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Effect of Municipal Solid Waste Compost on Soil Chemical Properties and Growth Performance of Cocoa (*Theobroma cacao L.*) Seedlings at the Nursery in Ghana

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Authors' contributions

This work was carried out in collaboration among all authors. Author AA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author JAD managed the nursery set up, managed treatment application and data collection, Author AKQ assisted in the development of the protocol, chose the treatments combination and managed the literature searches. Author SK wrote the protocol for parameters to be collected. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Availability of nutrients-rich topsoil for nursing cocoa seedlings is becoming limited and poor growth of cocoa seedlings in the nurseries has been ascribed to the use of unsuitable potting media. Experiments were conducted to investigate the suitability of compost in improving soil chemical properties and boost the growth of cocoa seedlings at the nursery.
Study Design: The experiment was laid out in a Completely Randomized Design (CRD) with four replications.
Place and Duration of Study: The experiment was carried out at the main nursery of Cocoa Research Institute of Ghana, New Tafo-Akim, between September, 2014 and June 2015.
Methodology: Polybags were filled with soil obtained from an old cocoa plot (K6O2) at Cocoa Research Institute of Ghana. The soil has been classified as Rhodic-Lixic Ferrasol. Three soil:

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compost mixtures treatments, that is, 90:10, 80:20 and 70:30% w/w were tested. A Standard foliar fertilizer and unamended soil were included as treated and untreated controls. Seedlings were raised from mixed hybrid cocoa and assessed at bi-monthly intervals for six months for growth. Pre and post treatments soil analyses were carried out using standard laboratory procedures.
Results: Initial soil analyses showed that OC (1.18%), Ca (5.60 cmol kg^{-1}), P (14.23 mg kg^{-1}) and pH (5.63) were below the critical values required for good cocoa growth. The 70:30 soil: compost treatment produced significantly (*P* = .05) tallest plant (41.9 cm) with the unamended control the shortest (30.7 cm) at the end of the study. Residual pH (6.98), OC (2.30%), P (14.23 mg kg^{-1}) and Ca (13.02 cmol kg^{-1}) were significantly (*P* = .05) higher under the same treatment compared to the unamended control; pH (5.36), OC (1.04%), P (11.65 mg kg^{-1}) and Ca (5.60 cmol kg^{-1}).
Conclusion: Less fertile soils could be improved with the addition of Municipal Solid Waste (MSW) compost for raising good quality cocoa seedlings at the nursery in Ghana.

Keywords: Cocoa; compost; topsoil; seedling growth.

1. INTRODUCTION

The seed and seedling supply system of the Seed Production Division (SPD) and Cocoa Health and Extension Division (CHED) of COCOBOD is based on raising cocoa seedlings in nurseries using topsoil usually procured from contractors but the fertility of such topsoil could be problematic. Topsoil is becoming limited and poor growth of cocoa seedlings in the nurseries has been ascribed to the use of unsuitable potting media. This problem is compounded by inadequate quantities of fertile topsoil for potting cocoa [1,2]. With the introduction of the cocoa rehabilitation programme in Ghana, different types of soils are used for filling the polybags. These soils differ in their fertility status, with the less fertile soils impacting negatively on the growth of cocoa seedlings [3,4]. There is therefore, the need to search for suitable materials / soil additives with the view to improve the fertility status of the soils for raising healthy cocoa seedlings. A potting medium is a composition of organic materials formulated to achieve desirable chemical and physical needs required by the crop to attain its potential growth and development. According to khan mm et al. [5], good potting media management is essential to the production of quality fruit tree seedlings, since vigorous growth is needed to face the seasonal hazards encountered on the field. The work by Gockowski et al. [6] indicated that cocoa seedlings need nitrogen, phosphorus, potassium and metabolites such as proteins, lipids, carbohydrates for their growth. Thus it is important that young nursery seedlings and transplanted seedlings are in optimal condition as far as their nutrient and energy status are concerned. Cocoa pod husk-based compost was used to raise cocoa seedlings at the nursery in Ghana [7]. However, soil amended with inorganic NPK fertilizer resulted in significantly poor seedling performance. The use of organic materials in potting media will not only improve the growth performance of cocoa seedlings but also improve the quality of soil used for raising the seedlings [8]. This will ensure adequate plant nutrients for the seedlings to boost its survival and establishment rates during field transplanting. However, the use of Municipal Solid Waste (MSW) compost in improving the fertility status of nutrient poor topsoil in the context of producing good quality cocoa seedlings at the nursery in Ghana has not been studied. The objective of this study was therefore, to determine the effect of soil: Compost mixtures on soil chemical properties and growth performance of cocoa seedlings in the nursery.

2. MATERIALS AND METHODS

2.1 Study Site

The experiment was conducted at the main nursery of the Cocoa Research Institute of Ghana, New Tafo (latitude 6°13’ N, longitude 0°22’ W, altitude 222 m above sea level) in between September, 2014 and June, 2015.

2.2 Soil Sampling and Analyses

Topsoil (0-15 cm depth) collected from an old cocoa plot (K6O2) was used for the experiment. The soil at the site has been classified as Rhodic-Lixic Ferrasol [9] and belongs to the Wacri series according to the Ghanaian system of classification [10]. A sample of the soil was air-dried and sieved through a 2 mm mesh and stored for analysis of its physico-chemical properties. Soil samples were analyzed before and at the end of the experiment to find out the changes in soil properties following treatments application. Soil pH was determined using the glass electrode at soil: water ratio of 1:2.5 [11], organic carbon by the Walkley and Black wet oxidation method [12] and total N by the Kjeldahl digestion and distillation method [13]. Available phosphorus was measured by the Troug method [14]. Exchangeable basic cations (K, Ca and Mg) were extracted with IN ammonium acetate solution and the leachate analyzed by the Atomic Absorption Spectrophotometer [15].

2.3 Nursery Studies

The experiment was conducted in the nursery at the Cocoa Research Institute of Ghana, Tafo. Standard nursery polybags measuring 18 cm x 25 cm were used for raising the cocoa seedlings [2,16]. Different proportions of soil and Municipal Solid Waste compost (NPK 2-1-0.5 + 0.85 Ca + 0.17 Mg + 0.65 Fe + 0.02Z n + 18% OM) were mixed and used to fill the polybags. The following treatments were tested (i) Soil alone (ii) Standard foliar fertilizer (10 ml/11 liters (iii) Soil: compost (90:10 w/w) (iv) Soil: compost (80:20 w/w) and (v) Soil: compost (70:30 w/w). The polybags with the soil: Compost mixtures were subsequently watered and allowed to settle for two weeks. Mixed hybrid cocoa seeds were sown at a seeding rate of two per polybag which were thinned to one seedling per polybags one month after sowing. The Standard foliar fertilizer was sprayed on the seedlings at monthly interval using pneumatic knapsack sprayer. Each treatment had thirty seedlings and the experiment was laid out in a Completely Randomized Design (CRD) with four replications. Watering was done on weekly basis. Seedling girth, height, number of leaves and dry matter production were measured at bi-monthly intervals for six months. Residual soil analyses were carried at six months after sowing.

2.4 Data Analysis

Data collected were subjected to analysis of variance (ANOVA). Treatment means were compared using the least significant difference (LSD) method at *P* = .05. All statistics were performed using Gen Stat Statistical Package [17].

3. RESULTS AND DISCUSSION

3.1 Initial Soil Fertility Status

Initial analysis showed that organic carbon, available P and exchangeable Ca contents of the soil were below the critical levels considered adequate for good cocoa growth [Table 1]. A good cocoa soil is reported to have organic carbon of above > 3%, 20 mg kg^{-1} available P and 7.5 cmol kg^{-1} exchangeable Ca respectively [18]. Total N, exchangeable K and Mg were above the critical values of 0.09%, 0.25 $cmolkg^{-1}$ and 1.33 $cmolkg^{-1}$ respectively, considered adequate to support the growth of cocoa. The soil was moderately acidic with pH value below the soil critical limit required for cocoa.

3.2 Effect of the Different Treatments on Soil Chemical Properties

Soil chemical properties as affected by the application of MSW compost and foliar fertilizer at the end of the study are presented in Table 2. Municipal Solid Waste (MSW) compost application increased soil chemical composition compared to the untreated control and Standard foliar fertilizer treatments. Soil nutrient content tended to increase with the level of compost applied except exchangeable K. Residual soil properties decreased under the Standard foliar fertilizer and unamended control treatments below the threshold values required for good cocoa growth.

3.3 Growth Parameters

3.3.1 Seedling girth

Girth increments of cocoa seedlings due to the various treatments are presented in Table 3. There was a significant (*P* = .05) seedling girth increment between the treatments at 2 months after sowing. The values recorded ranged between 2.0 and 3.5 mm. Similar trends were observed at 4 and 6 months after sowing. Seedling girth was generally bigger in the soil: compost (70:30) treatments compared to the unamended soil and Standard foliar fertilizer treatments.

3.3.2 Seedling height

Table 4 shows height increments of cocoa seedlings under the different treatments. All the treatments except 90:10 soil: compost were significantly (*P* = .05) taller than the untreated control 2 months after sowing. The 70:30 soil: compost treatment produced significantly (*P* = .05) taller plants than the other treatments at 4 and 6 months after sowing. Height increments were linearly related to the quantity of compost applied.

3.3.3 Number of leaves

Seedlings grown on soil: Compost mixture treatments developed significantly (*P* = .05) more leaves relative to unamended soil and the Standard foliar fertilizer treatments at 2 months after sowing (Table 5). Seedlings grown on 70:30 soil: Compost produced significantly (*P*=.05) more leaves compared to the other treatments at 4 and 6 months after sowing.

3.3.4 Dry matter production

Dry matter yield of the cocoa seedlings was found to increase with time for all the treatments [Table 6]. The variations in dry matter production between the fertilizer treatments at the different sampling periods were significant (*P* = .05). Similar to the growth measurements (seedling height and girth increments and number of leaves), highest compost level (70:30 w/w) produced significantly (*P* = .05) higher dry matter yield than the other treatments.

4. DISCUSSION

The observed significant effects of soil: compost mixture on the growth (girth and height) and total biomass production of cocoa seedlings in this present study could be attributed to the bioavailability of vital nutrients in the compost. Similar effect of compost on the growth of cocoa seedlings has been reported by Adejobo et al. [19]. This result indicates that the seedlings that were raised in soil: compost mixture are of higher growth performance and would have higher survival and establishment rates after field transplanting than those raised in sole soil and seedlings treated with foliar fertilizer. The observations made in this present study confirm earlier findings on growth of cocoa seedlings [7; 20].

It is observed in this study that number of leaves of cocoa seedlings and total dry plant biomass increased with increasing compost rate. This emphasizes the importance of the compost in providing nutrient for the growth of the cocoa seedlings as noted by Sosu G [20]. Better cocoa seedlings growth performance with the use of cocoa pod husk-based compost as potting medium was reported by Ofori-Frimpong et al. [7]. However, on the contrary, the authors observed that potting media amended with inorganic NPK fertilizer significantly produced

Table 1. Some chemical properties of the soil used in the experiment (0-15 cm)

Parameter	Measured value
pH (soil: water, 1:2.5)	5.63
Organic carbon (%)	1.18
Total N (%)	0.16
Available P (mg kg^{-1})	14.23
Exchangeable cations (cmol kg^{-1})	
K	0.38
Ca	5.60
Mg	1.79

Table 2. Effect of soil: Compost mixture and foliar fertilizer on soil chemical composition at 6 months of application

Treatments	pH	% OC	%N	P (mg kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})
T1 Control (soil alone)	5.36^{c}	1.04^{c}	0.15^{c}	11.65^{d}	0.20^{c}	5.60^{d}	1.22^{d}
T2 Standard foliar fertilizer	5.38^{c}	1.17^{c}	0.13^{c}	11.29^{d}	0.20^{c}	5.92^{c}	1.23^{d}
T3 Soil: compost (90:10)	6.43^{b}	2.03^{b}	0.21^{b}	23.64^{c}	0.30^{b}	8.01^{b}	1.49^{c}
T4 Soil: compost (80:20)	6.76^{a}	2.20^{a}	0.25^{a}	32.48^{b}	0.27^{c}	12.11^{a}	2.29^{b}
T5 Soil: compost (70:30)	6.98^{a}	2.30^{a}	0.27^{a}	40.17^{a}	0.30^{a}	13.02^{a}	2.55^{a}
Lsd (*P*=.05)	0.27	0.22	0.03	2.45	0.02	0.28	0.15

Means in a column followed by the same superscript alphabets are not significantly different P>.05

Table 3. Girth increments of cocoa seedlings grown in different soil: Compost mixtures or sprayed with foliar fertilizer at 2, 4 and 6 months after sowing

Treatments	Seedling girth increments (mm)		
	2 months	4 months	6 months
T1 Control (soil alone)	2.0^{c}	3.8^{c}	5.1^{c}
T2 Standard foliar fertilizer	2.3^{b}	4.0^{bc}	5.7^{bc}
T3 Soil: compost (90:10)	2.4^{b}	4.1^{b}	5.9^{b}
T4 Soil: compost (80:20)	3.3^{a}	4.3^{b}	5.8^{b}
T5 Soil: compost (70:30)	3.5^{a}	5.3^{a}	7.3^{a}
Lsd (*P*=.05)	0.2	0.3	0.6

Means in a column followed by the same superscript are not significantly different (P=.05)

Table 4. Height increments of cocoa seedlings grown in different soil: Compost mixtures or sprayed with foliar fertilizer at 2, 4 and 6 months after sowing

Treatments	Seedling height increments (cm)		
	2 months	4 months	6 months
T1 Control (soil alone)	23.1^{c}	24.6^{c}	30.7^{c}
T2 Standard foliar fertilizer	25.6^{ab}	28.2^{b}	37.9^{ab}
T3 Soil: compost (90:10)	24.8^{ac}	26.6^{bc}	36.4^{b}
T4 Soil: compost (80:20)	25.4^{b}	28.7^{b}	38.9^{b}
T5 Soil: compost (70:30)	27.3^{a}	32.8^{a}	41.9^{a}
Lsd (*P*=.05)	1.9	2.1	2.2

Means in a column followed by the same superscript are not significantly different (P=.05)

Table 5. Number of leaves of cocoa seedlings grown in different soil: Compost mixtures or sprayed with foliar fertilizer at 2, 4 and 6 months after sowing

Treatments	Number of leaves		
	2 months	4 months	6 months
T1 Control (soil alone)	4.3 (2.08)^{b}	6.7 (2.58)^{c}	10.0 (3.16)^{c}
T2 Standard foliar fertilizer	5.1 (2.27)^{ab}	8.7 (2.94)^{b}	12.0 (3.46)^{b}
T3 Soil: compost (90:10)	6.2 (2.48)^{a}	8.3 (2.88)^{b}	11.7 (3.42)^{b}
T4 Soil: compost (80:20)	6.0 (2.45)^{a}	9.2 (3.03)^{ab}	12.8 (3.58)^{b}
T5 Soil: compost (70:30)	6.3 (2.51)^{a}	10.3 (3.21)^{a}	16.3 (4.04)^{a}
Lsd (*P*=.05)	1.5	1.4	1.8

Means in a column followed by the same superscript are not significantly different (P=.05); Values in bracket are square root transformation of actual values

Table 6. Dry matter yield of cocoa seedlings grown in different soil: Compost mixtures or sprayed with foliar fertilizer at 2, 4 and 6 months after sowing

Treatments	Dry matter (g plant^{-1})		
	2 months	4 months	6 months
T1 Control (soil alone)	0.87^{b}	1.96^{c}	3.35^{c}
T2 Standard foliar fertilizer	1.03^{b}	2.65^{b}	6.96^{ab}
T3 Soil: compost (90:10)	0.96^{b}	2.02^{c}	4.35^{bc}
T4 Soil: compost (80:20)	0.98^{b}	2.60^{b}	4.60^{b}
T5 Soil: compost (70:30)	1.43^{a}	4.69^{a}	8.23^{a}
Lsd (*P*=.05)	0.20	0.49	1.13

Means in a column followed by the same superscript are not significantly different (P>.05)

narrower leaves. The high total dry plant biomass production of cocoa seedlings in soil: compost mixture (70:30 w/w) could be attributed to the chemical composition of the compost and ability to release nutrients through mineralization for plant uptake.

Application of MSW compost to the less fertile topsoil used in this experiment improved the soil chemical properties at the end of the study compared to the unamended control and the foliar fertilizer treatments. The use of organic fertilizers has been associated with desirable soil characteristics including higher plant available nutrients, water holding capacity, CEC and lower bulk density, and can foster beneficial microorganisms [21,22]. Benefits of organic soil amendments also include pH stabilization and increased water infiltration rate due to enhanced soil aggregation. Since they are the ultimate slow-release fertilizers, it's very difficult to over fertilize (and harm) plants. There's little to no risk of toxic buildups of chemicals and salts that can be deadly to the cocoa seedlings.

The residual soil nutrients were high in the soil: compost mixtures compared to the unamended control and Standard foliar fertilizer treatments. The soil: compost mixture treatments increased the levels of carbon in the soil, which leads to an increase in fertility because of an increase in microorganism activity using carbon as energy source [23]. Similarly, high residual total N and available P were recorded by soil: compost mixtures. According to Wu et al. [24], the application of organic soil amendments increased the N content in soil because of the greater N and organic C concentration in the amendment. Organic fertilizers have been suggested to increase the availability of P because as the organic component decomposes it releases CO_2 and higher CO_2 concentrations would increase the rate of decomposition of phosphate minerals and thereby increase soil available P [25]. These minerals synthesize phospho-humic complexes that are available to the plant and allow for the exchange of organic radicals by phosphates. The increase in pH, K, Ca and Mg recorded for the Soil: compost mixtures treatments compared to the unamended control and Standard foliar fertilizer treatments could be attributed to the increased availability of organic matter and release of some cations from the decomposed organic amendment as noted by Agbede et al. [26]. The low residual soil nutrients value recorded under the unamended control could be ascribed to nutrient mining by the cocoa seedlings without soil amendment. This observation is consistent with the fact that organic fertilizers are a natural source of macro and micronutrients. The above findings suggest the need for application of organic amendments to less fertile topsoil in raising healthy cocoa seedlings to ensure balanced nutrition.

The high residual soil nutrients observed under soil: compost mixtures treatments meant that application of compost to less fertile topsoil could improve its fertility status and also ensure that adequate nutrients are available to the cocoa seedlings during field transplanting.

5. CONCLUSION

The results showed that MSW compost increases the level of soil organic carbon, total N, available P, soil pH and exchangeable cations of nutrients poor topsoil. Subsequently, the compost increased the growth of the cocoa seedlings compared to the unamended control and Standard foliar fertilizer. The compost is found to be a suitable source of nutrients for improving the fertility status of less fertile topsoil for raising good quality cocoa seedlings at the nursery in Ghana.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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