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CO-COMPOSTING OF ORGANIC SOLID WASTE AND SEWAGE SLUDGE – A WASTE MANAGEMENT OPTION FOR UNIVERSITY CAMPUS

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Abstract

Co-composting organic solid waste with dewatered sewage sludge was carried out to determine its suitability for managing waste on a University campus. Windrow composting method was employed in which dewatered sewage sludge and organic solid waste were mixed at volume ratios: 1:1, 1:2, 1:3, 0:1 and 1:0 sludge/organic solid waste. Parameters such as pH, percentage N, C, P, K, Ca, Mg, organic matter, ash content and C/N ratio were determined weekly. Total and faecal coliform population were measured biweekly with Pb and Cd levels determined at the beginning and end of the composting. With the exception of ratio 1:0 sludge/organic solid waste, all other ratios attained a favourable Carbon to Nitrogen (C/N) ratio both at the start and end of the composting process. Levels of major nutrients measured were found to be favourable for use as organic fertilizer. There was a general decline in carbon and organic matter in all the compost piles except the sewage sludge pile (1:0). Apart from the compost ratio 1:0 sludge/organic solid waste, all other ratios attained a temperature of 55^{o}C within 8 days of composting. Generally the compost ratios 1:2, 1:3 and 0:1 (sludge/organic solid waste) were found to be the most suitable for use as organic fertilizer.

Keywords: Co-composting, Organic solid waste, Sewage sludge, Compost quality, Waste Management option.

Introduction

Effective handling of waste is a major challenge for municipalities in most countries with increasing population, prosperity and urbanization. Developing countries are the most disadvantaged due to inadequate facilities and lack of adequate technology required for waste management (Fei-Baffoe *et al.,* 2014). Ghana as a developing country produces a lot of refuse especially in the cities as a result of growth in population, rapid urbanization and industrialization. However, there hasn't been a commensurate increase in essential infrastructure, human resource and logistics for effective and efficient waste management services to be delivered across the country. This often creates an unhealthy environment which eventually results in serious incidence of diseases.

Kwame Nkrumah University of Science and Technology (KNUST), one of the government assisted universities in Ghana has experienced an increase in student population over the years. This has resulted in a corresponding increase in waste generation with more than 50% of the waste classified as decomposable (Pare *et al*., 1999). The main method of disposal is by landfilling. This method is more expensive to operate and maintain. There is also the problem of land acquisition which is popularly referred to as NIMBY syndrome. Landfilling of waste has the potential of polluting soil and water resources as a result of the release of leachate. This occurs particularly from landfills that are poorly constructed and operated. The release of a greenhouse gas like methane from landfills is also an environmental concern for the current state of the globe where climate change has become a big problem to contend with (Mensah and Larbi, 2005). The case of Ghana is a cause for concern because most landfills are primarily open dumps without leachate or gas recovery systems, a number of them located in ecological or hydrologically sensitive areas, thus, posing a significant threat to public health especially for those living close to the landfill sites (Mensah and Larbi, 2005).

Composting, another means of handling waste has been an ancient technology for agricultural purposes (Richard, 1997). It is a well-established method of producing manure by decomposition and stabilization of organic waste through microbial activities. Different methods of composting especially of municipal organic solid waste have been advocated as an environmentally friendly, less expensive to operate and maintain, and sustainable means of recycling waste when used as fertilizers and soil conditioners.

Sewage sludge is a product of waste water treatment and is very rich in nutrient and trace element which can be reused as fertilizer (Tiquia *et al*., 2002). However, its high odour emission, high level of heavy metal and toxic compounds and the presence of pathogenic micro-organisms demand pre-treatment of sewage sludge before application in agriculture (Tiquia *et al*., 2002). The usage of sludge for agricultural purposes is considered the most appropriate alternative if pollutants in the sludge are found within the acceptable guideline values. Nevertheless, lack of acceptance from the public makes it difficult to use. Better means of sludge handling for agricultural use to promote patronage include drying, composting and co-composting with other materials (Hultman and Levlin, 1998; Strauss *et al*., 2003).

Co-composting is the controlled aerobic degradation of organics, using more than one feedstock (faecal sludge and organic solid waste) to provide a sustainable and cost effective disposal/re-use method for the co-composted material (Strauss *et al*., 2003). Good quality compost can be obtained by co-composting organic solid waste which is rich in fibre with sewage sludge which is also rich in nitrogen. High temperature should be attained during the composting process to destroy pathogens and weed seed that may occur in the sludge (Kraus and Wilke, 1997). The study therefore aims to assess the quality of compost produced from co-composting organic solid waste and dewatered sewage sludge, as a case study for the management of organic waste on university campus in Ghana.

Materials and Methods

Study Area

The study was undertaken during the dry season between the months of November and February at the premises of the sewage treatment plant of KNUST. The main university campus is about 11 square miles in area and is located about 5 km to the east of Kumasi, which is the capital of the Ashanti Region of Ghana.

Collection and preparation of composting material

Solid waste was collected from waste receptors at the halls of residence on the university campus and their canteens. A grab amount of the waste was collected using shovel into empty sacks for characterization into decomposable and non-decomposable fractions at site. Characterization was done manually by separating the waste into decomposable fractions which mainly composed of food left over, fruit wastes and vegetable wastes and non-decomposable portions such as, plastics and metal cans and others as shown in figure 1.

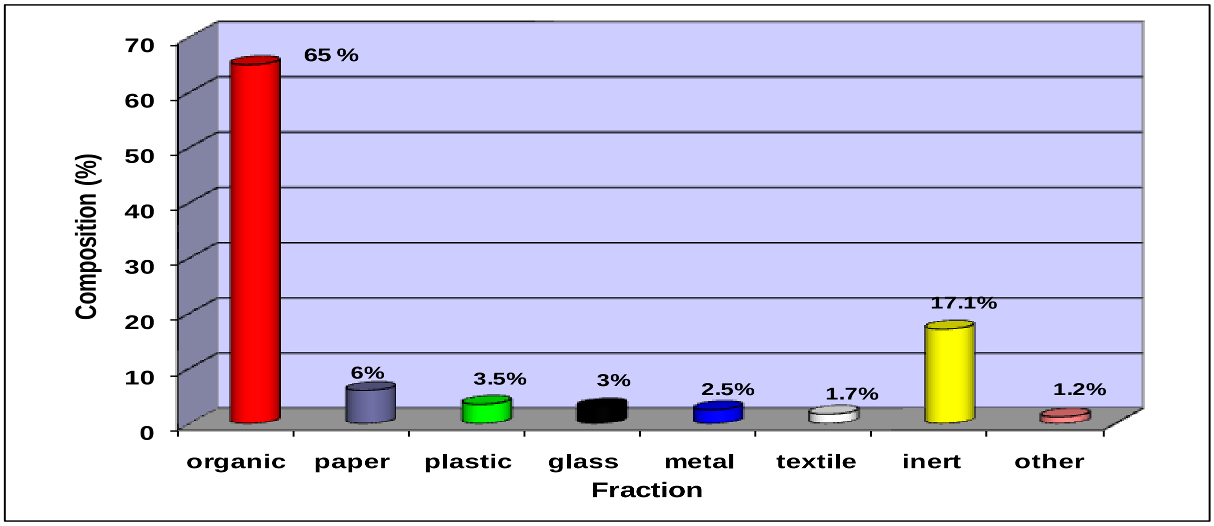

Figure 1: Waste composition of campus solid waste

Decomposable fraction of waste was then shredded and mixed to obtain a uniform mixture using cutlass and shovel respectively. The dewatered sludge was taken directly from the sludge drying beds of the sewage treatment plant of KNUST.

Characteristics and Composition of composting material

A preliminary analysis was conducted to determine the characteristics of the feedstock (organic solid waste and dewatered sewage sludge) including the C/N ratios and moisture (Table 1) so that different proportions of the materials could be mixed to achieve favourable C/N ratios (20 -30) and moisture (55 - 65%) necessary for effective composting. The most widely used parameter for composting is the C/N ratio of the initial composting material; high initial C/N ratio will cause a slower beginning of the process and the required composting time to be longer than usual while low initial C/N ratio results in high emission of NH_3 (Ogunwande *et al.*, 2008). It is also important to maintain the water content of the composting material at a proper level to avoid undesirable factors like longer composting period from arising. It is also reported that with too little water, the heat required for proper composting will not be attained while anaerobic conditions may set in with too much water (Ogunwande *et al.*, 2008).
Therefore, the preliminary analysis provided the basis for mixing the dewatered sewage sludge and organic solid waste at ratios of 1:1, 1:2, 1:3, 0:1 and 1:0 (v/v) respectively.

Table 1: Characteristics of the composting material

Parameter	Sewage sludge	Organic solid waste
Moisture	72.6±1.8	61.3±0.6
TS (%)	27.4±1.8	38.7±0.6
C/N	11.65 ±0.86	25.93±0.17

Composition analysis of the various ratios (sewage sludge/organic waste) before composting is summarized in Table 2.

Moisture content (MC) and C/N of the initial composting mixture was adjusted based on the results of the initial analyses shown in Table 1. The C/N ratio of the sewage sludge was raised to 22±2.0, 23.8±0.7 and 23.1±0.1 (1:1, 1:2, 1:3 sewage sludge / organic solid waste respectively) through the addition of organic solid waste (Rynk *et al*., 1992; Ogunwande *et al*., 2008). The MC of all the composting material was adjusted to (50-60 %) (wet basis) at the beginning of the composting process by the method given by Rynk *et al*. (1992).

Table 2: Composition analysis of the composting material at the start of the process

Parameter	**Ratios** (sewage/organic solid waste)				
	1:1	**1:2**	**1:3**	**0:1**	**1:0**
C (%)	45±1.0	47.1±0.3	47.3±1.5	49.4±06	40.9±0.8
N (%)	2.2±0.1	2.13±0.07	2.2±0.07	1.84±0.2	3.92±0.08
C/N	22±2.0	23.8±0.7	23.1±0.1	26.85±3.2	10.43±0.1
P (%)	0.64±0.08	0.42±0.11	0.39±0.06	0.25±0.07	0.84±0.05
K (%)	0.52±0.2	0.41±0.07	0.54±0.07	0.78±0.01	0.75±0.07
Ash (%)	22.6±1.7	19±0.5	18.7±2.6	15±1.0	29.7±1.3
OM (%)	77.4±1.7	81± 0.5	81.3± 2.6	85±1.0	70.3±1.3
pH	6.8±014	7.1±0.28	7.25±0.21	7.4±0.28	6.3±0.14
Ca (%)	1.2±0.08	1.03±0.13	1.06±0.18	0.6±0.12	0.82±0.2
Mg (%)	0.9±0.2	0.74±0.09	0.7±0.20	0.42±0.09	1.01±0.09
TC (MPN/g)	9.5± x 10^{11}	9.5± x 10^{10}	6.4± x10^{10}	7.5 ±x 10^{10}	2.4 ±x 10^{14}
FC(MPN/g)	2.1± x 10^{11}	6.4 ±x 10^{8}	1.5 ±x 10^{8}	2.4 ±x 10^{8}	2.9± x 10^{13}
Cd (mg / kg)	3.3±0.01	4.8±0.10	2.25±0.03	2.1±0.5	2.4±0.7
Pb (mg/kg)	56.4±2.1	59.6±1.4	37.8±2.0	49.2±0.09	34.8±1.03

Composting

The open windrow pile method was adopted with each heap measuring 1 metre high and 1.5 metres wide. Each compost pile was manually mixed with a shovel for about 10 minutes to turn the pile and provide better aeration. The turning of the compost piles were done every 3 days for the first 21 days. The turning of compost piles continued once every week until the compost piles reached maturity.

Each pile was watered at each time of turning to keep the moisture content at an appreciable level (50-60%) required for effective composting. The moisture content was determined at regular intervals by the oven drying method.

The ambient temperature and the temperature within each pile at a depth of 15 cm from the surface of the piles were determined using a thermometer. A thermometer attached to a rod of about 60 cm long was inserted into each pile, in the middle and at both edges of each pile. The temperatures were recorded and the averages calculated. Temperature measurements including the ambient were taken three (3) times daily for the entire composting period.

Sampling and Analysis

A 50 grams sample was taken from each compost pile by collecting sub samples at different depths and points in the piles and homogenised. Each compost sample was air dried, milled and sieved for physicochemical analysis.

Moisture content and total solids were determined using the gravimetric method. Loss on ignition at a temperature of 550^{o}C was used to measure total organic matter, carbon and ash content (Motsara and Roy, 2008). pH was determined using the pH meter. Total nitrogen was analysed using micro- Kjedahl method. Spectrophotometric vanadium phosphomolybdate method was employed to measure total phosphorus whiles magnesium, calcium, cadmium, potassium and lead content were determined using atomic absorption spectrophotometry (Levinson, 1998; Motsara and Roy, 2008). With the exception of cadmium and lead which were determined at the beginning and end of composting all other physicochemical analysis were done weekly.

For the microbiological determination, 10 grams sample each was also taken from all compost piles and analysed for total and faecal coliforms using the most probable number method (Anon, 1994). This was done biweekly throughout the composting period. All analysis were done in triplicates to reduce variation in results. Single factor ANOVA was used to make comparisons among the means of parameters measured in different compost ratios at 95% confidence limit.

Results and Discussion

The main physicochemical and microbiological characteristics of the feedstock and their ratios before and after composting are summarised in this section.

pH

There was gradual decline in pH in all the compost heaps (1:1, 1:2, 1:3, 0:1 and 1:0 sewage sludge/organic solid waste) during the initial composting phase (Fig. 2). This was likely caused by mineralization of organic acid by acid forming bacteria. These findings are in sync with those of Beck-Friis *et al*. (2003) and Lim *et al*., (2009). After 21 days of composting until maturity, the pH increased in all compost piles except the pile 1:0 (sewage sludge/organic solid waste). The increased pH could be attributed to intense proteolysis and rapid metabolic degradation of organic acid which must have liberated alkaline ammonia compound due to protein degradation. Nattinpong and Alissara (2006) made similar observations during composting of cassava pulp with swine manure.

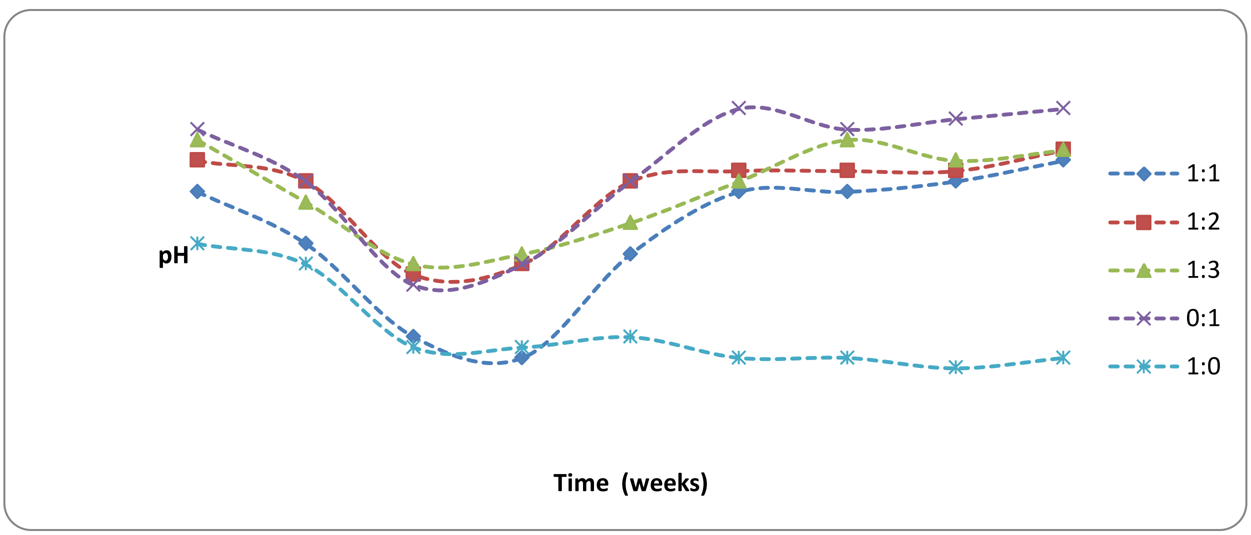

Figure 2: **Mean weekly pH of Compost (sewage sludge / organic solid waste)**

Near neutral pH (5.2 – 8.0) was recorded throughout the composting period. This must have enhanced efficient microbial activity that promoted effective degradation of the compost mass. In the maturity phase, as observed from the sixth week, the pH was almost neutral and stabilized; this was due to the buffering nature of humic substances as indicated by Lim *et al.* (2009). Four of the compost piles (i.e., 1:1, 1:2, 1:3 and 0:1 ratios) reached maturity by the sixth week (Fig. 2).

The heap that consisted of only sludge (i.e.,1:0 ratio), however recorded low pH by the eighth week, an indication that the process of decomposition and production of organic acids was still ongoing (Fig. 2).

Organic Matter, Carbon, Ash Content and C/N Ratio

Initial compost piles had high amount of organic matter and carbon. These parameters were highest in the compost pile that contained only organic solid waste (i.e., the 0:1 ratio). The lowest levels of these parameters were recorded in the compost pile that contained only sewage sludge (i.e., the 1:0 ratio) (Table 3). Percentage organic matter and carbon were found to have decreased rapidly within the first 21 days of composting pointing to high rate of degradation of the organic materials resulting in an increase in temperature from mesophilic to thermophilic phase of the composting process. Decomposition was however slower in compost pile 1:0 (sewage sludge/organic. solid waste). Decomposition during composting is associated with the conversion of biodegradable organic matter into volatile CO_2 and H_2O which are removed from the compost into the atmosphere (Edriss *et al*., 2006).

A decrease in the rate of organic matter and carbon degradation was recorded over time which is an indication of gradual stabilization of the organic matter and carbon forming humic compounds during the composting process. Cedric *et al*. (2005) reported a similar trend after 20 days of composting, which was attributed to the presence of organic substances that were recalcitrant to degradation.

Percentage reduction in both organic matter and carbon content, which indicated the extent of degradation of the compost mass was highest in the compost pile 0:1 **(**sewage sludge/organic solid waste) at 49.5% and lowest in the pile 1:0 (sewage sludge/organic solid waste) containing only sewage sludge (19.3%). The difference in organic matter and carbon content in the final compost amongst the heaps was statistically significant ($p < 0.05$).

Ash content in the compost was found to be inversely related to organic matter. Thus high amount of ash which is the inorganic fraction was an indication of the extent of composting in the various heaps. Mahdi *et al*. (2007) argued that the amount of ash in compost reflects microbial decomposition of organic matter and stabilization during composting. This was highest in pile 0:1 (sewage sludge/organic solid waste). Differences in the compost piles were also statistically significant ($p < 0.05$). Auldry *et al*. (2009) identified an increase in ash content and humic acid due to a decrease in organic matter content over the composting period caused by mineralization and humification.

All compost piles except pile 1:0 (sewage sludge/organic solid waste) had initial carbon/nitrogen ratio suitable for effective composting (Table 3), which is in agreement with studies conducted by Eldridge (1995) and Korner *et al*. (2003). Low initial C/N ratio in compost pile 1:0 was realized possibly due to relatively low carbon with corresponding high nitrogen content contained in the sludge (Table 3). Low C/N ratio in compost has the potential of slowing down decomposition with associated loss of nitrogen through ammonia volatilization (Ogunwande *et al*., 2008).

A significant reduction in carbon/nitrogen ratio over the composting period probably caused by carbon consumption was observed in all compost piles throughout the composting period. This is a reflection of microbial decomposition and stabilization of organic matter, a phenomenon also observed by Mahdi *et al.* (2007). C/N ratio is a factor that is used to indicate compost maturation. According to Nattinpong and Alissara (2006), compost with C/N ratio of 20 or less could be accepted as matured. This enhances net mineralization of nitrogen in the soil for plant use if used as fertilizer. C/N ratios recorded in the various compost piles were near stable after the fourth week which is a probable indication that they had entered the maturation phase. Each of the compost piles attained a final C/N ratio below 20 (Table 3). Decline in C/N ratio in the various compost piles over the composting period was found to be significant ($p < 0.05$).

Table 3: Values of organic matter, carbon, ash and C/N ratio at the start and end of composting

Parameter	Ratios (sewage/organic solid waste)									
	Initial					Final				
	1.1	**1.2**	**1.3**	**0.1**	**1.0**	**1.1**	**1.2**	**1.3**	**0.1**	**1.0**
OM (%)	77.4±1.7	81± 0.5	81.3±2.6	85±1.0	70.3±1.3	47.8±2.6	47.2±0.5	46.7±2.3	42.9±2.8	56.7±0.9
Ash (%)	22.6±1.7	19±0.5	18.7±2.6	15±1.0	29.7±1.3	52.2±2.3	52.8±0.5	53.3±2.6	57.1±2.8	43.3±0.9
C (%)	45±1.0	47.1±0.3	47.3±1.5	49.4±0.6	40.9±0.8	27.8±1.3	27.4±0.3	27.2±1.3	24.9±1.6	33±0.8
C/N	22±2.0	23.8±0.7	23.1±0.1	26.85±3.2	10.43±0.1	9.86±0.4	10.15±1.4	9.48±0.7	11.58±0.3	9.35±0.5

Macro-nutrients

Changes in macro-nutrients during composting are mainly due to mineralization which results from microbial activities. Total nitrogen increased slightly in the finished compost in all piles except pile 1:0 (sewage sludge/organic solid waste (Table 4). Nitrogen is needed by decomposing microorganisms for protein formation and body building to enhance degradation of the compost mass. This was realized at the initial stage of composting, which saw a slight reduction in nitrogen in each compost pile. However, an increase was realized later, which could be attributed to a decrease in compost mass due to degradation of organic carbon. Ajay and Kazmi (2007) and Auldry *et al*. (2009), measured increase in total nitrogen during the composting process and attributed it to the decrease in substrate carbon resulting from the loss of CO_2 (due to the decomposition of the organic matter which is chemically bound with nitrogen). Analysis of variance (ANOVA) showed a significant difference between nitrogen content in the final compost amongst the piles ($p< 0.05$).

Table 4: Values of macro-nutrients at the start and end of composting

Parameter	Ratios (sewage/org. solid waste)									
	Initial					Final				
	1.1	**1.2**	**1.3**	**0.1**	**1.0**	**1.1**	**1.2**	**1.3**	**0.1**	**1.0**
N (%)	2.2±0.1	2.13±0.07	2.2±0.07	1.84±0.2	3.92±0.08	2.82±0.04	2.7±0.3	2.87±0.1	2.15±0.1	3.53±0.3
P	0.64±0.08	0.42±0.11	0.39±0.06	0.25±0.07	0.84±0.05	1.06±0.04	0.99±0.02	0.73±0.08	0.49±0.01	1.7±0.08
K (%)	0.52±0.2	0.41±0.07	0.54±0.07	0.78±0.01	0.75±0.07	0.51±0.02	0.73±0.03	0.7±0.06	1.1±0.42	0.15±0.07
Mg (%)	0.9±0.2	0.74±0.09	0.7±0.20	0.42±0.09	1.01±0.09	0.59±0.09	0.58±0.01	0.56±0.08	1.54±0.01	0.82±0.04
Ca (%)	1.2±0.08	1.03±0.13	1.06±0.18	0.6±0.12	0.82±0.2	2.35±0.02	2.29±0.45	1.95±0.21	1.38±0.11	2.21±0.13

Total phosphorus and potassium increased over the composting period following a similar trend as recorded for nitrogen (Table 4). This increase could be caused by organic matter decomposition leading to the net loss of dry mass, which might have concentrated the phosphorus and potassium in the compost piles. Nattinpong and Alissara (2006) and Ajay and Kazmi (2007), share similar views. Slight decrease in phosphorus and potassium along the composting period probably resulted from the mineralization and consumption by microbes as stated by Ajay and Kazmi (2007).

Percentage phosphorus was highest in pile 1:0 (sewage sludge/organic solid waste) and lowest in pile 0:1 (sewage sludge/organic solid waste). Compost ratios that contained relatively higher proportion of sewage sludge recorded higher percentage phosphorus in the order; 1:0, 1:1, 1:2, 1:3, and 0:1 (sewage sludge/organic solid waste). This is an indication that the sewage sludge was rich in phosphorus. Nattinpong and Alissara (2006) recorded lower amount of total phosphorus in compost piles that had lower amount of swine manure as compared to other piles. This was related to high release of phosphorus from the swine manure. Potassium however showed a reverse trend where compost ratios containing higher proportion of organic solid waste measured higher percentage of potassium, an indication that the organic solid waste was rich in potassium.

Both phosphorus and potassium levels in all compost piles exceeded the minimum level required for land application ($P_2O_5 \geq 0.3\%$), ($K_2O \geq 0.5\%$) as stated by Strauss *et al*. (2003) and Nattinpong and Alissara (2006), respectively. Difference in mean values in phosphorus measured in the various ratios over the composting period was significant ($p < 0.05$). However that of potassium was not significant ($p > 0.05$). Calcium content increased significantly over composting period. This could be attributed to calcium mineralization during decomposition and reduction in compost volume. It is also an indication that the composting materials were rich in calcium. The final compost product however decreased in magnesium content compared to the initial material prior to composting except pile 0:1 (sewage sludge/organic solid waste) which contained only organic solid waste (Table 4). Lim *et al*. (2009) identified increased amount of P, K, Ca and Mg during windrow co-composting process of oil palm mesocarp fibre and palm oil mill effluent anaerobic sludge and described the resulting compost to be of high quality.

Temperature

Rapid decomposition of readily degradable organic matter, which was recorded especially in the initial stages of composting amongst the piles, was associated with heat generation which must have stemmed from the release of energy from the biochemical reaction of microorganisms. Rapid heat generation raised the temperature of compost piles, which caused the process to move from mesophilic phase (10 to 40ºC) to thermophilic phase (higher than 40ºC) where high rate of organic matter degradation was experienced (Fig. 3). This is in sync with the findings of Nelson *et al*. (2006). An initial temperature of $30^{o}C$ was recorded in all compost piles. However, temperature of $55^{o}C$ and above required for pathogenic destruction was attained in the 4^{th}, 6^{th}, 7^{th}, and 8^{th} days for compost ratios 0:1, 1:2, 1:3 and 1:1 (sludge / organic solid waste) respectively. This was probably due to high amount of organic carbon in the piles coupled with good aeration. Compost ratio 1:0 (sewage sludge / organic solid waste) however, could only attain a maximum temperature of 44 ^{o}C, probably due to relatively low amount of readily degradable carbon and less aeration.

By USEPA (1994) standards, windrows or piles must be exposed to a temperature of $55^{o}C$ for 15 days to maximize sanitation in the finished compost. From the study, the compost ratios 1:2, 1:3 and 0:1 (sludge / organic solid waste) could maintain the temperature of $55^{o}C$ for more than 15 days (1:2 and 1:3 – 18 days) and (0:1 - 16 days) thus having the potential to sanitize the compost (Fig. 3). Pile 1:1 (sludge / organic solid waste) could maintain the recommended temperature of 55°C for 11 days with pile 1:0 not attaining this temperature at all. A maximum temperature of 64°C was measured in pile 3 (1:3) and this was maintained for 4 days.

The ambient temperature ranged from 28 – 30°C. The core temperature in the piles after being retained for some days as mentioned above reduced gradually to the ambient temperature. Tiquia *et al.* (2002) reported that compost material could be considered matured when the temperature in the compost reached the ambient temperature. Thus compost ratios 0:1, 1:3, 1:1 and 1:2 could be said to have reached maturity by 35th, 40th, 41st and 47th days, respectively (Figure 3). Nelson *et al*. (2006), argued that a sustained drop in temperature of windrow composting where there is the failure of a cooled compost windrow to reheat after turning indicates that decomposition has slowed enough for the compost to be cured. Piles of sewage sludge and sawdust co-composting were considered to have reached maturity within 35-38 days of composting (Edriss *et al*., 2006). Nattinpong and Alissara (2006) also established compost maturity after 40 days in the composting of swine manure with cassava pulp.

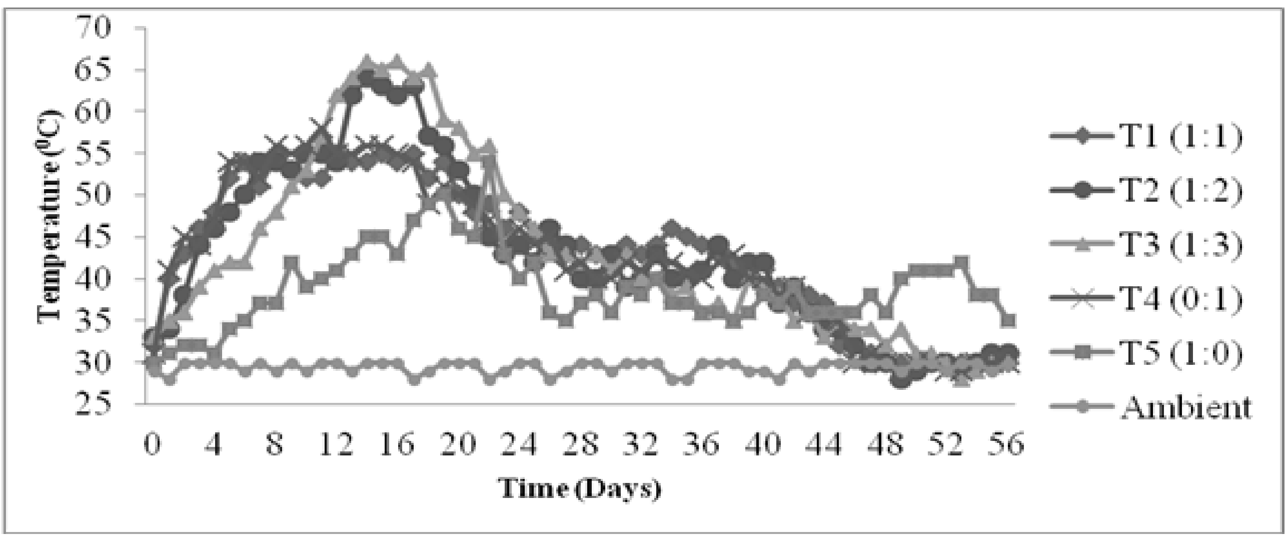

Figure 3: Temperature variation over composting period (Sewage sludge / Organic solid waste)

Coliforms

Ajay and Kazmi (2007) explained that, the presence of coliform bacteria is used as an indicator for the overall sanitary quality of compost. Standards set by USEPA (1994) for hygienization of compost recommend that faecal coliforms should be less than 1000 MPN / g. By the fourth week of composting, both total and faecal coliforms had reduced considerably in numbers. Faecal coliforms in piles 1:2, 1:3 and 0:1 (sewage sludge / organic solid waste) had attained the recommended standard (640, 430 and 930 MPN/g respectively), thus the finished compost can be considered safe for use as organic fertilizer (Table 5). The drastic drop in numbers of both total and faecal coliform could be attributed to thermophilic temperatures in those piles that could be sustained for at least 15 days as recommended by USEPA (1994) (Fig. 3). Ajay and Kazmi (2007) reported a considerable reduction in faecal coliforms, from 7.5×10^8 to 7.5×10^2 and 9.3×10^{10} to 2.5×10^5 MPN/g in two separate piles in composting food waste and cattle manure.

Pile 1:1 although experienced high thermophilic temperatures, it had values above the recommended standard for sanitary compost ($1.6\ x10^3$). Pile 1:0, however, recorded less reduction in total and faecal coliform population by the eighth week, an indication of poor thermophilic conditions recorded in the pile throughout the composting period (Table 5).

Table 5: **Values of Total Coliforms (TC), Faecal Coliforms (FC), Cadmium (Cd) and lead (Pb) at the start and end of composting**

Parameter	Ratios (sewage/org. solid waste)									
	Initial					Final				
	1.1	**1.2**	**1.3**	**0.1**	**1.0**	**1.1**	**1.2**	**1.3**	**0.1**	**1.0**
TC (MPN/g)	9.5×10^{11}	9.5×10^{10}	$6.4\ x10^{10}$	7.5×10^{10}	2.4×10^{14}	9.3×10^4	$2.1x\ 10^4$	2.3×10^3	2.4×10^4	1.2×10^7
FC (MPN/g)	2.1×10^{11}	$6.4\ x10^8$	1.5×10^8	2.4×10^8	2.9×10^{13}	1.6×10^3	7.5×10^2	6.4×10^2	7.5×10^2	1.6×10^8
Cd (mg /kg)	3.3±0.01	4.8±0.10	2.25±0.03	2.1±0.5	2.4±0.7	0.27±0.13	0.45±0.04	1.32±0.01	1.14±0.14	1.65±0.23
Pb (mg/kg)	56.4±2.1	59.6±1.4	37.8±2.0	49.2±0.09	34.8±1.03	21.9±0.91	13.2±1.05	15.3±0.41	9.1±2.1	6.6±1.7

Heavy Metals

According to Hsu and Lo (2000)**,** the composting process may increase the concentration of heavy metals due to reduction in volume of the compost mass. However, Hammadi *et al*. (2007)**,** recorded lower levels of copper and cadmium in matured sludge compost as compared to their respective concentrations in activated sludge. Results obtained after the composting process revealed highly significant decrease in both lead and cadmium levels as compared to levels measured in the piles before composting ($p < 0.05$) (Table 5). Reduction in metal levels may have resulted from complexing actions of the newly formed humic compounds to this metallic micro pollutant as indicated by Pare *et al.* (1999). Hogarh *et al.* (2008) ascribed low levels in Cd and Pb detected in household compost to the absence of contaminants such as plastics, printed materials and metals.

Both lead and cadmium concentrations found in each compost pile at the end of composting were below maximum levels specified by the Canadian Council of Ministers of the Environment that gave a maximum concentration of 3 mg/kg and 150 mg/kg for cadmium and lead, respectively in composts approved for use as fertilizer for food crops (Nova Scotia, 2006).

Conclusion

Co-composting dewatered sewage sludge and organic solid waste produced ideal compost with sufficient nutrient levels required for use as fertilizer. This was reflected in the compost pile ratios; 1:3, 1:2, 0:1 and 1:1 (Sewage sludge/organic solid waste), (*NB*. arranged in order of compost quality).

The compost pile 1:2, 1:3, and 0:1 (Sewage sludge/organic solid waste) recorded the appropriate temperature and prolonged thermophilic stage necessary for the inactivation/destruction of coliform bacteria per the USEPA (1994) threshold set for sanitary compost (< 1000 MPN/g). Composting sewage sludge (1:0) alone showed a slow rate of decomposition and also failed to attain the temperature required for pathogenic destruction. Compost produced from the, 1:2 1:3 and 0:1 ratios could be considered most safe for use as organic fertilizer because of low levels of heavy metals, faecal coliforms, and high levels of nutrient for plant growth. The overall composting experiment as shown in the result of the study was a success. This therefore indicates that the large quantities of organic waste and dewatered sewage sludge generated on the university's campus can be used to produce high quality compost which can be used at the university's greenhouse and for other agricultural activities on campus. This will help the university achieve its aim of providing environmentally sound, economically viable and sustainable waste management. It can therefore be concluded that co-composting sewage sludge and organic solid waste offers a better option for waste management across universities in Ghana and the world at large.

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References

Ajay, S. K. and Kazmi, A. A., 2007. Rotary Drum Composting of Mixed Organic Waste based on Different C/N Ratios. Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India. Pp. 258-265.

Anon, 1994. Centres for disease control and prevention. Food borne outbreaks of enterotoxigenic *Escherichia coli*. Rhode Island and New Hampshire, MMWR. 43:81-89.

Auldry, C. P., Osumanu, H. A., Abd Majid, N. M., Hassan, M. N., Make, J. and Michael, G. B., 2009. Chemical Characteristics of Compost and Humic Acid from Sago Waste. American Journal of Applied Sciences. 6 (11): 1880-1884.

Beck- Friis, B., Smars, S., Jonsson, H., Eklind, Y. and Kirchmann, H., 2003. Composting of source separated household organics at different oxygen levels: Gaining and understanding of the emission dynamics. Compost Science and Utilization. 11: 41-50.

Cedric, F., Maelenn, P. and Sabine, H., 2005. Stabilization of organic matter during composting: Influence of process and feedstock. Compost Science and utilization. 13 (1): 72-83.

Edriss, B., Zazouli, A .M., Javad, B. and Anoushirvan, M. B., 2006. Evaluation of microbiological and chemical parameters during wastewater Sludge and Sawdust Co-composting. J. Appl. Sci. Environ and Mgt. Vol. 10 (2): 115 – 119.

Eldridge, R., 1995. Development of a Composting Recipe for Swine. Soil Conservation Service Northeast, Department of Biological Systems Engineering, US Department of Agriculture. Engineering Service, Cooperative Extension, Ithaka, New York. Pp. 1-20

Fei-Baffoe, B., Nyankson, E.A., and Gorkeh-Miah, J., 2014. Municipal Solid Waste Management in SekondiTakoradi Metropolis, Ghana. Journal of Waste Management 2014: 1-9.

Hammadi, M. A. E., Trabelsi, M., Jrad, A. and Hanchi, B., 2007. Analysis and Comparison of Toxicants between Tunisian Activated Sludge and Produced Compost. Research Journal of Environmental Sciences. 1 (3): 122-126.

Hogarh, J.N., Fobil, J.N., Ofosu-Budu, G.K., Carboo, D., Ankrah, N.A. and Nyarko, A., 2008. Assessment of Heavy Metal Contamination and Macro-nutrient Content of Composts for Environmental Pollution Control in Ghana. Global Journal of Environmental Research. 2 (3): 133-139.

Hu, S.W. and Shy, S.M., 2001. Health effects of waste incineration: A review of epidemiological studies. J. Air waste management Association. 51: 1100-1109.

Hultman, B. and Levlin, E., 1998. Sustainable sludge Handling. Division of water Resources Engineering. Royal Institute of Technology (KTH) S- 100 44, Stockholm, Sweden, pp. 1 - 12

Hsu, J.H. and Lo, S.L., 2000. Effect of composting on characterization and leaching of copper, manganese and zinc from swine manure. Journal Environmental Pollution. 114: 119-127.

Korner, I., Braukmeier, J., Herrenklage, J., Leikam, K., Ritzkowski, M., Schlegelmilch, M. and Stegmann, R., 2003. Investigation and optimization of composting processes-test systems and practical examples. J. Waste Management. 23: 17–26.

Kraus, P. and Wilke, M., 1997. Schadstoffe in Bioabfallkompost. (Contaminants in bio-compost) Mull und Abfall. 211-219.

Levinson, A.A., 1998. Analytical Methods for Atomic Absorption Spectrometry. Perkin-Elmer Corp., Norwalk, Connecticut, USA. Pp. 3-30.

Lim, S. H., Azhari, S. B., Mohd, N. A., Umi, K. M., Nor, S., Aini, A. R., Suraini, A., Mohd, A. H. and Yoshihito, S., 2009. Physicochemical Changes in Windrow Co-Composting Process of Oil Palm Mesocarp Fiber and Palm Oil Mill Effluent Anaerobic Sludge. Australian Journal of Basic and Applied Sciences, 3 (3): 2809-2816.

Mahdi, A., Azni, I. and Syed, O., 2007. Physicochemical characterization of compost of the industrial tannery sludge. Journal of Engineering Science and Technology, 2 (1): 81-94.

Mensah, A. and Larbi, E., 2005. 'Solid Waste Disposal in Ghana" Well Factsheet-Regional Annex. Available at http://www.lboro.ac.uk/well/resources/factsheets/fact-sheets-htm/RSA%20Solid%20waste.htm. (Accessed on 18/04/2015).

Motsara, M.R. and Roy, R.N., 2008. Guide to laboratory establishment for plant nutrient analysis. FAO fertilizer and plant nutrition bulletin 19. Food and Agriculture Organisation of the United Nations. Rome, pp. 42-88

Nattinpong, K. and Alissara, R., 2006. Effect of C/N ratio on the composting of cassava pulp with swine manure. Journal of Water and Environment Technology. 4 (1): 9-32

Nelson, V.L., Crowe, T.G., Shah, M.A. and Watson, L.G., 2006. Temperature and turning energy of composting feedlot manure at different moisture content in southern Alberta. Canadian Biosystems Engineering., 48: 31–37.

Nova Scotia, 2006. Composting Facility Guidelines. Nova Scotia Environment and Labour. Pp. 1 - 22

Nsaful, F., Diewuo, F. and Qauye, T. N. A., 2006. Assessing the recycling potential and treatment option of waste streams of municipal solid waste generated on the KNUST campus. M.Sc Thesis, KNUST, Kumasi. Pp. 1-88.

Ogunwande, G. A., Osunade, J. A. and Ogunjimi, L. A. O., 2008. "Effects of Carbon to Nitrogen Ratio and Turning Frequency on Composting of Chicken Litter in Turned-Windrow Piles". Agricultural Engineering International: The CIGR Ejournal. Manuscript EE 07 016. Vol. X: 1-16

Pare, T., Dinel, H. and Schnitzer, M., 1999**.** Extractibility of trace metals during co-composting of biosolids and municipal solid wastes. Biol Fertil Soils. 29: 31-37.

Richard, St. J., 1997. On-farm manure composting techniques - understanding nitrogen and carbon conservation COESA Report No.: RES/MAN-003/97 Ecologistics Limited 490 Dutton Drive, Suite A1 Waterloo, Ontario N2L 6H7. Pp. 1 -137.

Rynk, R., van de Kamp, M., Wilson, G.B., Singley, M.E., Richard, T.L., Kolega, J.J., Gouin, F.R., Laliberty, L., Kay, Jr.D., Murphy, D.W., Hoitink H.A.J. and Brinton, W.F., 1992. *on farm composting*. Northeast Regional Agricultural Engineering Services, Ithaca, New York, Pp. 186.

Strauss, M., Montangero, A., Zurbrügg, C., Drescher, S., Olufunke, C. and Drechsel, P., 2003 Composting of faecal sludge and solid waste. A Literature and State-of-Knowledge

Review. EAWAG-SANDEC/IWNI (Ghana)/ French Ministry of Foreign Affairs Project report. Duebendorf, Switzerland. Pp. 1 – 44.

Tiquia, S.M., Wan, J.H.C. and Tam, N.F.Y., 2002. Microbial population dynamics and enzyme activity during composting. Compost Science and utilization. 10: 150 – 161.

Tiquia, S.M., Tam, N.F.Y. and Hodgkiss, I.J., 1997. Effects of turning frequency on compost of spent-pig manure. Pp. 37-42.

United States Environmental Protection Agency, 1994. A Plain English guide to the EPA part 503 biosolids rule. Washington, D.C: Office of wastewater management. U.S. Environmental Protection Agency. EPA/832-B-93-005, Pp. 144.