Physicochemical and biological properties of different Cocoa Pod Husk-based composts

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Abstract

The objective was to evaluate the properties of cocoa pod husk-based composts for potential application as soil amendments for crop production. The physicochemical and biological properties of the compost types were analysed. Four compost types were prepared by mixing cocoa pod husk, poultry manure and *Panicum maximum* in different proportions. A phytotoxicity test was carried out using maize (*Zea mays* L.) to test whether the compost types contain substances that inhibit seed germination or growth of the radicle. Bulk densities of the compost types were higher than 0.160 Mg m^{-3}, an indication that the compost types as soil amendment will restrict root growth thereby inhibiting plant growth. The average pH of the compost types falls within the optimum range of 6.5 to 8.5 and thus, the composts are stabilized. The compost types had high nitrogen content, so when utilized as a soil amendment would improve the nitrogen content of soils. Copper concentrations in the compost types were far below the WHO/FAO permissible limit of 100 mg kg^{-1}, therefore can be applied at high rates without any problem of copper accumulation in soil. *Phytophthora palmivora* and *Phytophthora megakarya* were not detected from the compost types, therefore the compost types could be used without *Phytophthora* disease infection. Germination percentage and germination index showed that the analyzed compost types achieved high percentages of the germinating capacity of maize seeds and had no phytotoxic substances. The cocoa pod husk-based composts showed substantially varied physicochemical and biological properties suitable to support plant growth. The results clearly showed that, CPHcomp3 made from CPH residues, poultry manure and *Panicum maximum* at the ratio 6: 1: 2 mixture is recommended for use as a soil amendment for crop production.

Introduction

Composting is the biological decomposition and stabilization of organic materials into a final product sufficiently stable for application as soil amendment without adverse environmental effects. It is a very popular technique in the management of organic solid wastes and provides macro and micronutrients to plants when used as soil fertilizer (Jara-Samaniego et al. 2017; Ferreira et. al. 2018). Compost is primarily used as a soil conditioner because it improves soil characteristics such as aeration, water holding capacity, bulk density, aggregation, cation exchange capacity and activity of beneficial microflora (Jilani et al. 2007). Additionally, compost provides a stabilized form of organic matter that imparts longer lasting residual effects to soil (Preusch et al. 2002). The beneficial effects of compost on crop production are directly related to the physical, chemical and biological properties of the composts (Atiyeh et al. 2001). However, the quality of the compost depends on the chemical, microbiological and physical properties of the composting materials (Rynk et al. 1992).

Organic materials from crop and livestock production are rich sources of different nutrients and have all been recommended for use as renewable resources in media production (Mehmood et al. 2013). In Ghana, agricultural waste materials including cocoa pod husks (CPH) and animal manures especially poultry manure (PM), abound and are increasing in quantity each year due to the growing number of cocoa and poultry farms. CPH is obtained after the removal of the beans and it represents about 70 - 80% in dry weight of the fruit (Prabhakaran Nair, 2010a). Ghana is a major exporter of cocoa with a wide planted area of more than 1.68 million ha (FAOSTAT, 2014). For cocoa, each tonne of dry beans produced results in the production of 10 tonnes of CPH (Khanahmadi et al. 2015), thereby, creating enormous quantities of cocoa wastes which host pests and disease-causing organisms and a serious challenge in waste management. An estimated 595,000 tonnes of dry CPH residues was generated in Ghana in 2008 (Dukua et al. 2011). When these CPH which might come from black pod disease infected and uninfected pods are left untreated in farms, they act as a source of inoculum for the *Phytophthora spp* which is the causal agent for the cocoa black pod disease. Cocoa black pod diseases are controlled by spraying the pods mainly with copper-based fungicides. Cocoa pod husk is disinfected during composting due to the high temperatures produced (Ofori-Frimpong et al. 2010), thus, reducing the inoculum levels of the pathogen. Poultry manure is considered as a valuable organic resource for providing plant nutrients, building soil organic matter and structural stability (Evers, 2002; Singh et al. 2004). It also has a higher fertilizing value than other livestock manure because it is richer in nitrogen (Hirzel et al. 2007). Likewise, *Panicum maximum* (*Pmax*), a high biomass-producing plant considered as weed on farmers' fields in Ghana, provides the needed macro and micro elements when composted and applied to the soil (Quansah et al. 2001).

There is a huge potential for the use of CPH and agricultural wastes like PM and *Pmax* in the production of good quality compost in Ghana. However, the quality of the CPH-based compost for use as growing media needs to be ascertained because, the degree of maturity of compost has a great impact on its utilization. It is, therefore, important to assess the properties of the CPH-based compost that will affect plant growth potential, compost utilization and the soil. Consequently, the objective of this work was to evaluate the properties of CPH-based composts for potential application as soil amendments for crop production.

Materials and Methods

Study area

Compost was prepared out at the main nursery of the Cocoa Research Institute of Ghana (CRIG) at New Tafo - Akim in the Eastern Region of Ghana with geographical location of latitude 06°13' N and longitude 00°22' W. The topography is undulating and rises about 222 m above sea level. Climate characteristics of the location are as described by Dogbatse et al. (2019).

Raw materials and composting process

Cocoa pod husks and *Pmax* were obtained from CRIG New Tafo Station, Ghana. Poultry manure was obtained from a poultry farm at Bunso - Eastern Region, Ghana. The data on chemical properties of composting materials are shown in Table 1. The data indicated that, PM had the highest OC, TN, AP and exchangeable Ca, whereas CPH had the highest exchangeable K and Mg. The CPH and *Pmax* were shredded and air-dried before being composted into pits (1.2 m deep, 0.9 m width and 3.2 m long). The composts specifically Compost 1 (CPHcomp1), Compost

TABLE 1
Mean values for the chemical properties of the raw materials

Properties	Raw materials		
	CPH	PM	Pmax
OC (%)	2.75	2.77	1.08
TN (%)	1.99	2.68	1.90
AP (%)	0.04	0.05	0.02
K (%)	3.49	2.74	0.89
Ca (%)	0.11	0.20	0.03
Mg (%)	0.16	0.15	0.07
C/N ratio	1.38	1.03	0.57

OC = organic carbon; TN = total nitrogen; AP = available phosphorus; CPH = cocoa pod husk; PM = poultry manure; *Pmax = Panicum maximum*

TABLE 2
Quantity (kg) of cocoa pod husk, poultry manure and Panicum maximum used in producing the compost types

		Quantity (kg)		
Compost type	Ratio	CPH	PM	Pmax
CPHcomp1	3: 1: 2	210	70	140
CPHcomp2	3: 1: 1	210	70	70
CPHcomp3	6: 1: 2	210	35	70
CPHcomp4	6: 2: 1	210	70	35

CPHcomp1 = Compost 1; CPHcomp2 = Compost 2; CPHcomp3 = Compost 3; CPHcomp4 = Compost 4

2 (CPHcomp2), Compost 3 (CPHcomp3) and Compost 4 (CPHcomp4) were produced by mixing different combinations of CPH, PM and *Pmax* as indicated in Table 2. The CPH served as substrate (bulking material) and the PM and *Pmax* were used as a source of microbes and other nutrients. The composting materials were turned at two weeks interval. The composting process was completed within six months. Compost samples were taken from four locations of the pile: top (100 cm from the base of the pile), middle (60 cm from the base of the pile), bottom (25 cm from the base of the pile), and surface (5 cm from the surface of the pile) for each type of compost. Each sample was made by mixing five subsamples taken from five points in the pile. Samples were placed in polyethylene bags and conveyed to the laboratory for analyses.

Physicochemical properties analysis

Physical properties

Moisture content was determined by the gravimetric method. The bulk density of the compost was determined using the method described by Day et al. (1998). Porosity of composts was determined by using the method described by Trautmann and Krasny (1997). Water holding capacity was determined by using the method as described by Trautmann and Krasny (1997).

Chemical properties

The composts were analysed for pH in a 1:2.5 compost-water suspension using a pH meter, total nitrogen (TN) using Kjeldahl digestion method (Bremmer and Mulvaney, 1982), available phosphorus (AP) using Truog method (Truog, 1930) and colourimetrically on Spectrophotometer. Exchangeable bases were determined by the ammonium acetate pH 7.0 method (Black, 1965) and the filtrates analyzed on atomic absorption spectrophotometer for potassium (K), calcium (Ca) and magnesium (Mg). Organic matter content of composts was determined by the method described by Trautmann and Krasny (1997) and subsequently the percentage of carbon in compost samples were estimated by dividing the percentage of organic matter by 1.8, a number derived through laboratory measurements (Trautmann and Krasny, 1997).

Biological properties analysis

Microflora assessment

Compost samples were assessed for the type and population of microflora. Sampling for microflora assessment was done at three depths (0-30, 30-60 and > 60 cm) of each of the four compost types. Samples were randomly taken from these depths and then bulked together to form a composite sample. The samples were sieved with a sterile 4 mm metallic sieve to eliminate the roughest fractions. The sieved samples were put in labeled sterile polythene bags for biological analysis. A modification of the serial dilution plating method as described by Waksman, (1922) was used to dilute the compost samples. For each of the compost, 20 g was added in 100 mL sterile distilled water and thoroughly shaken to mix. The solutions were serially diluted to 10^{-1} by aseptically transferring 10 mL from the solutions into vials containing 90 mL sterile distilled water. 0.2 mL of 10^{-1} was spread with a glass rod on 9.0 cm diameter Petri dish containing carrot agar (200 g carrot, 20 g agar in 1000 mL SDW and autoclaved at 120°C for 15 min.) amended with chloramphenicol (100 mgL^{-1}) to inhibit bacterial growth. The plates were incubated at 28°C for 3 days. Fungal colonies that emerged were counted with a colony counter and expressed as log of colony forming units per gram (log CFU/g). Colonies with markedly different morphological characteristics (size, texture and colour) were aseptically transferred onto sterile carrot agar plates and incubated for growth and identification. Pure cultures of differently isolated fungi were studied macroscopically by observing morphological characteristics. Microscopic studies were done by staining slides with lacto phenol cotton blue and observed under compound microscope for hyphal structures and arrangement of spores and conidia on sporangiosphores and conidiophores respectively. The isolated fungi were identified with the help of identification manual (Barnett and Hunter, 1972).

Phytotoxicity bioassay

Compost maturity which is associated with phytotoxicity was evaluated using seed germination test. Phytotoxicity of the composts was evaluated in distilled water extracts (1:4, w/v) following the method of Tooba et al. (2014) which was slightly modified. Twenty-five grams (25 g) dry weight of each compost type was extracted in 100 mL of distilled water by vigorous agitation for 6 hours at room temperature in the dark. The supernatants were filtered through Whatman No. 42 filter paper. The test was conducted with maize (*Zea mays* L.). Ten maize seeds were evenly distributed on filter paper in Petri dishes (68.6 mm diameter) and moistened with 10 mL of each compost extract. Petri dishes with filter paper and 10 mL of distilled water served as control. Parafilm was used to seal each Petri dish to prevent water loss while allowing air penetration. Three replicate dishes containing 10 maize seeds for each compost sample and control were placed in a dark area for seed germination. After 48 hours, the number of germinated seeds and the total length of radicle of each maize seed were measured. The dry weight was determined after drying seedlings at 70°C for 24 hours. The germination index (GI) was calculated for each extract using the following formula:

$$\text{Germination Index (GI)} = \frac{\text{\% Germination (\%G) x Relative radicle growth (\%L)}}{10{,}000}$$

Where:

$$\textbf{\% Germination} = \frac{\textbf{Mean germination for extract x 100}}{\textbf{Mean germination for control}}$$

Results and Discussions

Nutrients composition of the raw materials

The exchangeable bases in CPH were high in the order K > Mg > Ca with values of 3.49, 0.16 and 0.11%, respectively compared to the lowest values of 0.89, 0.07 and 0.03%, respectively in *Pmax* (Table 1). The high exchangeable K content of CPH is due to the high level of K reported in cocoa pod products (Onwuka et al. 2007). PM had high concentrations of OC (2.77%), TN (2.68%) and AP (0.05%) compared to that of CPH and *Pmax*. This may be due to the high content of nutrient especially N and P of PM as reported by Ayeni et al. (2008). CPH had the highest C/N ratio of 1.38 but *Pmax* had the lowest C/N ratio (0.57). *Panicum maximum* also had the lowest concentration of all nutrients.

Physical properties

There were significant differences in bulk densities among the compost types (Table 3). The average bulk densities of the compost types ranged from 0.705 to 0.735 Mg m^{-3}. Bulk density of CPHcomp1 was significantly ($p<0.05$) higher than that of the other compost types. The bulk densities of the CPH-based compost in this study were higher than those found in composts of other studies (Romeela et al., 2008; Hurerta-Pujol et al., 2010), however, these bulk densities are higher than 0.160 Mg m^{-3} which tends to restrict root growth (McKenzie et al. 2004). This indicates that all the compost types when used as soil amendment will restrict root growth and penetration thereby inhibiting plant growth.

Moisture contents were significantly different for the compost types and it averagely ranged from 60.1 to 68.1%. CPHcomp1 had

TABLE 3
Mean values for the physical properties of the compost types

Compost type	Properties			
	Bulk density (Mg m^{-3})	Moisture content (%)	Water holding capacity (mL L^{-1})*	Porosity (%)
CPHcomp1	0.735	60.1	7.0	51.1
CPHcomp2	0.722	63.6	7.1	52.2
CPHcomp3	0.705	68.1	7.5	54.8
CPHcomp4	0.716	67.8	6.9	50.0
SED	0.001	1.58	0.69	0.67

* mL of water per L of compost
SED = Standard errors of differences of means
CPHcomp1 = Compost 1; CPHcomp2 = Compost 2; CPHcomp3 = Compost 3; CPHcomp4 = Compost 4

significantly ($p<0.05$) lower moisture content compared to the other compost types. Detected moisture in CPHcomp3 and CPHcomp4 was higher than the recommended standards of 45 to 65% as reported by Biotreat (2003). The high moisture content of the composts indicates that these composts can provide the moisture needed for the transport of dissolved plant nutrients.

Water holding capacity for the compost types on the average ranged from 6.9 to 7.5 mL L^{-1} of compost. There were no significant ($p>0.05$) differences in water holding capacity among the compost types. CPHcomp4 had the lowest value of water holding capacity whereas CPHcomp3 had highest of water holding capacity.

The average porosity ranged from 50.0 to 54.8% for the compost types. There were significant differences in porosity among the compost types. CPHcomp3 had significantly ($p<0.05$) higher porosity than that of the other compost types. The porosity depends on bulk density and moisture content of compost (Fig. 1 and 2). The results indicate that the porosity of compost decreased when the bulk density increased, and when the moisture content also increased. These results agree with those obtained by Ahn et al. (2008). Porosity decreased with increasing bulk density, because the the more compact the compost, the less the pore space. Moisture content of compost decreased with increasing bulk density (Fig. 3). This implies water and minerals uptake by plants would be limited with the increasing bulk density.

Chemical properties

According to Misra et al. (2003), organic substrates having a wide range of pH levels (pH 3 to 11) can be composted. The pH values were not significantly ($p>0.05$) different for the compost types except for CPHcomp2 and it ranged from 7.1 to 8.3. The highest pH was found for CPHcomp2 while the lowest pH was obtained for CPHcomp4 (Table 4). The pH values of the compost types fall within the recommended range of 6.5 to 8.5 for compost (Willson, 1993). The pH variations in the CPH-based composts were like that reported in compost of animal manure and rice straw (Zhu, 2007; Li et al. 2008). A pH of 7.0 is an indication of stabilized organic matter (Sesay et al. 1997), thus, the composts produced are stabilized compost.

Organic carbon contents were significantly

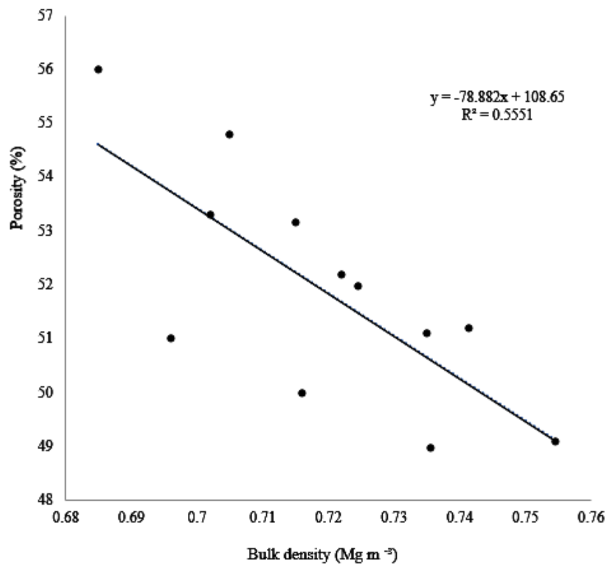

Figure 1. The relationship between the porosity and bulk density of composts

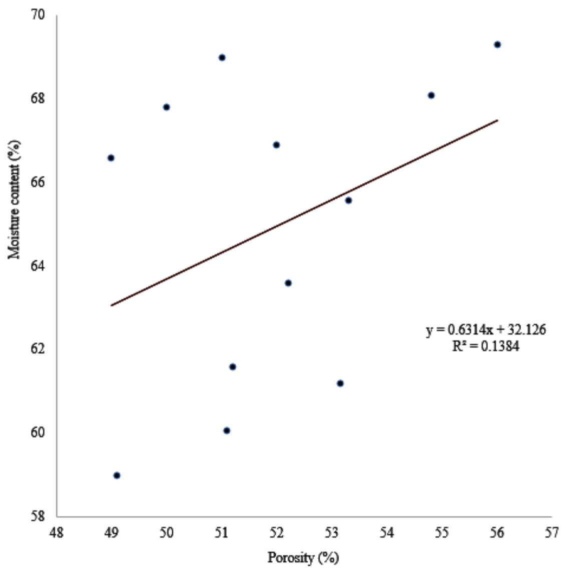

Figure 2. The relationship between the porosity and moisture content of composts

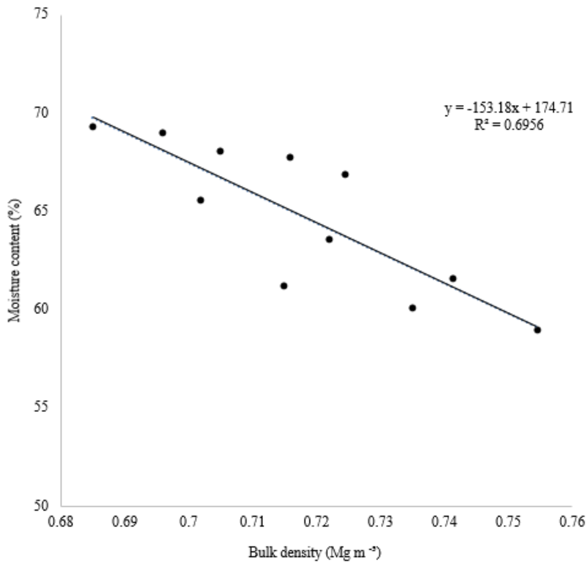

Figure 3. The relationship between moisture content and bulk density of composts

different for the compost types. The percentage OC of the compost types varied from 18.86 to 26.81% and was found to be high (Table 4). Batjes (1996) reported that, the optimum value of OC of compost should be higher than 10%. CPHcomp2 had significantly ($p<0.05$) higher OC than that of the other compost types. The high OC obtained in this study shows that, part of the carbon in the decomposing residues was not assimilated by the microbial biomass.

In this study, the TN contents were not significantly ($p>0.05$) different for the compost types and varied from 0.65 to 0.67% (Table 4). These TN contents of composts fall within the range of 0.5 to 2.7 % reported by Hamid et al. (2019) and are more than the recommended N level of 0.6 % for compost (Adhikari et al. 2009; Hamid et al. 2019). This implies that, the compost types when utilized as a soil amendment would improve the N content of soils to satisfy the N needs of the plants. The lowest value of TN was found in CPHcomp3 and the highest in CPHcomp1 and CPHcomp2.

C/N ratio is one of the most important indicators for maturity, quality and stability of final compost product because of its effect on immobilization and release of nitrogen and

TABLE 4
Mean values for the chemical properties of the compost types

Compost type	pH	OC	TN	AP	K	Ca	Mg	Cu	C/N ratio
	Properties								
				(%)				(mg kg^{-1})	
CPHcomp1	7.40	18.86	0.67	0.0232	0.89	0.33	0.27	1.22	28
CPHcomp2	8.30	26.81	0.67	0.0219	0.96	0.19	0.17	1.25	40
CPHcomp3	7.60	21.70	0.65	0.0242	0.93	0.25	0.20	1.82	33
CPHcomp4	7.10	22.66	0.66	0.0238	1.06	0.26	0.23	1.41	34
SED	0.47	0.43	0.05	0.0002	0.12	0.03	0.03	0.05	0.46

SED = Standard errors of differences of means
CPHcomp1 = Compost 1; CPHcomp2 = Compost 2; CPHcomp3 = Compost 3; CPHcomp4 = Compost 4; OC = organic carbon; OM = organic matter; TN = total nitrogen; AP = available phosphorus

other important nutrients in the soil (Herrera et al. 2008). It is a relatively crude measurement that gives an indication of nitrogen released from compost. Regardless of the ratio of the materials used for composting, the C/N ratio varied from 28:1 to 40:1 for the compost types (Table 4). The lowest C/N ratio was found in CPHcomp1 while the highest C/N ratio was found in CPHcomp3. These results disagree with the results obtained by Rosen et al. (1993) that the C/N ratio range from 15:1 to 20:1 is ideal for ready-to use compost. Dimambro et al. (2007) recommended C:N ratios of 15:1, 20:1 and 30:1 for compost when applied as fertilizer. However, the C:N ratio values obtained in this study are greater than 30:1 except for CPHcomp1. This suggests that except for CPHcomp1, there is the possibility of initial nitrogen immobilization when the other composts are applied to the soil.

There were significant ($p<0.05$) differences in the AP contents of the compost types. The AP concentration of the compost types ranged from 0.0219 to 0.0242% (Table 4). The lowest concentration of AP was found in CPHcomp2 and the highest concentration in CPHcomp3. All the compost types had P concentrations lower than the recommended P content of 0.5 % (Dadi et al. 2012), therefore would not be able to provide the P needed by plants. According to Morgan, (1998), insufficient P concentration in plants could lead to stunted growth and purple coloured stems and leaves. Potassium concentrations were not significantly ($p>0.05$) different in the compost types and it varied from 0.89 to 1.06% (Table 4). The lowest K concentration was found in CPHcomp1 and the highest in CPHcomp4. Potassium is highly soluble in the compost and therefore, easily leached. Calcium concentrations were significantly different in the compost types and varied from 0.19 to 0.33% (Table 4). CPHcomp1 had significantly ($p<0.05$) higher Ca content compared to the other compost types. Calcium concentration was lower in all the compost samples compared with recommended standards of 1 to 4% (Barker, 1997). The implies that, the compost types when utilized as a soil amendment would not provide adequate Ca to plants leading to poor growth of plants due to curling of young leaves and stunting of roots. Magnesium concentrations were not significantly ($p>0.05$) different in compost types. Magnesium concentrations of the compost types ranged from 0.17 to 0.27%. Generally, Mg levels in compost samples falls within the recommended standards of

0.2 to 0.4 % (Barker, 1997). Magnesium concentration was found to be lower than Ca in all the compost samples.

Copper concentrations were significantly different in the compost types. The concentration of Cu varied from 1.22 to 1.82 mg kg^{-1} with CPHcomp3 having significantly ($p<0.05$) higher Cu concentration than the other compost types (Table 4). Although, cocoa pods are sprayed regularly with Cu based fungicides to control black pod diseases, the levels of Cu found in the compost types were below the permissible limits of Dutch standards (60 mg kg^{1}) which is higher than that of other European countries (Hogg, et al. 2002). Copper content in the composts were also below the WHO/FAO permissible limit of 100 mg kg^{-1} (WHO/FAO, 2001). This indicates that, all the four composts can be use at high application rates without any problem of Cu accumulation in plants.

Biological properties

Phytophthora was not detected on carrot agar from any of the composts. Carrot agar was used to selectively isolate *Phytophthora* but saprophytes such as *Rhizopus* and *Aspergillus* species were also isolated. The composts contained untreated cocoa pod husks, potential source of inoculum of *Phytophthora palmivora* which causes seedling blight of cocoa (Aini et al. 2016). Non-appearance of either *P. palmivora* or *P. megakarya*, causal agents of black pod (Opoku et al. 2000; Appiah et al. 2003), is an indication that the composts were free of *Phytophthora* and could be used as a potting media for cocoa seedlings without *Phytophthora* diseases. Species of *Rhizopus* and *Aspergillus* might have been introduced in the composts by any of the compost materials or contaminated the composts from the environment due to the ubiquitous nature of microorganisms. Except for compost 3, *Rhizopus* was isolated from all the other composts. Compost 1 had the least colonies of *Rhizopus* of 1.7 CFU/g. Higher colonies of 3.0 CFU/g of Aspergillus were obtained from compost 3 (Fig. 4). The presence of *Rhizopus* and *Aspergillus* in composts is no cause for worry, because these microbes do not cause any damage to plant seedlings.

The seed germination and root elongation technique has been developed to evaluate the damaging effects and toxicity of compost. The germination index is one of the most sensitive parameters for evaluating the toxicity and the

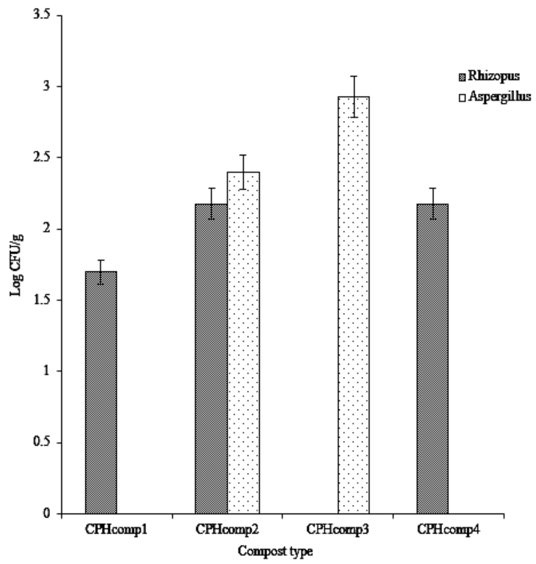

Figure 4. Frequency and type of fungi isolated from the four composts

degree of compost maturity, and is known to increase with the decomposition of toxic materials in the compost, such as short-chain volatile fatty acids mainly acetic acid (Chikae et al. 2006; Guo et al. 2012). With respect to maize seed germination, mean germination time of 2 days was observed in all the composts (Table 5). All the germination percent values were above 50%, the limiting value to phytotoxicity problems (Himanen and Himanen, 2011). It also indicates the promotion of germination by the compost types (Paradelo et al., 2008). The highest value was 90% for extract of CPHcomp3 and the lowest value 70% was observed in CPHcomp1 extracts, when compared to distilled water control (100%) (Table 5).

Root lengths of 48-hour old maize seedlings in aqueous extracts of different composts are presented in Table 5. The longest roots were observed in CPHcomp3 i.e. 20 mm. Extracts of CPHcomp1 had an adverse effect on root length, hence, the shortest root length observed (Table 5). The shortest relative root growth and low germination percent of maize was observed in CPHcomp1 extract (Table 5), indicating some level of inhibition of plant growth possibly due to the presence of toxic substances such as methane or ammonia (Trautmann and Krasny, 1997; Said-Pullicino and Gigliotti, 2007) in CPHcomp1.

Germination index (GI) of maize seeds in the CPH-based composts varied from 0.5 to 1.3. Maize seeds in the CPHcomp1 had the lowest GI value whereas those in CPHcomp3 had the highest GI value. The observed GI values of 0.5 or more in all the compost types agreed with the work of Lasaridi et al. (2006) who reported GI of cress seeds in 28 composts ranging from 0.25 and 1.5. Germination index of 0.5 indicates the presence of phytotoxic substances but GI values greater than 0.8 indicate mature compost free of phytotoxic substances (Warman, 1999). The observed values of GI in this study were greater than 0.8 and it is an indication of absence of phytotoxic substances in all the mature composts except CPHcomp1. The low GI of CPHcomp1 was probably due to the presence of phytotoxic substances as a result of the high ratio of *Pmax* in CPHcomp1 and also its low nutrients content (Table 1), therefore, requiring a longer period to ensure the degradation of the phytotoxic substances. CPHcomp3 could be considered as a carrier of growth stimulating properties due to its high GI value of 1.3 (Warman, 1999). This implies that, CPHcomp3 when utilized as a soil amendment would have a beneficial effect on seed germination and plant growth.

Conclusion

The results clearly showed that, cocoa pods can be effectively used to produce nutrient-

TABLE 5
Phytotoxicity assay of the compost types

Compost type	Mean germination time (days)	Root length (mm)	Germination %	Relative root growth (%)	Germination Index
CPHcomp1	2	9	70	67	0.5
CPHcomp2	2	16	85	111	0.9
CPHcomp3	2	20	90	145	1.3
CPHcomp4	2	16	80	115	0.9
Control	2	14	100	100	1.0

CPHcomp1 = Compost 1; CPHcomp2 = Compost 2; CPHcomp3 = Compost 3; CPHcomp4 = Compost 4 enriched composts of suitable quality. The CPH-based composts showed substantially varied physical, chemical and biological properties, suitable to support plant growth. Collectively, the properties measured provide ample evidence that suitable CPH-based composts can be obtained within six months using pit method. However, CPHcomp3 made from CPH residues, poultry manure and *Panicum maximum* at the ratio 6: 1: 2 mixture is recommended for use in crop production.

Conflict of interest

The authors declare that they have no conflict of interest.

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