International Journal of Recycling of Organic Waste in Agriculture (2022)11: 15-31
Doi: 10.30486/IJROWA.2021.1901356.1121

ORIGINAL RESEARCH

Enhancing food waste compost quality with nutrient amendments

John Boateng Nkansah[1*], Samson Oduro-Kwarteng[1], Helen Michelle Korkor Essandoh[1], Richard Amankwa Kuffuor[2]

Received: 21 August 2020 / Accepted: 17 July 2021 / Published online: 29 January 2022

Abstract

Purpose Recycling of food waste fraction of municipal solid waste into compost for use in agriculture is seen as an effective environmentally–friendly option. In developing countries, however, there are few commercial composting facilities producing composts whose use in agriculture is low, mainly due to their low nutrient content compared to chemical fertilizers.

Method This study investigated the effect of the food waste (FW) nutrient-amendment ratio on compost quality using amendments such as Cocoa Pod Husk Ash (CPHA), poultry manure (PM), and cow manure (CM). Six treatments (T1, T2, T3, T4, T5, and T6) and control were composted for 70 days.

Results The total Nitrogen, total Phosphorous, and total Potassium content ranged from 0.96–1.42%, 0.19–0.78%, and 0.86-1.42%, respectively, for the different compost types. In all treatments, the C/N ratio reduced significantly, while concentrations of heavy metals (Pb and Zn) were within the acceptable international limits. Toxicity of composts to cucumber (*Cucumis sativus*) was ascertained. Germination index (GI) was the highest in T5 (FW amended with PM only) whereas the control (FW only) recorded the least GI.

Conclusion This study shows that the use of PM, CM, and CPHA seems to be beneficial for the enrichment of food waste compost.

Keywords Food waste recycling, Composting, Compost quality, Nutrient amendments, Municipal solid waste

Introduction

Globally, about 1.3 billion tons of solid waste is currently generated per year with an expected increase to 2.2 billion tons by 2025. The rate of waste generation, especially in low-income countries, is projected to double over the next twenty years (Samwine et al. 2017). In Ghana, the current rate of generation of solid waste stands at 0.47 kg/person/day with 61% of the total waste generated which is organic (Miezah et al. 2015). Despite the increasing generation of food waste, the utilization of food waste for material and energy conversion remains challenging for several reasons that are related to its inherent heterogeneous composition, high moisture content, and low calorific value. These challenges impede the development of the robust, large-scale, and efficient industrial material and energy conversion process (Adhikari et al. 2008). The application of sustainable methods for waste management has led to extensive research into options for food waste treatment. Waste diversion by composting provides a city with a unique opportunity to improve its overall waste collection service. Composting stabilizes food waste, destroys most parasites and pathogens as well as reduces odour emissions by reducing levels of biodegradable hydrocarbons (Barrington et al. 2002). Although most composting facilities in many developing countries have folded up over the years, those in operation currently are barely operating to their designed capacities primarily due to high operational and maintenance costs as well as unavailability of markets to absorb compost produced (Zerbock 2003). Many researchers in their quest to improve the quality of compost have used some additives. Thus, they have used different feedstocks in combination with sludge, manure, bulking agents, etc. as amendments all to improve the quality of organic waste compost. Similar works rather targeted the mini-

---

✉ John Boateng Nkansah
johnbn9957@gmail.com

[1] Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, PMB KNUST, Kumasi, Ghana
[2] Department of Environmental Health and Sanitation, University of Education, Mampong, Ghana

mization of nitrogen loss, hence the addition of amendments. Thus, the loss of nitrogen reduces the fertilizer value of composts and constitutes an important economic loss (Ogunwande et al. 2008). A study by Iowa State University Extension Service (2004) showed that gypsum could reduce ammonia losses from dairy manure storage by 14%. Koenig et al. (2005) reported that the addition of gypsum at rates of 4% and 12%, when composting poultry manure with wood chips, significantly decreased the evolution of ammonia.

Nakasaki et al. (2001) in their stud used biodegradable plastic that acted as a 'reserve acid' for decreasing pH to minimize NH_3 emissions during composting. However, high doses of chemical additives in composting become toxic to most microorganisms (Liang et al. 2000). Torkashvand (2010) in his study used different amounts of molasses, office paper, sulfuric acid, and paper mill sludge as nutrient amendments to improve the quality of compost from organic waste as well as minimize the loss of nitrogen. He concluded that sulfuric acid and paper mill sludge were suitable amendments for increasing the agronomic value of the produced compost quality, however, paper mill sludge had a more impact on total nitrogen of the produced compost than the sulfuric acid. Understanding the nutrient availability and transformation during and after composting food waste will help composting facilities to improve their technologies and processes, thereby increasing the quality and use of compost products in agriculture.

The purpose of this study was to evaluate the effect of organic additives as nutrient amendments on the process conditions and the overall quality of the food waste amended compost. This study sought to suggest appropriate food waste feedstock–nutrient amendments ratios that could best produce high-quality compost.

Materials and methods

Study Area

The study was conducted in the Kumasi Metropolis, one of the thirty districts in the Ashanti Region of Ghana. It is located between Latitude 6.35 °N and 6.40 °S and Longitude 1.30 °W and 1.35 °E and elevated 250 to 300 meters above sea level (Ghana Statistical Service 2014). The Metropolis falls within the wet sub-equatorial type. The population of Kumasi Metropolis is 1,730,249 represents 36.2% of the total population of Ashanti Region (Ghana Statistical Service 2014). The dominant economic activities in the municipality include civil service, sales work, skilled agricultural forestry, and fishery workers. Out of the 37,456 households which are into agricultural activities, 91.6% are into crop farming.

Experimental design

The experimental study was carried out under a constructed shed structure during January and April 2018. Municipal food waste was source-separated from some households, fast food restaurants, and markets within the Kumasi metropolis and transported to the composting site. Manual sorting was then carried out to remove non-biodegradable materials such as plastics. The nutrient amendment materials; cow manure (CM) and poultry manure (PM) were obtained from the Kumasi abattoir and KNUST Agricultural animal farm, respectively. Fresh Cocoa pod husks were collected from a nearby cocoa farm, dried, and subjected to a temperature of 550 °C to produce Ash. Characteristics of the FW and nutrient amendments employed in this study are presented in Table 1.

The nutrient amendment materials considered in this study were selected based on their relatively high nutrient levels and how readily available they were, which are important considerations for any future large-scale composting of food waste to be undertaken in Kumasi. The FW having a moisture content of 60-65% was shredded to particle sizes ranging between approximately 3-12 mm and well mixed to obtain a uniform mixture before adding the amendment materials. The composition of treatments (FW: nutrient amendments ratios and control) is shown in Table 2.

Composting process

The Aerated-turned windrow composting method was employed for the 10-week composting period. This experiment was on a farm-scale in a completely randomized design (CRD) with two replications. Each treatment consisted of an equal quantity (40 kg) of the source-separated FW combined with different quantities of the nutrient amendment materials. Ambient temperatures and temperatures within each compost pile were measured daily using a mercury-in-glass thermometer until the full compost maturity stage was reached. Treatments were aerated by turning piles twice every week manu-

Table 1 Mean physicochemical characteristics of the component feedstock materials used in the compost pile formulations for this experiment

Parameters	Unit	FW	CM	PM	CPHA
pH		5.53	7.63	7.84	6.69
MC	%	63.50	62.88	54.55	0
TOC	%	22.45	23.14	32.32	21.15
TN	%	1.19	1.51	3.64	0.01
C: N ratio		18.87	15.32	8.88	21.15
OM	%	38.70	39.90	55.72	36.45
P	%	0.98	0.47	1.16	1.21
K	%	2.39	1.49	1.83	9.39
EC	mS/cm	3.10	7.20	5.84	17.10
Ca	%	5.60	1.48	3.20	4.92
Mg	%	0.15	0.05	0.79	2.23
Zn	mg/kg	0.52	0.26	0.56	1.34
Pb	mg/kg	0.04	0.37	0.38	0.04
Faecal coliform	CFU/g	1.9×10^3	4.0×10^5	4.6×10^4	0
E. coli	CFU/g	1.3×10^3	2.1×10^5	3.4×10^4	0
Helminth eggs	g	8	14	15	0

***FW**- Food Waste; **CM-** Cow Manure; **PM**- Poultry Manure; **CPHA**- Cocoa Pod Husk Ash

Table 2 Formulations (Kg) and compositions of treatments used for composting

Treatments (Pile)	(FW)	(CM)	(PM)	(CPHA)	Total weight (kg) by dry weight
T1	40	15	15	0.3	70.3
T2	40	10	20	0.3	70.3
T3	40	20	10	0.3	70.3
T4	40	30	0	0	70
T5	40	0	30	0	70
T6	40	0	0	0.3	40.3
C	40	0	0	0	40

***FW**- Food Waste; **CM-** Cow Manure; **PM**- Poultry Manure; **CPHA**- Cocoa Pod Husk Ash
Compositions **(FW: CM: PM: CPHA) -** T1 (40:15:15:0.03) kg; T2 (40:10:20:0.3) kg; T3 (40:20:10:0.3) kg; T4 (40:30:0:0) kg; T5 (40:0:30:0) kg; T6 (40:0:0:0.3); C (40:0:0:0) kg

ally using a shovel, and moisture content was adjusted to about 40-60% by adding water (Cooperband et al. 2003). The comparison of treatments and control was focused on the following:

- Treatments (T1, T2, and T3) were compared with each other to assess the effect of the CM to PM ratios on the compost quality,
- Treatments T4, T5, T6 were compared with each other to assess the effect of the individual nutrient-amendment material on the compost quality.
- All the treatments (T1 to T6) were compared with the control to determine the best treatment and its effect on compost quality.

Analysis of samples

A stratified sampling method was employed in this study, where a compost pile was subdivided into separate zones (top, middle, and bottom) and a series of point samples were collected and composited within each zone. Compost samples (100 g) consisted of mixed composites taken immediately after turning (weekly) from the beginning to the end of the experiment. The samples were air-dried and ground to pass through a 1mm sieve. The physical, chemical, and microbiological properties of the composts were ascertained. Total Kjeldahl Nitrogen (TKN) and the Total Organic Carbon (TOC) of the samples were determined using the Kjeldahl method and Walkley and Black procedure, respectively (Walkey and Black 1934; Singh and Pradhan 1981). Phosphorus (P) was determined with a spectrophotometer according to the phosphomolybdate blue method (Olsen and Sommers 1982). Potassium, Calcium, Magnesium, Lead, and Zinc in composts were measured with a flame photometer (Soltanpur and Workman 1979).

The pH and EC were determined on a water extract from compost using compost to water ratio of 1:5 by weight. The microbiological assays (microbial activity detection) were done for bacteria using the membrane filtration technique. Parameters such as pH, C/N ratio, and germination tests were used to determine the extent of compost. A modified phytotoxicity (germination) test described by Mendes et al. (2016) was used to test the maturity of the compost samples. Cucumber seeds (*Cucumis sativus*) were used in this study because they have early germination properties and are easily attainable locally in Ghana than raddish, cress, or ryegrass, which are also widely used for such maturity determinations (Ofosu-Budu et al. 2010).

Ten seeds of cucumber (*Cucumis sativus*) acquired from Agrimat Company Limited (viability as tested = 90%) were sown on filter paper moistened with different concentrations of compost extract (50% and 100%) and these were compared with the control (100% distilled water) for each type of treatment. This setup was prepared in triplicates and kept at room temperature in the laboratory. The germinated seeds were counted and root length measured after 7 days of incubation. The seeds' responses to the compost treatments were calculated by a germination index (GI) based on the formula below (Chen et al. 2011):

The results are generally expressed as an index.

$$GI = \frac{G \, X \, L}{Go \, X \, Lo} X \, 100$$

where, G and L are Seed germination and Root Length of Treatment, respectively, whereas G_0 and L_0 are the Seed germination and Root Length of the 100% distilled water control.

Statistical analysis

The differences in chemical properties between treatments and control ratios were statistically analyzed. Shapiro-Wilk normality test was used to check the normality of the obtained data. For normally distributed data, comparisons between the seven variables were carried out using one-way ANOVA, whilst data not conforming to normal distribution were compared using the Kruskall-Wallis in Graphpad prism 8. Results with $p \leq 0.05$ were considered significant. To compare the differences, Dunn's test was used ($p < 0.05$). Descriptive analysis was used to determine the phytotoxicity of the matured composts.

Results and discussion

Biodegradation (Mass and volume reduction)

The weight and volume of compost at the end of composting were, on average, reduced by 46.1% and 45.3.5%, respectively (Tables 3 and 4). The biodegradation rate was relatively higher in the treatments than the control indicating that additional biodegradable nutrient source was provided by the amendment materials in the treatments. This is because the additional carbon and nitrogen provided by the nutrient amendments in the treatments supported the increasing microbial biomass and hence increased microbial activity resulting in higher decomposition (Torkashvand 2010).

Also, further average weight and volume reductions of about 28.9 and 27.4% were realized after sieving the finished composts through a 2 mm sieve at the end of the composting period (Table 4).

Quality of compost - Nutrient content

Effect of cow manure and poultry manure (T1, T2, and T3) on compost quality

Effects of nutrient content on compost quality were observed for piles T1, T2, and T3, which contained equal amounts of the FW and CPHA (40 kg and 0.3 kg, respectively), with varying amounts of PM and CM (Table 2). The effect of PM and CM on total nitrogen (TN) of compost is shown in Tables 5 and 6. Levels

Table 3 Material flow in weight during composting

		End of composting			After sieving		
Compost piles	Weight at start of composting (kg)	Weight (kg)	Change in weight (kg)	% Reduction	Weight (kg)	Change in weight (kg)	% Reduction
T1	70.3	35.6	34.7	49.4	20.9	14.7	41.3
T2	70.3	39.1	31.2	44.4	26.7	12.4	31.7
T3	70.3	36.2	34.1	48.5	28.8	7.4	20.4
T4	70	40.8	29.2	41.7	25.4	15.4	37.8
T5	70	26.7	43.3	61.9	21.4	5.3	19.9
T6	40.3	24.4	15.9	39.5	18.2	6.2	25.4
C	40	25.0	15.0	37.5	18.6	6.4	25.6

Table 4 Material flow in volume during composting

		End of composting			After sieving		
Compost pile	Volume at start of composting (m^3)	Volume (m^3)	Change in volume(m^3)	% Reduction	Volume (m^3)	Change in volume(m^3)	% Reduction
T1	0.048	0.025	0.023	47.9	0.015	0.01	40.0
T2	0.048	0.027	0.021	43.8	0.019	0.008	29.6
T3	0.048	0.025	0.023	47.9	0.02	0.005	20.0
T4	0.047	0.028	0.019	40.4	0.018	0.01	35.7
T5	0.047	0.018	0.029	61.7	0.015	0.003	16.7
T6	0.039	0.024	0.015	38.5	0.018	0.006	25.0
C	0.038	0.024	0.014	36.8	0.018	0.006	25.0

Compositions **(FW: CM: PM: CPHA) -** T1 (40:15:15:0.03) kg; T2 (40:10:20:0.3) kg; T3 (40:20:10:0.3) kg; T4 (40:30:0:0) kg; T5 (40:0:30:0) kg; T6 (40:0:0:0.3); C (40:0:0:0) kg

of TN in the treatments and control were in the order T2> T1> T3. Since TN content in PM was higher than CM, the addition of 20 kg of PM to T2 may have promoted better microbial activity and further immobilization (Liang et al. 2006) resulting in the comparatively higher level of total nitrogen recorded.

There was an obvious reduction in total carbon in these treatments compared to the control, the highest being in T2 having 61.42% reduction and lowest being 55.16% recorded for T1. Generally, the source of raw material used during composting influences the humification process (Chefetz et al. 1998). There was a direct association between phytotoxicity and the content of the compost extracts as all treatments were more toxic than the control (Fig. 3). Thus, it was realized that amongst all the treatments (T1, T2, and T3) and control studied, major nutrients like TN and TK were highest in compost T2 (Table 6). However, in terms of germination Index (50%-extract), T2 recorded the least of 19.2 (Fig. 3) proving higher phytotoxicity.

Effect of CM, PM, and CPHA (T4, T5, and T6) on compost quality

For temperature stabilization, the temperature was highest in pile T5 recording 56 °C on the **7**th day. This pile reached maturity within the shortest period which was prepared from FW amended with poultry manure only. Among these treatments, it was observed that the poultry manure effect on total nitrogen was greater than treatments amended by CM and CPHA. This could be as a result of pile T5 having a higher nitrogen content at the start of the composting process. Nutrient content recorded at the end of the composting period was thus the highest for T5 and reduced in the order of T4 and T6 (lowest). This order was found to correspond with

Table 5 Average (± standard error) chemical properties of compost piles before composting

Parameter	T1	T2	T3	T4	T5	T6	C
Total N (%)	1.72±0.03	1.65±0.11	1.83±0.01	1.5±0.04	2.27±0.01	1.28±0.05	1.19±0
Total P (%)	0.62±0.02	0.91±0.03	0.88±0.04	0.23±0.02	1.04±0.07	0.92±0.01	0.98±0.05
Total K (%)	1.49±0.04	1.84±0.02	1.42±0.02	1.26±0	1.04±0.01	2.44±0.13	2.39±0.02
(%) TOC	44.69±0.06	49.12±0.04	50.03±0.12	40.57±0.51	51.21±0.13	24.19±0.08	22.45±0.16
C: N	25.98±1.54	29.77±0.18	27.34±0.24	27.05±0.42	22.56±0.22	18.9±0.1	18.87±0.21
pH	6.58±0.04	6.4±0.01	6.38±0	6.17±0.1	6.46±0.03	6.01±0.06	5.53±0.02
EC(mS/cm)	5.23±0.04	6.02±0.08	7.12±0.01	5.44±0.02	5.25±0.02	3.56±0.05	3.1±0.04
MC (%)	64.95±0.01	68.74±0.06	58.00±2.90	67.49±0.23	54.56±0.02	65.46±1.03	63.04±0.03

Table 6 Average (± standard error) chemical properties of compost piles after composting

Parameter	T1	T2	T3	T4	T5	T6	C	P- Value
Total N (%)	1.2±0.13^{abce}	1.3±0.01^{ace}	1.19±0.02^{abc}	1.08±0^{ad}	1.42±0^{c}	1.01±0.03^{bde}	0.96±0.01^{d}	0.000*
Total P (%)	0.78±0.02^{ae}	0.66±0.03^{a}	0.54±0^{ad}	0.19±0.05^{bde}	1.06±0.0^{c}	0.71±0.03^{ac}	0.77±0.02^{ac}	0.000*
Total K (%)	0.86± 0^{abc}	1.36± 0.04^{bd}	0.97±0.01^{abc}	0.02^{abc}±1.07	0.88±0^{c}	1.42±0.03^{d}	1.31±0.03^{d}	0.000*
(%) TOC	20.04^{a}±0.01	18.95^{a}±0.03	21.08^{a}±0.51	18.92^{a}±0.88	16.29^{a}±0.04	19.62^{a}±1.12	18.28^{a}±0.40	0.092
C: N	17.13^{a}±1.93	14.58^{a}±0.16	17.71^{a}±0.15	17.57^{a}±0.77	11.50^{a}±0	19.39^{a}±0.56	19.04^{a}±0.32	0.083
pH	8.5^{a} ±0.03	8.88^{a} ±0.08	8.44^{a}±0.01	8.74^{a}±0.09	7.95^{a}±0.18	9.01^{a}±0.08	9.03^{a}±0.01	0.920
EC (mS/cm)	8.42±0.12^{ab}	5.63±0.02^{ad}	7.03±0.1^{bc}	7.24±0.03^{ac}	3.42±0.07^{d}	6.18±0.02^{d}	6.11±0^{d}	0.000*
MC (%)	14.80^{a}±0.05	27.95^{a}±0.03	28.20^{a}±0.56	35.90^{a}±0.05	25.95^{a}±0.12	20.40^{a}±0.02	19.66^{a}±0	0.762

Levels in the rows (end of composting process) not connected by the same letter are significantly different using Dunn's test.
* denotes statistical significance among the compost piles ($P < 0.05$). This implies that the compost treatments (compositions) studied had a significant effect on the compost parameters measured and thus, values recorded were statistically different amongst

the nutrient content of the amendments. This suggests that the quality of starting feedstock affects the quality of the final compost produced at the end of the process.

The compost quality of the individual treatments (T1-T6) compared with the control

Concentrations of plant nutrients in the composts as influenced by the amount and type of amendment materials are presented in Tables 5 and 6. TP concentrations increased from an initial value of 0.62% and 1.04% in treatments T1 and T5 to 0.78% and 1.06%, respectively. This increase is similar to results observed by Afifi et al. (2012), who reported that the loss of organic matter contributes to the increase in phosphorous in composting. Khater (2015) observed similar results in his study and attributed the increase to precipitation of phosphorus in solid forms which were not easily dissolved and leached out.

There was, however, a reduction in phosphorous recorded for piles T2, T3, T4, T6, and C. This conforms to work done by Frossard et al. (2002) who reported that only 2 to 16% of total phosphorus in finished compost is rapidly exchangeable, whereas about 40 -70% is slowly exchangeable or not exchangeable. He emphasized the general assumption that a larger proportion of phosphorus in finished compost may not be readily available for plant uptake and use because it is incorporated in organic matter.

Potassium recorded was lowest in pile T1 (0.88%) and highest in pile T6 (1.42%) at the end of the composting process. Generally, Potassium decreased in all composts due to microbial activities and watering, causing the leaching of soluble potassium from the feedstocks during the composting process. This leaching phenomenon occurs mostly in uncovered windrows (Fricke and Vogymann 1994). Chatterjee et al. (2013) attributed this decrease to the loss of potassium salts through excessive leaching during the composting period. The final potassium content (%) in all composts though adequate constituted less than 3% of the total weight (Table 6). All finished composts, except for pile T4, contained a substantial amount of micronutrients at the end of the composting period. Statistically, there was a significant difference in TP and TK levels measured between the piles ($p<0.05$).

pH evolution

The pH in all piles generally showed an increasing trend throughout the composting period varying between 6 to 9. Based on Fig. 1, the pH value levels increased from day 1 until day 14. This increase indicates the reduction of volatile acids and their further combination with ammonia gas released during denaturing of protein (Ramaswany et al. 2010). Results indicated that the pH pattern of pile T2 in week 2 was slightly different from the other treatments and control where the value slightly dropped and later rose to slightly alkaline conditions in week 4. As for the control, pH of 5.53 (explained by the acidic character of the FW used) was comparatively the lowest amongst all piles at the start of composting process, later rising to neutral pH in week 4 and further rising and ending the composting process with pH of 8.86. Sundberg et al. (2004) noted that acidic pH affects the rate of respiration of microbes and degradation during composting. This assertion was observed in the control, which had comparatively high acidity at the start of the process (pH of 5.53), hence recording the lowest rate of degradation amongst all the treatments studied at the end of the process (Tables 3 and 4). The sharp increases of pH values observed throughout the period, for instance, from 7.56 in week 5 to 8.36 in week 6 in the control, could be due to the frequency of turning (twice a week) employed in this study (Zakarya et al. 2015).

According to Sundberg et al. (2004), the change of mesophilic to thermophilic conditions of compost pile results in the more alkalinity of pH. This was evident in T5 which achieved thermophilic temperatures in the

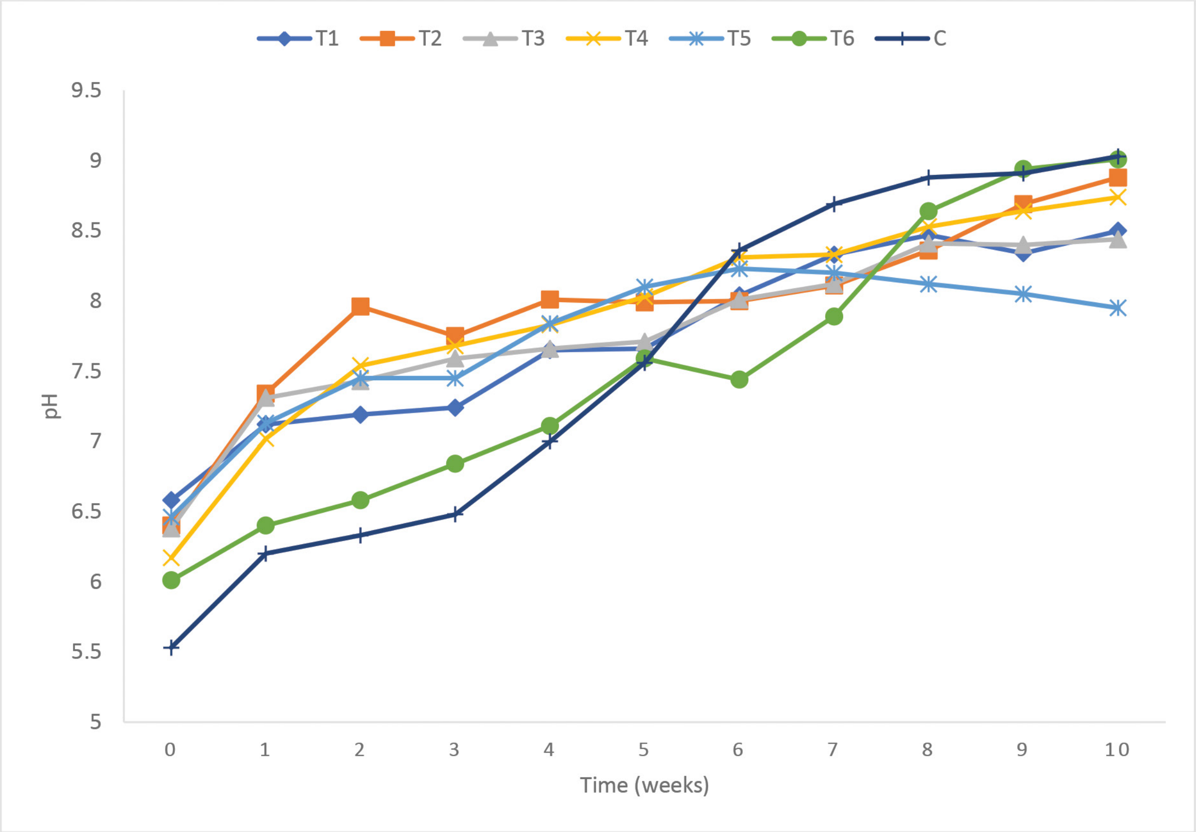

Fig. 1 Evolution of pH values during the composting process

first two weeks of composting with an accompanying pH rise from 6.46 to 7.45. Thus, maximum degradation is achieved by microbes in the pH range of 7 to 8 (Nakasaki et al. 2001). After week 6, all but pile T5 showed an increasing trend in pH recorded. The notable decline of pH registered in the case of T5 (FW + Poultry Manure only) started at 8.23 to finalize at 7.95 at the end of the composting process. Such a pH profile can be explained by the action of acid-producing bacteria that breaks down complex organic materials (biodegradation of poly-carbohydrates by Krebs cycle) to organic acid intermediates (Dumitrescu and Manciulea 2006). Zakarya et al. (2015) attributed this decrease to the formation of carbon dioxide gas and organic acid during organic matter decomposition an unstable fraction of OM which was mineralized, and it can also be directly related to the rate of microbial actions since microorganisms consume these organic elements during the process.

At the end of the process, pH values for the control and all the treatments except T5 (7.95) were above 8, creating conditions for ammonia and amine-related odour generation. Notwithstanding, all but T6 and control were within the pH acceptable range (6-9), thus these composts are suitable as agricultural fertilizers (Eklind and Kirchmann 2000). There was a statistical difference for pH measured between piles at $p < 0.05$.

Electrical conductivity

EC reflects the degree of salinity in a composting mixture, which shows its possible phytotoxic/ Phyto inhibitory effects such as low germination rate, withering, etc. on the growth of plants after its application to soil (Lin 2008). The control pile had the lowest EC value of 3.10 mS/cm while pile T1 recorded the highest EC (7.23 mS/cm) at the start of the composting process as shown in Table 5. At the end of the composting period, the increase in EC observed in T1, T3, T4, T6 and the control could be due to the accumulation of nitrate. Although nitrate was not measured in this study, Smith and Doran (1996) reported that the presence of nitrates may be responsible for the high EC observed in agricultural waste composts. Butler et al. (2001) reported that a high EC value in composting indicates the high presence of nutrient elements or a slower decomposition of the organic matter, therefore, a lower release of mineral salts into the solution in the process of biodegradation of biomass waste. Also, Composts with elevated EC values, however, can be especially rich in nutrients, since nutrients are responsible for much of the measured conductivity (Crohn 2016).

EC levels in pile T5 reduced fairly from week 7 to the end of the composting period. At the end of the composting period, T5 recorded the lowest salinity value of 3.42 mS/cm attributed to the precipitation of mineral salts and the production of metabolites such as ammonium during the process (Valkili et al. 2012). This EC value was thus slightly below the acceptable limit of 4 mS/cm and hence, its application in agriculture can support plant growth and remediate soils that are very saline (Hargreaves et al. 2008). According to Noguera et al. (2003), EC values less than 3.5 mS/cm, which indicates low soluble salt levels, are suitable as potting compost. Low EC values indicate a lack of available salts, whereas high values indicate a high concentration of soluble salts that may inhibit the biological activity or may be unsuitable for land application if large quantities of the composts are used (Tibu et al. 2019). Statistically, the difference in the mean EC after composting in all the piles was significant ($p < 0.05$).

Carbon: Nitrogen ratio

C:N ratio is considered as an objective indicator of compost quality and measurement of compost maturity (Radovich et al. 2011). The C:N ratio of treatments and control at the start of composting ranged from 18 to 30 and was lowest in pile C (18.87) and highest in T2 (29.77). There was a decreasing trend of C: N observed in all piles throughout the experimental period indicating a reduction in carbon content and nitrogen by microbial activities (Tibu et al. 2019). During composting, C:N ratio for all treatments decreased faster than the control because the amendment materials especially poultry manure provided additional nitrogen for microbial use (Fig. 3). The reduced C:N ratio at the end of the composting period observed is similar to findings by Al-Bataina et al. (2016) who in his study stated that as the age of compost increases, C:N ratio is decreased. Pile T5 had the highest Nitrogen content of 2.27% and 1.42% at the start and end of the composting period, respectively (Tables 5 and 6). These results are similar to those obtained by Benito et al. (2005) who found that the total nitrogen rate ranged from 0.99 to 2.01% at the end of his experimental period. Nitrogen loss in compost piles may be attributed to microbial and enzymatic processes responsible for breaking down nitrogenous organic materials in the waste to ammonium (NH_4+). Under sufficiently alkaline conditions ammonium is converted into ammonia gas, which tends to escape into the atmosphere (Hubbe et al. 2010). However, this ammonia gas was sufficiently retained in pile T5 when moist and cooler conditions were created as the highest volume of water used in this study (50 L) was added to the outer layer (Hubbe et al. 2010), explaining why TN loss in pile T5 was slower and fairly constant especially from week 5 to week 10 (Fig. 2). Thus, the relatively small particle size (powdery nature) of poultry manure which was more in T5 required high amounts of water to keep the moisture content within optimum range (40-60%) during composting.

The addition of a high amount of PM (30 kg) to T5 may have led to the production of acidic intermediate compounds due to microbial metabolism and hence reduction in pH value of the compost, retaining a greater percentage of ammonia as NH_4+ ,thereby reducing NH3 loss (Torkashvand 2010). Although C:N ratio in all piles was < 25:1 at the end of the composting process and thus considered matured for agriculture application (Hong Kong Organic Resource Centre 2005), only T5 was well matured as it recorded the lowest of 11.47. According to Gale et al. (2006), C: N ratio ≤15 in final compost proves higher maturity above which net nitrogen immobilization may occur soon after compost addition to soil. Statistical analysis carried on the data obtained for mean TOC, OM, TN and C:N contents in all the compost piles at the end of the process were significantly different ($p < 0.05$).

Stability and maturity

Germination test

One of the most important criteria used to assess the suitability of compost in crops is its toxicity to plants

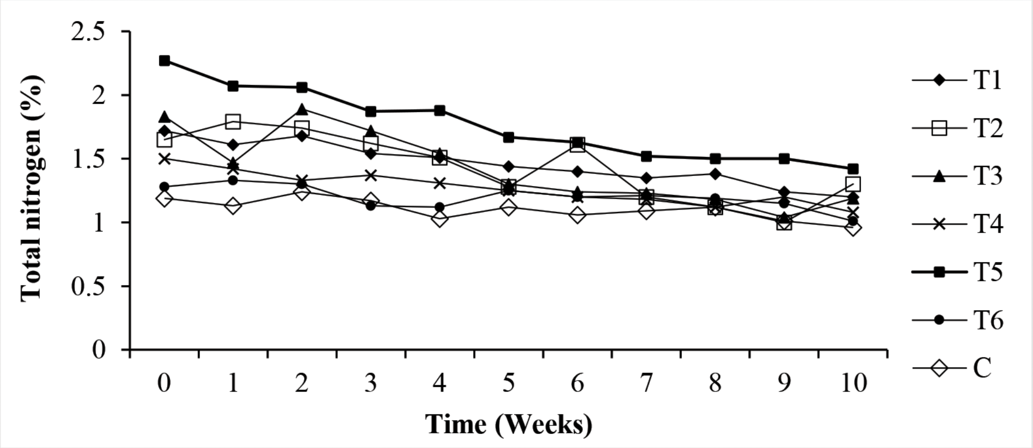

Fig. 2 Total Nitrogen (%) observed throughout the composting period

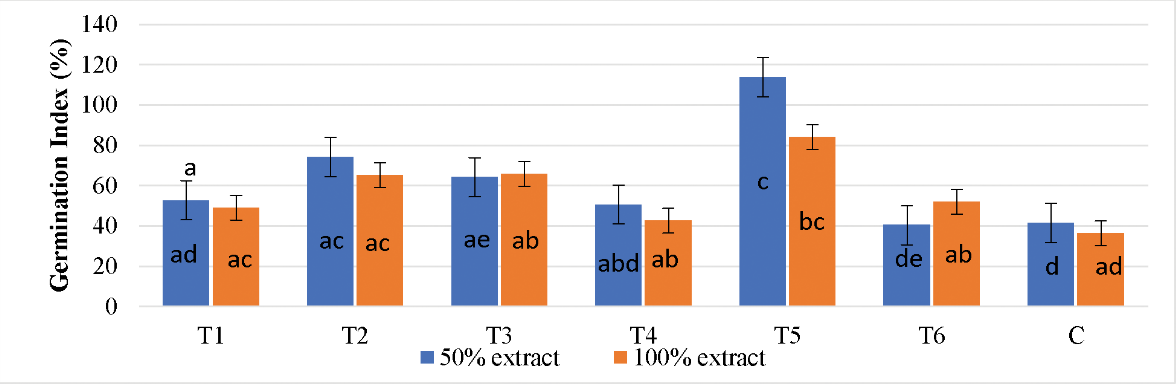

Fig. 3 Germination Index (%) recorded for compost

Compositions of Treatments and control **(FW: CM: PM: CPHA)** - T1 (40:15:15:0.03) kg; T2 (40:10:20:0.3) kg; T3 (40:20:10:0.3) kg; T4 (40:30:0:0) kg; T5 (40:0:30:0) kg; T6 (40:0:0:0.3); C (40:0:0:0) kg.

Bar not connected by the same letter are significantly different using Dunn's test.

(Cooperband et al. 2003). Germination index (GI) has been frequently used to estimate phytotoxicity and thus maturity of composts, which is an important criterion for evaluating the suitability of composts for land application. For instance, GI is itemized in the quality assessment regulation of compost for commercialization in Italy (Luo et al. 2018). Biomaturity of composts in this study was determined using cucumber seeds, which have early germination properties and are easily attainable locally in Ghana. It was observed that both extract concentrations (50% and 100%) of all the treatments caused better growth of the cucumber seeds and higher GI than C (Fig. 3).

Many authors have concluded that composts with GI values greater than 100% are considered non- phytotoxic (Piemonte 2001), whereas Zucconi et al. (1981) reported that the compost is phytotoxin-free when GI values are higher than 80%. Results showed that pile T5 had a mean GI of 113.3% and 84.2% for its 50% and 100%-extracts respectively. This indicates that pile T5 investigated in this study contained low levels of toxic factors such as salinity or phenolic compounds and therefore could be considered phytotoxin-free (Hargreaves et al. 2008). The increase of the compost concentrations generally affected GI. This was because GI values recorded for 50% compost-extract for piles T1, T2, T4, T5, and C decreased when 100% compost-extract was used (Fig. 3). The levels of phytotoxins such as volatile fatty acids present in the 100% compost-extract were higher than the 50% compost-extract, hence, inhibiting growth and subsequent low GI (Bazrafshan et al. 2016). On the other hand, for 50% compost-extract concentration, GI values of 64.2% (T3) and 40.3 (T6) rather increased for 100% compost-extract concentration to 65.8% (T3) and 52.1% (T6) 100%-extract). This may have been due to the presence of adequate amounts of NH_4^+ and other nutrients allowing better growth and GI (Romero et al. 2013).

Generally, high inhibitory effects on cucumber seeds were recorded for composts T1, T2, T3, T4, T6, and C extracts, as GI (%) were all below 80%, which probably meant that the respective composts may not be matured, and there might be the presence of some phytotoxic organic compounds (Estaún et al. 1985). GI increases with composting time as phytotoxic organic compounds are gradually eliminated during the composting process (Saña and Oliva 1987). This indicates that the ten weeks composting period and 2 weeks of curing in this study were not enough in reducing these phytotoxic compounds and therefore a longer composting period is recommended. Zahrim et al (2016) in their study used cabbage seeds (*Brassica oleracea*) and found out that the germination index increases with the age of composting. Thus, their results indicated that the germination index increased gradually from 115.66% to 157.61% on days 0 and 40, respectively. Consequently, the germination index of composts produced in this study over 70 days using cucumber seeds (*Cucumis sativus*) was highest in pile T5 (113.8%), which was lower than germination indexes observed by Zahrim et al (2016). These contrasting observations could be attributed to the type of seed used for the germination test. Emino and Warman (2004) in their study concluded that cabbage seed was more sensitive to phytotoxicity than cucumber, hence comparatively better in determining the maturity of composts.

Heavy metals

The Level of Heavy metals present in compost is among the crucial factors that limit its marketing and use because of the bioaccumulation potential of these metals. Compost samples were analyzed for Zinc (Zn) and Lead (Pb) as shown in Table 7. The heavy metal concentration found to be the highest in all the finished composts was Zn recorded in pile C (0.52 mg/

Table 7 Heavy metals content in the compost treatments

		Treatments						
		T1	T2	T3	T4	T5	T6	C
Pb	Start	0.04±0.03	0.26±0.02	0.30±0.03	0.37±0	0.36±0.04	0.04±1.78	0.04±0.05
(mg/kg)	End	0.03±0.01	0.26±0.03	0.23±0.04	0.05±0	0.07±0.01	0.04±0	0.02±0.01
Zn	Start	0.60±0.02	0.44±0.03	0.52±0	0.48±0	0.55±0.04	0.71±0.02	0.52±0.05
(mg/kg)	End	0.17±0.01	0.13±0.03	0.12±0	0.22±0.04	0.16±0.01	0.46±0.03	0.49±0.01

Compositions of Treatments **(FW: CM: PM: CPHA)**. T1 (40:15:15:0.03) kg; T2 (40:10:20:0.3) kg; T3 (40:20:10:0.3) kg; T4 (40:30:0:0) kg; T5 (40:0:30:0) kg; T6 (40:0:0:0.3); C (40:0:0:0) kg kg), whereas pile T3 recorded the lowest Zn of 0.12 mg/kg. This observation is affirmed by Zheljazkov and Warman (2004) who reported that Zn is the most abundant heavy metal in the source-separated food waste. Heavy metals are said to non-degradable throughout the composting process, even in specialized separation systems (Richard and Woodbury 1992). Each compost pile recorded a reduction in metal content at the end of the composting period. The reduction might be attributed to the formation of humic acids and their accompanying complexing action (Wilson and Dalmat 1983).

The presence of high levels of heavy metals such as Pb and Zn in compost poses an obvious concern when it is to be applied to food crops. Notwithstanding that organic substrates may experience some level of contamination contributing to high heavy metal concentration by undergoing multiple handling processes before they are applied for composting, which may further cause some level of contamination in the final compost (Xiujin et al. 2008). Therefore, the production of clean compost starts from the feedstock raw material used (Rockson 2014). The highest Pb content recorded was 0.26% (T2) and the least was 0.03% (T1). Pb levels in all composts were generally lower than the recommended limit by Brinton (2000) probably due to the use of source-separated feedstock (FW, PM, CM, and Cocoa pod husks) which had minimal or no contamination. The source-separation of the organic fraction of municipal solid waste is a key process that helps in reducing the non-organic content in bio-waste, and other impurities such as heavy metals (Brinton 2000).

Table 8 Microbial load in the treatments

Composts (Treatments)		FC (CFU/g)	E. coli (CFU/g)	Helminth Eggs (g/TS)
T1	Start	3.7×10^4	3.0×10^3	12
	End	2.7×10^3	5.6×10^2	6
T2	Start	5.1×10^4	5.2×10^3	7
	End	8.3×10^2	1.6×10^2	2
T3	Start	6.8×10^4	1.2×10^3	8
	End	9.8×10^3	5.0×10^2	3
T4	Start	4.3×10^5	7.6×10^3	10
	End	6.6×10^4	5.3×10^2	6
T5	Start	4.0×10^4	3.3×10^3	10
	End	4.8×10^2	1.0×10^2	2
T6	Start	2.1×10^3	1.0×10^2	8
	End	1.5×10^3	0	4
C	Start	1.9×10^3	0	8
	End	1.6×10^3	0	5

Microbial load in the composts

Pathogenic levels recorded for the various composts at the end of the ten-week composting period were generally low. It can be inferred from Table 8 that there was a significant reduction in the concentration of all the various pathogens in all the composts over the composting period due to the high temperatures (Fig. 4) generated although the thermophilic temperatures were not sustained long enough for effective pathogen inactivation. In general, values for Faecal Coliforms and *E. coli* in all composts (Treatments and control) were less than 10^5. Helminth eggs were not detectable in compost T5 and T6. *E-Coli* was also not detected in composts T6 and C at the end of the composting period (Table 8). All values of *E-Coli* for all composts were below the acceptable standard of 1000 CFU/g (Hong Kong Organic Resource Centre 2005).

Helminth eggs in compost are considered to be the most resistant pathogens to extreme conditions and therefore if their population reduces significantly by the composting process, it could be considered that all other pathogens have been removed as well (Feachem et al. 1983). However, this was not the case for this study because although Helminth eggs were absent in T5 and T6, TC and FC were detected in composts T5 and T6.

This might be due to the short thermophilic phase that was observed in the piles attributable to frequent turning (twice every week carried out in this study) and the small size of piles (Ogunwande et al. 2008).

Operating conditions affecting compost quality

Temperature

The progress of the composting process is assessed by monitoring temperatures generated over a period. According to Eusufzai et al. (2013), effective sanitization of feedstock used and efficiency of the composting process occurs during the period when piles go through the three temperature phases; mesophilic phase where temperatures range between 15 and 45 °C; the thermophilic phase with temperatures ranging between 45 and 70 °C; and cooling phase when the pile temperatures drop below 60 °C. Although temperatures recorded throughout the composting period as shown in Fig. 4 indicated that all piles reached the mesophilic phase, only piles T1, T2 and T5 reached the thermophilic phase.

Results further showed that the thermophilic stage occurred in the first two weeks during composting for most treatments. Pile T5 recorded the highest mean temperature of 56 °C on the 7th day, attributed to the high levels of TOC and Nitrogen (51.21% and 2.27% respectively) adequate for microbial utilization and increased microbial activity. This temperature was, however, not sustained for a long time and hence was not adequate to ensure efficient pathogen inactivation. Thus, maintaining a minimum temperature of 55 °C or greater for at least 15 days during the composting period is recommended for effective pathogen inactivation (De Bertoldi et al. 1983). Pile T5 sustained the thermophilic phase from day 3 to day 10 (7 days), which was the highest, followed by pile T2 (4 days) and pile T1 recording the lowest (1 day). The remaining treatments and control rather exhibited a dominant mesophilic phase over the composting period.

Generally, there was a gradual decline in mean temperatures recorded for all piles as the process progressed. This observation could be as a result of the exhaustion of available substrate (feedstock) and the replacement of the thermophilic microflora by a mesophilic one, which partially degrades existing bio-resistant compounds, essentially cellulose and to a lesser degree, lignin (El-Housseini et al. 2002). Turning was done twice every week throughout the study period. It was observed that every turning caused a rise in temperature for a short time, for instance in pile C, which recorded a mean temperature increase of 8 °C (from 36

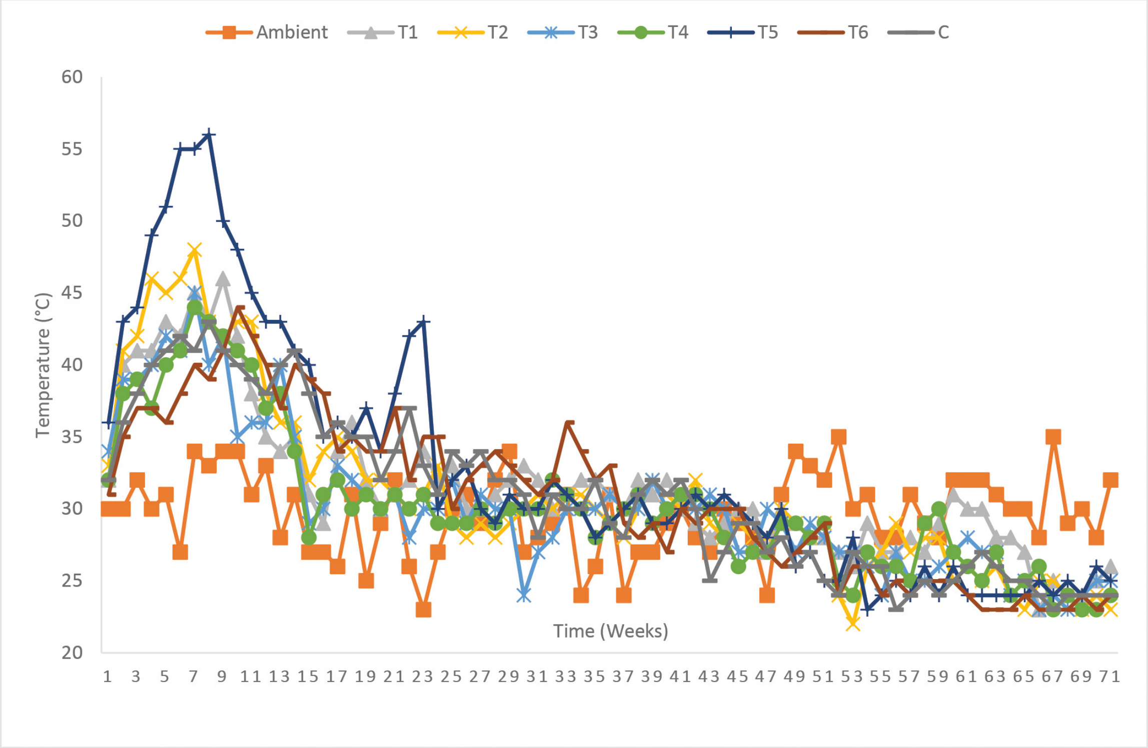

Fig. 4 Daily average temperature readings for the compost piles over the composting period

°C on day 21 to 42 °C on day 23). It was also observed that most treatments experienced high temperatures for an extended period compared to the control (Fig. 4). Statistical analysis carried out on all the composts showed that there was no significant difference (P> 0.05) in the temperature readings in all the different compost treatments (piles). Statistically, there was no significant difference (p> 0.05) in the temperature readings in all the different compost piles.

Moisture content

Moisture content is one of the essential factors in the composting process that affects the degradation level of organic matter making available a suitable medium for microorganisms to stay alive and perform their activities. A study carried out by Tirado (2008) indicated that water provides a medium for the transportation of dissolved nutrients required for metabolic and physiological activities of microorganisms. Roughly, based on the graph in Fig. 4, there was a general fluctuation and decreasing trend in the amount of moisture content in each of the compost medium over the composting period. Results indicate that all compost piles before composting had moisture content ranging between 50-70 %. Moisture content between 40 and 60% (by weight) provides adequate moisture without limiting aeration. The highest moisture content recorded at the start and end of the experimental period was in Pile T2 (68.74%) and T4 (35.90%), respectively. Consequently, Pile T5 and T1 recorded the lowest moisture content of 54.55% and 14.80% at the start and end of the process, respectively. Generally, all moisture content values recorded showed a general decreasing trend from the start-up to the end of the process (Fig. 5). This reduction is due to the evaporation of MC inside the materials by produced heat from microbial activities and turning (Larney and Blackshaw 2003). Thus, the proportion of moisture losses during the composting process is an indication of disintegration rates (Kalamdhad and Kazmi 2009).

Moisture content values recorded in some piles increased as the composting process progressed. For instance, Pile T4 (week 6) increased from 45.66% to 57.35%, which is attributable to the high quantity of water that was added in that week (4.5 L). Pile T5 maintained a fairly constant MC in the first 4 weeks before declining in week 5. The constant MC could be attributed to the fact that the particle size of poultry manure pile T5 was relatively small and compressed together anytime water was added. Thus, a high moisture content reduces the pore space available for air as well as reducing its structural strength. This permits greater

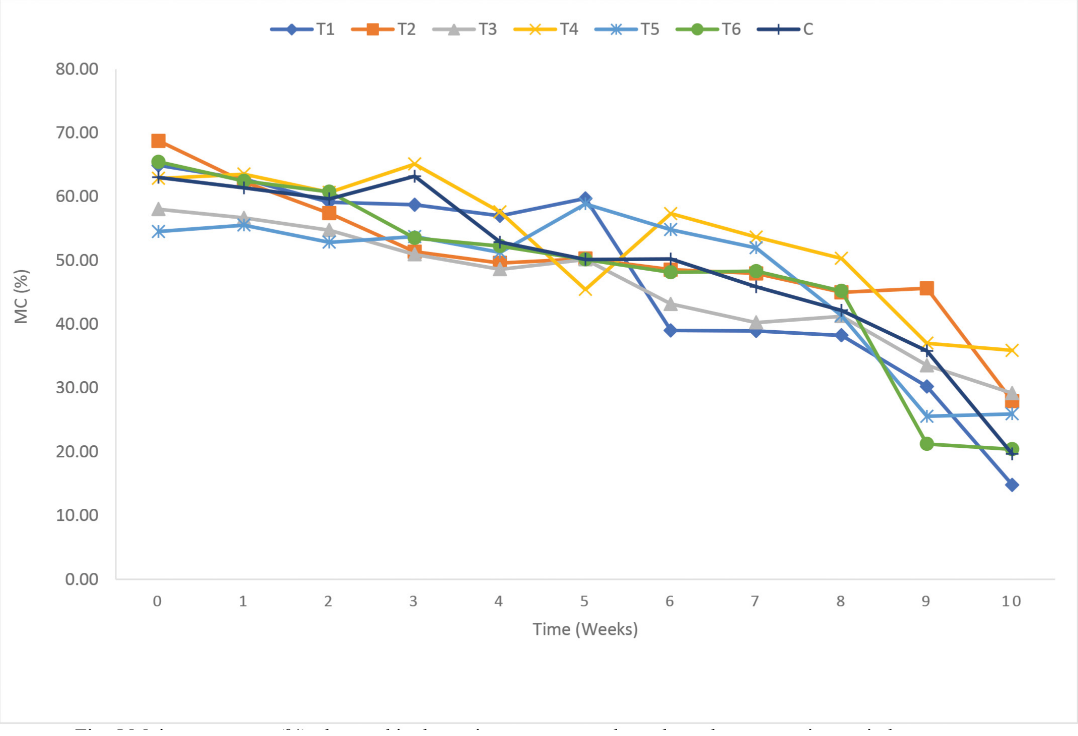

Fig. 5 Moisture content (%) observed in the various treatments throughout the composting period

compaction and less interstitial or air space in the pile leading to a reduced loss of water by evaporation (Urban Composting 2014). At the end of the process, the final amounts of MC in all composts were within the optimum range for mature compost, suggested by Shilev et al. (2007). Statistically, there was no significant difference (p> 0.05) in the temperature readings in all the different compost piles.

Turning

Turning of the compost pile is very critical in ensuring rapid decomposition of organic matter and production of high-quality compost (Kuo et al. 2013). In this study, all piles and control were turned twice every week in accordance with work done by Beck (1997) who suggested that turning should be done twice a week with the reason that more frequent turning may not be a good investment of time and energy.

Rockson (2014) in his study observed that a 3-day turning frequency (3DT) achieves a better process efficiency and sanitization potential, organic matter mineralization, and nutrients quality compared to other turning frequencies (7-day turning frequency and 14-day turning frequency); however, turning on a weekly (7DT) basis ensures a better TN conservation in the compost pile than the 3-day turning frequency. Although nitrogen losses were observed in all treatments and control at the end of the process, pile T5 had the highest nitrogen loss of 37.44% whiles the control recorded the lowest of 19.33% (Table 6). This implies that higher nitrogen losses are likely to occur when starting feedstocks are high in nitrogen.

There were slight increases in pile temperatures immediately after each turning operation in the early days of the experiment. This was responsible for the rise and fall pattern of the temperature profile observed in Fig. 4 as re-activation of the composting process occurred by the incorporation of external material into the piles, providing degradable substrate for the microbial biomass (Ogunwande et al. 2008). However, this turning frequency significantly decreased temperature build-up and the short thermophilic observed in the piles during the composting period (Tognetti et al. 2007).

Conclusion

It was observed that the final composts produced met international standards set by Hong Kong Organic Resource Centre (2005). This suggests that the proposed strategy for handling and recycling food waste sources by co-composting with nutrients amendment materials has demonstrated their feasibility to produce composts of high quality for their increased usage in agriculture. There were appreciable levels of Total Nitrogen, Total Phosphorus, and Total Potassium in final composts; 0.96-1.42%, 0.19–0.78%, and 0.86-1.42%, respectively. All treatments showed relatively higher nutrients' content and germination rates than the control (FW only) at the end of the composting period. Generally, the development of this type of nutrient-enriched bio-inputs requires additional research and development, not only in the scale (medium/ large) and composting method but also the process conditions like turning, temperature, etc.

Acknowledgement The authors would like to thank the Regional Water and Environmental Sanitation Centre Kumasi (RWESCK) at the Kwame Nkrumah University of Science and Technology, Kumasi with funding from the Ghana Government through the World Bank under the Africa Centre's of Excellence project for fully funding this research work.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

References

Adhikari BK, Barrington S, Martinez J, King S (2008) Characterisation of food waste and bulking agents for composting. Waste Manag 28: 795-804. https://doi.org/ 10.1016/j.wasman.2007.08.018

Afifi MMI, Estefanous AN, El-Akshar YS (2012) Biological chemical and physical properties of organic wastes as indicators maturation of compost. TJASR 8(4): 1857-1869

Al-Bataina BB, Young TM, Ranieri E (2016) Effects of compost age on the release of nutrients. ISWCR 4: 230–236. https://doi org/10 1016/j iswcr 2016.07.003

Barrington SD, Choiniere M, Trigui WK (2002) Effect of carbon source on compost nitrogen and carbon losses. Bioresour

Technol 83(3):189-194. https://doi: 10.1016/s0960-8524(01)00229-2

Bazrafshan E, Zarei A, Mostafapour KF, Poormollae N, Mahmoodi S, Zazouli A (2016) Maturity and stability evaluation of composted municipal solid wastes. Health scope 5(1): 1-9. https://doi.org/10.17795/jhealthscope-33202

Beck M (1997) The secret life of compost. A guide to static-pile composting- Lawn, Garden, Feedlot or Farm. Acres USA, Austin, TX. 13-15

Benito M, Masaguer A, De Antonio R, Moliner A (2005) Use of pruning waste compost as a component in soilless growing media. Bioresour Technol 96: 597–603. https://doi.org/10.1016/j.biortech.2004.06.006

Brinton WF (2000) Compost quality standards and guidelines: An international view. Compost standards and guidelines. Report to NYSAR by Woods End Research Laboratory Inc

Butler TA, Sikora LJ, Steinhilber PM, Douglas LW (2001) Compost age and sample storage effects on maturity indicators of biosolids compost. J Environ Qual 3: 2141-2148. https://doi.org/10.2134/jeq2001.2141

Chatterjee N, Flury M, Hinman C, Cogger CG (2013) Chemical and physical characteristics of compost leachates: A review report prepared for the Washington State, Department of Transportation, Washington State University

Chefetz B, Adani F, Genevini P, Tambone F, Hadar Y, Chen Y (1998) Humic-acid transformation during composting of municipal solid waste. J Environ Qual 27: 794–800. https://doi.org/10.2134/jeq1998.00472425002700040011x

Chen L, De Haro MM, Moore A, Falen C (2011) The composting process: dairy compost production and use in idaho. CIS 1179. University of Idaho. 89-94. https://www.cals.uidaho.edu/edcomm/pdf/cis/cis1179.pdf

Cooperband LR, Stone AG, Fryda MR, Ravet JL (2003) Relating compost measures of stability and maturity to plant growth. Compost Sci Util 11: 113-124. https://doi.org/10.1080/1065657X.2003.10702118

Crohn D (2016) Assessing compost quality for agriculture. ANR Publication 8514: 1-10. https://doi.org/10.3733/ucanr.8514

De Bertoldi M, Vallini G, Pera A (1983) The biology of composting: A review, Waste Manage Res 1: 157–176

Dumitrescu L, Manciulea I (2006) Elements of biochemistry. Brașov Transilvania, University of Brașov Press

Eklind Y, Kirchmann H (2000) Composting and storage of organic household waste with different litter amendments: nitrogen turnover and losses. Bioresour Technol 74: 125-133. https://doi.org/10.1016/S0960-8524 (00)00005-5

El-Housseini M, Fahmy Soheir S, Allam EH (2002) Co-compost production from agricultural waste and sewage sludge. 17th Wisconsin Council for the Social Studies (WCSS) Thailand 58: 1755- 1768

Emino ER, Warman PR (2004) Biological assay for compost quality. Compost Sci Util 12: 342–348. https://doi.org/10.1080/1065657X.2004.10702203

Estaún V, Calvet C, Grasses JM (1985) Chemical determination of fatty acids organic acids and phenols during olive marc composting process. Acta Hortic 172: 263-270. https://doi.org/10.1080/01140671.2002.9514208

Eusufzai M, Deb S, Maeda T, Fujii K (2013) Mass loss and C and N release from decomposing fresh and composted residues as affected by cold climate conditions. Environ Nat Resour J 3:116. https://doi.org/ 10.5539/enrr.v3n2p116

Feachem RG, Bradley DJ, Garelick H, Mara DD (1983) Sanitation and disease: Health aspects of excreta and wastewater management. Int J Environ. John Wiley and Sons Chichester UK

Fricke K, Vogtmann H (1994) Compost quality: Physical characteristics, nutrient content heavy metals and organic chemicals. Toxicol Environ Chem 43: 95-114. https://doi.org/10.1080/02772249409358021

Frossard E, Skrabal P, Sinaj S, Bangerter F, Traore O (2002) Forms of exchangeability of inorganic phosphate in composted solid organic waste. Nutr Cycl Agroecosystems 62: 103-113. https://doi.org/10.1023/A:1015596526088

Gale ES, Sullivan DM, Cogger CG, Bary AI, Hemphill DD, Myhre EA (2006) Estimating plant- available nitrogen release from manures composts and specialty products. J Environ Qual 35: 2321-2332. https://doi.org/10.2134/jeq2006.0062

Ghana Statistical Service (2014) 2010 Population and housing census, District analytical report, Kumasi Metropolitan.

Hargreaves JC, Adl MS, Warman PR (2008) A review of the use of composted municipal solid waste in agriculture. Agric Ecosyst Environ 123: 1-14. https://doi.org/10.1016/j.agee.2007.07.004

Hong Kong Organic Resource Centre (2005) Compost and soil conditioner quality standards. 1-3

Hubbe MA, Nazhad M, Sanchez C (2010) Composting as a way to convert cellulosic biomass and organic waste into high-value soil amendments: A review. Bio Resour 5(4): 2808-2854. https://doi.org/10.15376/biores.5.4.2808-2854

Iowa State University Extension Service (2004) Practices to reduce ammonia emissions from livestock operations. PM 1971a. Iowa State University. Ames, Iowa

Kalamdhad AS, Kazmi AA (2009) Effects of turning frequency on compost stability and some chemical characteristics in a rotary drum composter. Chemosphere 74(10): 1327-1334 813. https://doi.org/10.1016/j.chemosphere.2008.11.058

Khater E (2015) Some physical and chemical properties of compost. Int J Waste Resour 5: 1–5. https://doi org/10 4172/2252-5211 10001 72

Koenig RT, Palmer MD, Miner FD, Miller BE, Harrison JD (2005) Chemical amendments and process controls to reduce ammonia volatilization during in- house composting. Compost Sci Util 13: 141-149. https://doi.org/10.1080/1065657X.2005.10702231

Kuo S, Ortiz-Escobar ME, Hue NV, Hummel RL (2013) Composting and compost utilization for agronomic and container crops. Department of Crop and Soil Sciences, Washington State University, Research and Extension Center, Puyallup, WA

Larney F, Blackshaw R (2003) Weed seed viability in composted beef cattle feedlot manure. J Environ Qual 32:1105-13. https://doi.org/10.2134/jeq2003.1105

Liang YK, Quan X, Chen JW, Chung JS, Sung JY, Chen S, Xue DM, Zhao YZ (2000) Long-term results of ammonia removal and transformation by biofiltration. J Hazard Mater 80(1-3): 259-269. https://doi.org/10.1016/j.biortech.2005.03.041

Liang Y, Leonard JJ, Feddes JJR, McGill WB (2006) Influence of carbon and buffer amendment on ammonia volatilization in composting. Bioresour Technol 97: 748-761. https://doi.org/10.1016/j.biortech.2005.03.041

Lin C (2008) A negative-pressure aeration system for composting food wastes. Bioresour technol 99: 7651-6. https://doi.org/10.1016/j.biortech.2008.01.078

Luo Y, Liang J, Zeng G, Chen M, Mo D, Li G, Zhang D (2018) Seed germination test for toxicity evaluation of compost: Its roles problems and prospects. Waste Manag 71: 109–114. https://doi.org/10.1016/j.wasman.2017.09.023

Mendes PM, Becker RCorrêa LB, Bianchi I, Dai PRÁ MA, Lucia TJR, Corrêa EK (2016) Phytotoxicity as an indicator of stability of broiler production residues. J Env Manag 167: 156-159. https://doi.org/10.1016/j.jenvman.2015.11.031

Miezah K, Obiri-Danso K, Zsófia K, Mensah MY (2015) Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Manage 46:15-27. https://doi.org/10.1016/j.wasman.2015.09.009

Nakasaki K, Ohtaki A, Takano H (2001) Effect of bulking agent on the reduction of NH_3 emissions during thermophilic composting of night-soil sludge. Waste Manag Res 19: 301–307. https://doi.org/10.1177/0734242X0101900406

Noguera P, Abad M, Puchades R, Maquieira A, Noguera V (2003) Influence of particle size on physical and chemical properties of coconut coir dust as container medium. Commun Soil Sci Plant Anal 34: 593–605. https://doi.org/10.1081/CSS-12001 7842

Ofosu-Budu GK, Hogarh JN, Fobil JN, Quaye A, Danso SKA, Carboo D (2010) Harmonizing procedures for the evaluation of compost maturity in two compost types in Ghana. Resour Conserv Recycl 54(3): 205–209. https://doi.org/10.1016/j.resconrec.2009.08.001

Ogunwande GA, Osunade JA, Adekalu KO, Ogunjimi LAO (2008) Nitrogen loss in chicken litter compost as affected by carbon to nitrogen ratio and turning frequency. Bioresour Technol 99(16): 7495-7503. https://doi.org/10.1016/j.biortech.2008.02.020

Olsen SR, Sommers LE (1982) Phosphorus. In: Page AL (ed) Methods of Soil Analysis Part 2 Chemical and Microbiological Properties, ASA SSSA, Madison, pp 403-430

Piemonte R (2001) Composting: Process, techniques and application. Ambient Series 25: 83–88

Radovich T, Nguyen H, Archana P (2011) Compost quality. Accessed from: http://www ctahr hawaii edu/huen/nvh/compost pdf (Accessed on 14/03/18)

Ramaswany J, Prasher SO, Patel RM, Hussain SA, Barrington SF (2010) The effect of composting on the degradation of a veterinary pharmaceutical. Bioresour Technol 101(7): 2294-2299. https://doi.org/10.1016/j.biortech.2009.10.089

Richard TL, Woodbury PB (1992) The impact of separation on heavy metal contaminants in municipal solid waste composts. Biomass Bioenergy 3: 195-211. https://doi.org/10.1016/0961-9534(92)90026-M

Rockson G (2014) Composting of abattoir waste and river reed: Effect of feedstock and aeration mechanism on process efficiency. Doctor of philosophy thesis KNUST

Romero C, Ramos P, Costa C, Marquez MC (2013) Raw and digested municipal waste compost leachate as potential fertilizer: Comparison with a commercial fertilizer. J Clean Prod 59: 73–78. https://doi.org/10.1016/J.JCLEPRO.2013.06.044

Samwine T, Wu P, Xu L, Shen Y, Appiah E, Yaoqi W (2017) Challenges and prospects of solid waste management in Ghana. International Journal of Environmental Monitoring and Analysis. IJEMA 5(4): 96–102. https://doi.org/10.11648/j.ijema.20170504.11

Saña JY, Oliva M (1987) The Composting process, systems and applications. Diputació de Barcelona 96

Shilev S, Naydenov M, Vancheva V, Aladjadjiyan A (2007) Composting of food and agricultural wastes: Utilization of byproducts and treatment of waste in the food industry. Oreopoulou V, Russ W (Eds). Springer US. New York USA

Singh R, Pradhan K (1981) Determination of nitrogen and protein by Kjeldahl method In: Forage Evaluation Science Pvt Publishers Ltd. pp. 23

Smith JL, Doran JW (1996) Measurement and use of pH and electrical conductivity for soil quality analysis: Methods for assessing soil quality. Madison: SSSA Special Publication 169–85

Soltanpur PN, Workman S (1979) Modification of the NH_4H-CO_3-DTPA soil test to omit carbon black. Commun Soil Sci Plant Anal 10: 1411- 1420

Sundberg C, Smårs S, Jönsson H (2004) Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. Bioresour Technol 95(2): 145-150. https://doi.org/10.1016/j.biortech.2004.01.016

Tibu C, Ted YA, Negasi S, Dzidzo YT (2019) Effect of the composting process on physicochemical properties and concentration of heavy metals in market waste with additive materials in the Ga West Municipality Ghana. Int J Recycl Organic Waste Agricult 8:393–403. https://doi.org/10.1007/s40093-019-0266-6

Tirado SM (2008) Effects of turning frequency pile size and season on physical chemical and biological properties during composting of dairy manure/sawdust (dm+s). Doctoral Dissertation, The Ohio State University

Tognetti C, Mazzarino MJ, Laos F (2007) Improving the quality of municipal organic waste compost. Bioresour Technol 98: 1067–1076. https://doi.org/10.1016/j.biortech.2006.04.025

Torkashvand MA (2010) Improvement of compost quality by addition of some amendments. Aust J Crop Sci 4(4): 252-257

Urban Composting (2014) Composting tutorial. Accessed from http://www urban-composting com/composting tutorial html (Accessed on 17/03/2018)

Valkili M, Haque AA, Hosseini SM, Salamatinia B (2012) Evaluation of maturation and stability some indexes of mixed Palm oil biowaste composting process and poultry litter. World Appl Sci J 19(2): 234-240. https://doi.org/10.5829/idosi.wasj.2012.19.02.1404

Walkey JA, Black JA (1934) Estimation of organic carbon by the chromic acid titration method. Soil Sci 37: 29-31

Wilson GB, Dalmat D (1983) Sewage Sludge Composting in the USA. Biocycle 24: 20-23

Xiujin LX, Zhang R, Pang Y (2008) Characteristics of dairy manure composting with rice straw. Bioresour Technol 99: 359–367. https://doi.org/10.1016/j.biortech.2006.12.009

Zahrim AY, Leong PS, Ayisah SR, Janaun J, Chong KP, Cooke FM, Haywood SK (2016) Composting paper and grass clippings with anaerobically treated palm oil mill effluent. Int J Recycl Org Waste Agric 5:221–230. https://doi.org/ 10.1007/s40093-016-0131-9

Zakarya I, Khalib S, Yusuf ST (2015) Composting of food waste using microorganisms as organic additives. JESTCH 4(8): 181-184

Zerbock O (2003) Urban solid waste management: Waste reduction in developing nations Michigan Technological University. http://www cee mtuedu/peacecorps/documents_july03/Waste_reduction_and_incineration_FINAL pdf> (Accessed on 7/12/2018)

Zheljazkov VD, Warman PR (2004) Phytoavailability and fractionation of copper manganese and zinc in soil following application of two composts to four crops. Environ Pollut 131:187–195. https://doi.org/10.1016/j.envpol.2004.02.007

Zucconi F, Pera A, Forte M, De Bertoldi M (1981) Evaluating toxicity of immature compost. BioCycle 22: 54–57