decrease in organic carbon level [6] as well as decrease in soil beneficial microorganism populations [7]. Also, these inorganic fertilizers are scarce, costly and beyond the reach of small scale farmers.

The second option is the use of organic fertilizers in form of plant materials and animal manures. Organic fertilizers enhance soil fertility by increasing nutrient availability [8], soil organic carbons [9], available N and P, micronutrients, soil aggregation, and water holding capacity, as well as leading to a high soil buffering capacity against external disturbances [10] when added to soil. The major limitations to the use of organic fertilizers are their low nutrient level which is the reason why several quantities are required to effectively cover a large area when used alone.

Hence, this research work was designed to examine the effects of the compost of readily available sources of organic fertilizer like cocoa

pod husks (CPH), and CPH compost fortified with mineral fertilizer to avoid bulkiness on the yield of cocoa. CPH is annually being generated in large quantity on cocoa farms in south west Nigeria. Unfortunately, the CPH scattered on the farm can harbour and pre-dispose spread of black pod disease caused by *Phytophthora* spp. inoculum [11]. Soil-borne *P. megakarya* can survive in soils and infected debris for months to several years, causes root infections, thereby maintaining a reservoir of inoculum releasing zoospores that can infect other parts of the plant through water splashing from the soil to the foliage [12]. Therefore, to avoid the disease further emphasizes the use of CPH compost. It is hoped that the CPH-based compost and mineral fertilizers combination will provide a suitable option in integrated soil fertility management with reduced compost bulkiness, increase in cocoa yield and disease incidence for small holder farms.

2. MATERIALS AND METHODS

2.1 Site Selection

Ondo and Osun States were purposively selected for the study based on the fact that the two States are high cocoa producing States in south west Nigeria. From each of the selected States, two cocoa producing Local Government Areas (LGAs) were randomly selected thus making four LGAs selected for the study. In each of the selected LGA, one community was randomly selected. Therefore, a total of four cocoa communities of Soko (7.1782°N, 4.9905°E, Ondo State), Ipinlerere (7.1734°N, 5.0402°E, Ondo State), Ode-Omu (7.5406°N, 4.4028°E, Osun State) and Koola (7.9189°N, 4.8130°E, Osun State) were selected for the study.

2.2 Selection of Farmers and Administration of Questionnaires

Cocoa farmers were selected with the assistance of community heads and World Cocoa Foundation/Cocoa Livelihood Program (WCF/CLP) farmers' field school facilitators in the selected communities. The questionnaires were

structured to assess the current level of farmers' awareness and understanding of composting practices for soil fertility, pest and disease management in the study areas. These were administered to the participating farmers in each of the selected locations with not less than 30 farmers (respondents) per location. The questionnaires were distributed to the selected farmers for filling.

2.3 Soil Samples Collection

Soil samples at the depth of 0 – 20 cm were collected with the use of soil auger from selected cocoa farms in each of the communities after removing all leaf litter on the soil surface. The core augered samples per location were bulked into composite in order to have a representative sample for each of the location. Each composite soil sample was air-dried, ground, sieved through 2-mm sieve and analyzed for their chemical and physical properties. Particle analysis was determined using the hydrometer method [13]. Organic carbon content determination was by the potassium dichromate oxidation method [14]. The total nitrogen (N) was determined by Kjeldahl method; available P by ammonium-vanadomolybdate colorimetric method; exchangeable K and Na by flame photometer; and exchangeable Mg, Ca and Mn were by atomic absorption spectrophotometer [15]. Soil pH was read in soil-water suspension at the ratio of 1:1 using pH meter.

2.4 Experiment to Determine Effects of CPH Compost on Cocoa Yield

2.4.1 Training on composting

Farmers' participatory training on composting was carried out in the selected cocoa farm locations. Farmers were practically trained, using the illustrative manual on the procedure of setting up, watering, turning, curing and drying compost. Participating farmers were involved in the procurement and processing of compost raw materials. Cocoa pod husks, poultry droppings and *Chromolaena odorata* and/or *Glyricidia sepium* were collected, and separately chopped into smaller pieces to increase the surface area of the organic material for quick decomposition. The materials were then properly mixed to homogeneity to make the ratio 2:1 of Cocoa pod husks: Poultry droppings and leaves of *Chromolaena odorata* respectively, after which the materials were packed into the compost box 1.5 m by 1.5 m made with wooden planks. Watering of the compost was done every other

day to keep the compost moist during the composting period. Turning of the compost was also carried out once in a month to ensure uniform decomposition of the compost materials. Materials at the top of the box went to the bottom of the box each time the turning was carried out. Matured compost gotten at 8-10 weeks, when the temperature of the compost became similar to that of the ambient, in each of the locations was air-dried and kept for application on cocoa. Matured compost was subjected to chemical analysis to determine some of its nutrient contents.

2.4.2 Weeding of selected cocoa farms

Cocoa farms selected for the participatory study were cleared of weed in readiness for the compost application to cocoa trees.

2.4.3 Experimental design

Five treatments were laid out in Randomized Complete Block Design with three blocks. Each treatment was administered to 10 cocoa trees in each of the block. The treatments with three replications consisted of Compost (100%), Compost (75%) + NPK (25%), Compost (50%) + NPK (50%), NPK (100%) and Control (no fertilizer).

2.4.4 Fertilizer application

Prior to fertilizer application, all ripe pods on cocoa trees in the selected farms were harvested and green pods counted. This was done so as to have a true picture of the effects of the fertilizers on the cocoa trees. Farmers were practically trained on the ring method of fertilizer application around the cocoa trees. The rates of fertilizer application per cocoa tree which were based on the result of soil test and nutrient content of the compost included: 4 kg compost, 3 kg compost + 100 g NPK, 2 kg compost+ 200 g NPK, 400 g NPK and the control where no amendment was applied.

2.4.5 Data collection and analysis

Data were collected on cocoa flowers, cherelles, pod productions and disease expression. Healthy pods were separated from black pods indicating pod rot during data collections. Two types of yield were considered: potential yield (total of healthy and rotten pods) and actual yield (healthy pods only). The estimation of yield losses caused by black pod diseases was determined by the difference between the potential yield and actual yield.

All data collected were subjected to analysis of variance using Statistical Analysis Software (SAS). Significant means were separated using Least Significant Difference (LSD) at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Questionnaires Results

Results from the analyses of the questionnaires showed that 56% of the cocoa farmers were 50 years and above, 77% of the farmers were male while 23% were female. The male dominance in cocoa farming may be attributed to the fact that males often have resources including land and other properties by inheritance [16,17]. However, women play significant roles in cocoa farming. For example, while men are focused on land preparation and pesticides and fertilizers application, women are mainly involved in the treatment of new plants, weeding and post-harvesting handling [18,19]. All the cocoa farmers (100%) had acquired knowledge on Good Agricultural Practices (GAP) through Farmer Field School (FFS) training previously organized and executed by WCF/CLP. For instance all the farmers (100%) do not use cocoa pod husks generated on their farms.

More than 200 cocoa farmers had had training on production of cocoa pod husks based compost and its applications on cocoa. However, none of the farmers previously applied any other organic or inorganic fertilizers on their cocoa farms. This is in agreement with previous reports that most farmers do not use fertilizer [20] due to farmers' rational perception of high risks of failure

with no response [21], high fertilizer costs, unfavourable weather conditions and low cocoa market prices [22].

3.2 Nutrient Content of Compost

The compost was safe for use and of high quality with no heavy metals (Table 1): The C/N ratio ranged between 16.46 and 24.4 which has been reported not to be more than 30 [23]. The pH of the compost was slightly alkaline ranging between 8.2 and 8.7 and was ideal for the slightly acidic soil of the selected sites. This confirmed the previous report that ripe compost usually has pH value which approaches neutral [24].

3.3 Soil Fertility Status of the Sites

Soils of the selected cocoa farms were slightly acidic to near neutral with pH ranging from 6.4 - 6.7 (Table 2). Organic carbon content of the soils was low below 3%. Exchangeable potassium was grossly inadequate in selected sites below the critical value of 0.3 cmol/kg. Available phosphorus (P) of the soils was below the critical level of 12 mg/kg required for cocoa [25]. Previous studies have also reported low levels of available P in West African cocoa farms [26,27,28,29,30]. This can be attributed to soil acidity, causing interference with the availability and uptake of certain nutrients, such as P [27], and the relatively low use of mineral fertilizers [30]. Our results of the farmers interviewed further confirms communications from earlier studies that have consistently shown that most Nigerian cocoa farmers do not use chemical fertilizers [31,4,32,33], hence inadequate nutrients in the soil.

Table 1. Nutrient contents of compost produced in each of the selected sites in Nigeria

Properties	Ipinlerere	Soko	Koola	Ode-Omu
pH	8.7	8.2	8.2	8.4
Nitrogen (%)	0.41	0.32	0.33	0.36
Phosphorus (%)	1.45	1.05	0.61	0.42
Potassium (%)	0.78	0.97	0.68	1.29
Calcium (%)	11.06	9.53	2.94	1.01
Magnesium (%)	1.86	0.96	0.54	0.55
Sodium (%)	0.76	0.95	0.66	1.26
Organic carbon (%)	10.02	5.69	5.43	8.41
C/N ratio	24.4	17.79	16.46	23.37
Iron (%)	0.98	1.85	1.46	1.12
Copper (%)	0.006	0.007	0.004	0.005
Zinc (%)	0.014	0.006	0.014	0.009
Manganese (%)	0.07	0.10	0.06	0.08
Lead (%)		0.0001	-	-
Cadmium (%)	-	-	-	-

-: not detectable

Table 2. Soil properties in the selected sites prior to fertilizer application

Soil properties	Ipinlerere	Soko	Koola	Ode-Omu
pH	6.7	6.4	6.5	6.5
Org. carbon (g/kg)	13.4	25.0	15.7	13.3
Nitrogen (g/kg)	1.5	1.9	0.8	1.3
Phosphorus (mg/kg)	3.7	3.6	3.4	3.5
Potassium (cmol/kg)	0.23	0.32	0.16	0.21
Calcium (cmol/kg)	16.60	21.07	16.51	20.86
Magnesium (cmol/kg)	2.21	3.55	0.79	1.35
Sodium (cmol/kg)	0.47	0.64	0.34	0.44
Exch. Acidity (cmol/kg)	0.06	0.07	0.08	0.08
ECEC (cmol/kg)	19.57	25.65	17.88	22.94
Base Saturation (cmol/kg)	99.57	99.72	99.55	99.65
Iron (mg/kg)	0.7	1.11	0.62	0.51
Copper (cmol/kg)	0.16	0.05	0.24	0.35
Zinc (cmol/kg)	0.66	0.46	0.63	0.53
Sand (%)	89.8	90.0	85.8	88.8
Silt (%)	6.8	5.6	5.8	4.8
Clay (%)	3.4	4.4	8.4	6.4
Textural class	Sandy	Sandy	Loamy sand	Sandy

3.4 Cocoa Yield Response to CPH Compost and NPK

Effects of fertilizer application on flower production as from three months after application indicated that compost and combinations with NPK significantly enhanced flower production more than the control in all locations (Table 3). Nutrients available to the cocoa plant could be attributed to the flower production enhancement. This is in agreement with earlier report that fertilizer application had very significant influence on the number of flowers and cherelles [34]. In the same vein, the potential yield obtained with the compost fertilization with or without NPK was significantly greater than the control (Table 4). Cocoa flowering and pollination patterns are influenced by climatic factors; long drawn drought or cold weather hinders flower growth; on the other hand, warm rainfall and weather trigger the flowering and pollination of cocoa [34]. Some of the cherelles will become wilted and dead (Cherelle wilt) within 1-2 months of their development. Physiologically, cherelles are withered as a result of nutritional competition between cherelles with vegetative and other reproductive organs that are actively growing. Cherelle wilt can also be caused by *Phytophthora palmivora* [35]. The enhanced flowering and potential yield obtained in this research study compared to the control can be attributed, amongst others, to improved nutrition made available by the fertilizer application. Soil N is needed to support vegetative growth and it

greatly influences cocoa yields by increasing the number of flowers and pods [36]. Phosphorus and Potassium release into the soil from the compost can enhance the productivity of the soil for crop growth and yield [37].

3.5 Impact of Fertilizer Use on Cocoa Black Pod Rot Incidence

Compost plus NPK fertilization significantly reduced black pod losses compared to sole compost, NPK, and control (Table 5). Percentage loss rate ranged from 9.9 to 13.4%, 21.6 to 23.1, 19.6 to 22.3, 32.2 to 35.5, for compost plus NPK, compost, NPK and control respectively, in all locations. Earlier results from the antagonism test showed that CPH based compost water extract (CWE) has some suppressive effects on *Phytophthora megakarya*, the pathogen causing black pod disease of cocoa [38]. The observed inhibition of mycelial growth of the pathogen by CWE will limit the production of sporangia and zoospores that germinate from mycelium, which is a principal source of the inoculum. Thus, the reduction of primary and secondary inoculum will result in the reduction of the disease incidence and severity [38]. The inhibition of cocoa pod disease pathogen has been attributed to the antagonistic effects of beneficial microorganisms [39,40] and chemical composition of the organic materials [41]. The observed significant reduction in black pod losses from our results may be attributed to antagonistic microbes and inhibitory chemical composition of the compost.

Table 3. Effect of fertilizer treatments on cocoa flower production

Fertilizer treatments	Ipinlerere	Soko	Koola	Ode-Omu
Compost (100%)	107c	108c	110c	105c
¾ Compost + ¼ NPK	155a	160a	161a	151a
½ Compost + ½ NPK	135b	137b	135b	132b
NPK (100%)	101c	112c	109c	100c
Control	90d	88d	91d	91d

Values followed by the same letter are not significantly different from each other using LSD at $P = .05$

Table 4. Effect of fertilizer treatments on potential yield of cocoa

Fertilizer treatments	Ipinlerere	Soko	Koola	Ode-Omu
Compost (100%)	85a	86a	84a	85a
¾ Compost + ¼ NPK	86a	87a	85a	86a
½ Compost + ½ NPK	87a	88a	84a	86a
NPK (100%)	84a	87a	83a	84a
Control	75b	74b	76b	75b

Values followed by the same letter are not significantly different from each other using LSD at $P = .05$

Table 5. Effect of fertilizer treatments on cocoa loss due to black pod rot

Fertilizer treatments	Ipinlerere		Soko		Koola		Ode-Omu	
	Pod loss	% loss	Pod loss	% loss	Pod loss	% loss	Pod loss	% loss
Compost (100%)	28b	22.0	28b	23.1	30b	21.7	29b	21.6
¾ Compost + ¼ NPK	14a	11.0	12a	9.9	18a	13.0	16a	11.9
½ Compost + ½ NPK	17a	13.4	15a	12.4	14a	10.1	15a	11.2
NPK (100%)	26b	20.5	27b	22.3	27b	19.6	29b	21.6
Control	42c	33.1	39c	32.2	49c	35.5	45c	33.6

Values followed by the same letter are not significantly different from each other using LSD at $P = .05$

The actual yield obtained with the compost plus NPK fertilization was significantly higher than all other applications and control in all locations (Table 6). There was no significant difference between the actual yield obtained from sole compost and sole NPK applications. However, their actual yields were significantly higher than the control. Percentage dry cocoa bean yield gain was 72.4% with the compost plus NPK fertilization, while sole compost and NPK was 36.4% in comparison to the control (Table 7). Enriched cocoa pod composts were earlier shown to improve plant height, dry matter production, and foliar N concentration in cocoa seedlings [42]. Compost incorporation enhanced

vegetative growth of tea plants [43], increase availability of N, P, K, Ca, and Mg in soil and their uptake by cucumber thereby leading to enhanced growth and yield performance of the cucumber plant [44,45], and marketable fresh weight and dry biomass production of Chinese cabbage crop over control [46]. When added to soils, compost enhances soil fertility by increasing nutrient availability [8], soil organic carbons [9], available N and P, micronutrients, soil aggregation, and water holding capacity, as well as leading to a high soil buffering capacity against external disturbances [47,48,49,10]. Our results revealed that compost plus NPK fertilization enhanced cocoa yield significantly

Table 6. Effect of fertilizer treatments on actual yield of cocoa

Fertilizer treatments	Ipinlerere	Soko	Koola	Ode-Omu
Compost (100%)	57b	58b	54b	56b
¾ Compost + ¼ NPK	72a	75a	67a	70a
½ Compost + ½ NPK	70a	73a	70a	71a
NPK (100%)	58b	60b	56b	55b
Control	33c	35c	27c	30c

Values followed by the same letter are not significantly different from each other using LSD at $P = .05$

Table 7. Effect of fertilizer treatments on dry cocoa bean yield

Fertilizer treatments	Ipinlerere		Soko		Koola		Ode-Omu	
	Yield (t/ha)	Gain (%)	Yield (t/ha)	Gain (%)	Yield (t/ha)	Gain (%)	Yield (t/ha)	Gain (%)
Compost (100%)	1.5b	36.4	1.7b	41.7	1.4b	30.0	1.5b	36.4
¾ Compost + ¼ NPK	1.9a	72.7	2.1a	75.0	1.7a	60.0	1.8a	63.6
½ Compost + ½ NPK	1.9a	72.7	2.1a	75.0	1.7a	60.0	1.8a	63.6
NPK (100%)	1.5b	36.4	1.7b	41.7	1.4b	30.0	1.5b	36.4
Control	1.1c	-	1.2c	-	1.1c	-	1.1c	-

Values followed by the same letter are not significantly different from each other using LSD at $P = .05$

compared to sole compost, sole NPK and control. This is in agreement with other studies that showed combination of manure and NPK fertilizers increased crop yield higher than that of NPK fertilizer treatment [50,51].

4. CONCLUSION

Results from our study revealed that CPH-based compost plus NPK fertilization not only improve soil fertility and cocoa yield, but also reduce cocoa losses caused by black pod disease. The use of CPH-based compost plus NPK fertilization in combination with GAP has the potential to provide efficient integrated soil fertility management that sustainably enhances cocoa bean yield. Raising soil fertility status through integrated management is a sustainable alternative to enhance cocoa production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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