Wastewater Bio-solids Management for Fertilizer Quality Using Co- composting Process

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ABSTRACT

Co-composting process can be acquired by combining organic fraction of municipal solid waste (OFMSW) with sewage sludge (SS) and mature compost (MC) as enhancement and bulking agent to overcome the problems of municipal solid waste and wastewater treatment plants besides the finally produced fertilizer usage for agriculture and horticulture. The effects of different mixture ratios of (OFMSW), (SS) and (MC) on the performance of composting process were investigated in this study. Piles of about 10 kg were prepared by mixing OFMSW, SS and MC in three different ratios (w/w) [OFMSW: SS: MC= 3:1:1, 3:2:1, and 3:3:1]. Results showed that the pile [3:1:1] was most beneficial to composting. The final compost products contained a C/N ratio (12.17), nitrification index (N-NH_4/N-NO_3) (0.2), organic matter degradation (36%), N content (1.75%), and Germintation Index (GI) 77.4%. Final compost showed low amounts of heavy metals, and significant reduction of pathogens indicating mature and stable bio-mass

Key Words: co-composting**,** organic fraction of municipal solid waste**,** sewage sludge mature, compost**.**

ادارة حمأة مياه الصرف الصحي لتحسين قيمتها السمادية باستخدام طريقة التحلل البايولوجي المترافق

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الخلاصة

يمكن تحقيق التحلل البايولوجي المترافق بمزج نسب مختلفة من النفايات الصلبة العضوية مع الحمأة المتولدة من مشاريع تصفية مياه الصرف الصحي مع السماد العضوي المحضر(MC) والذي يعد مادة محفزة ومالئة، وذلك للتغلب على مشكلة تراكم النفايات الصلبة البلدية ومشاكل مشاريع الصرف الصحي في التخلص من الحمأة المتجمعة وفي الوقت ذاته الاستفادة من المادة الجديدة الناتجة كمحسن تربة في مجال الزراعة والبستنة.

تم التحري عن أحسن نسبة خلط من النفايات الصلبة العضوية والحمأة والسماد العضوي المحضر بتغيير نسبة الحمأة، إذ أن ارتفاعالمحتوى المائي للحمأة وأحتوائها على نسبة مثالية من (الكاربون/النتروجين)(C/N)يجعلها مادة مثالية لتحسين خواص الخلطة الاولية.

تم تهيأة ما يقارب من 10 كغم من خلط نفايات عضوية صلبة مع الحمأة مع السماد العضوي المحضر وبالنسب الوزنية التالية: نفايات عضوية صلبة : حمأة :سماد عضوي محضر = 3:2:1، 3:1:1 ، 3:3:1

أثبتت النتائج أن الخلطة بالنسبة 3:1:1 كانت الافضل كمادة مسمدة محضرة اذ حصلت على أعلى نسبة تحلل مواد عضوية(36%) وأعلى محتوى نتروجيني(1.75%). أحتوت الخلطة الناجحة على النسبة C/N(12.17) والتي هي ضمن الحدود الموصى بها (25-12) وبلغ معامل النترجة ($N-NH_4/N-NO_3$) (0.2) وبلغت تراكيز النتروجين والفسفور والبوتاسيوم (NPK) %1.75, %0.98 ,%1.99 على التوالي ,أما معامل الإستنبات (GI) فقد بلغ 77.4% .وكذلك احتواءه على نسب قليلة من العناصر الثقيلة واخيرا الانخفاض الحاد في كثافة المحتوى البكتيري مما يعطي دلالة عن نضوج وأستقرار السماد الحيوي الناتج.

الكلمات الرئيسية: التحلل البايولوجي، الجزء العضوي من النفايات الصلبة البلدية ، حمأة احواض التجفيف الناضجة، سماد عضوي.

1. INTRODUCTION

Due to rapid increases in urban population, organic fraction of municipal solid waste (OFMSW) and sewage sludge (SS) (bio solids) have increased dramatically in the past 20 years. Environmental pollution caused by OFMSW and SS has become a serious social problem which hinders urban development **Girovich, 1996.** In many nations there are now strict mandatory targets to reduce the amount of biodegradable municipal waste (BMW) entering landfill due to the lack of available landfill space and increasing concerns about climate change **EC, 2001**. Further some countries also advocate that any waste that enters the landfill must first be treated to reduce its environmental impact. Treatment options include incineration, separation of recyclable and compostable materials at the source by householders, or raw waste undergoing some form of mechanical biological treatment (MBT), with the residuals being landfilled **Farrell and Jone, 2009**. The organic content of a waste is generally higher in developing countries; therefore, composting is an appropriate alternative for waste management **Kanat et al., 2006**. Composting not only helps to solve the problem of waste disposal, but also produces a useful bio amendment agent (compost) **Banegas et al., 2007**. OFMSW usually has the characteristics of an incompact structure and a relatively high carbon to-nitrogen ratio (C/N), whereas SS usually has the characteristics of a dense structure due to its high moisture content and low C/N. Therefore, SS requires a larger amount of bulking agent (such as sawdust, vegetal remains, or straw) to absorb moisture, provide the composting mass with an appropriate degree of sponginess and aeration, and increase the C/N ratio **Chen et al., 1996 ; Marek et al., 2003** ; **Banegas et al., 2007 and Guardia et al., 2008**. OFMSW could act as a bulking agent for sewage sludge due to its loose structure and relative high C/N. Mixing OFMSW and SS can thus improve the sewage structure, increase the nitrogen content of municipal solid waste (MSW) for the compost product, and meet the goal of fast sanitization and stabilization **Banegas et al., 2007.**

Composting is a popular way to treat organic solid waste **Bari and Koenig, 2001**, but there are many factors that affect the composting process, such as the proportions of the mixture, the aeration rate, oxygen consumption rates, compost recycling, moisture content, pH and C/N, **Golueke and Diaz, 1996; Smith and Hughes, 2004 and Meunchang et al., 2005.**

For different materials, the composting parameters are different. For example, **Banegas et al. 2007** studied the composting of SS with sawdust as the bulking agent and found that a 1:1 weight ratio was most suitable for aerobic compost process. **Meunchang et al. 2005,** conducted composting experiments with a 2:1 weight ratio of filter cake and bagasse to reduce the C:N ratio in order to reduce N loss during composting.

An optimal composting mixture of 50% food waste, 40% manure, and 10% bulking agent was found from previous in-vessel composting study by **Cekmecelioglu et al. 2005**. **Marek et al. 2003**. They suggested that only a small part of the SS could be utilized for composting because of the limitations of the volumetric ratio between the organic wastes and SS, considering the required properties of the raw mixture (moisture, porosity and the ratio C/N). The use of chicken dung and soil as feedstock seems to be necessary to increase carbon to nitrogen ratio (C/N) in the optimal range for efficient composting and to compensate for the presence of poorly degradable sources of carbon in SS **Yamada and Kawase, 2006**.

Despite many previous studies on MSW or SS composting processes, information on the characteristics of the co-composting of MSW and SS are not available.

The objectives of the present study is to investigate the characteristics of the co-composting of municipal solid waste (MSW) and sewage sludge (SS) through changes in temperature, organic matter, moisture content, carbon (C), nitrogen (N), C/N, and N loss, using three different mixing ratios.

2. MATERILS AND METHODS

2.1 Experimental Composting Configuration

A column vessel of 30 cm diameter and 45 cm height was used as a bioreactor with a perforated steel plate elevated 10 cm from the bottom of the vessel as given in **Fig. 1**. The perforated steel plate was installed to ensure air intrusion through mass voids, leachate collection and raw materials supporting. A glass thermometer was mounted below the surface of the materials for rapid temperature monitoring. A top slot next to the main opening was fitted tightly with a valve to ensure fermentation gases outlet. Humidity and pH sensors were installed inside the bioreactor. The composting material was rolled every 12h, for 5 min each time in order to provide proper mixing and aeration. Hydration was adjusted manually to maintain mixture humidity rate between 40% and 50%. The bioreactor was buried in the soil to maintain and control temperature for the composting process.

2.2 Composting Material

Approximately 10 kg of raw material consisted of sewage sludge that were taken from the drying beds in Al Rustemeyia wastewater treatment plant at Al-Rusafa side in Baghdad which treats mainly domestic wastewater, blended with kitchen organic fraction of municipal solid waste (OFMSW) as presented in **Table 1,** and finally with mature compost (MC) prepared previously. The composting process consisted of four experiments lasted about 40 days each, as follows:

1-An OFMSW with same components and weights as indicated in **Table 1** was composted alone in the bioreactor to prepare mature compost (MC), to be used as a raw material for the following experiments.

2- Mixture of (OFMSW), SS, and MC was composted in experiments E1, E2, and E3 with different proportions. The three experiments were compared to find one appropriate proportion out of the three following mixtures: (OFMSW: SS: MC, 3:1:1, 3:2:1, 3:3:1).The ratio of MSW, SS and MC was chosen to achieve optimal homogenization and an incompact structure. It was noticed that if the SS content is high, the mixture will not mix uniformly because of the structure of dewatered SS is viscous and is not easy to spread.

2.3 Sampling and Analyses

Samples were taken at regular intervals, using compositing sampling method which offers the advantage of increased accuracy through the use of large numbers of sampling units per sample **Banegas et al., 2007**. Organic analysis samples were taken every three days, while temperature and pH analysis samples were taken daily. The final sample was formed after mixing six samples together to form a homogeneous material. From this homogeneous material a portion of sample was air-dried and crushed into powder using a laboratory mortar until no gritty particles can be detected and then stored for heavy element analysis. Another portion was used for the, $N\text{-}NH_4$, $N\text{-}NO_3$, total nitrogen, organic carbon content, organic matter content and pathogenic bacteria **TMECC, 2002**.

2.4 Characterization of Composted Material

Organic matter was determined using the combustion method **ASAE, 2004**: Two grams of the sample were weighed and dried in an air oven at 105°C for 24hr. The dried sample was weighed to determine dry weight (A). The dried sample was then burned in a furnace at 550°C for 4 hours, then weighted to measure the ash weight (B).
The contents of organic matter and carbon are measured as follows **ASAE, 2004**:

$$\%\ organic\ matter = (A-B)/A \times 100 \tag{1}$$

$$\%\ carbon = (\%\ organic\ matter) / 1.8 \tag{2}$$

The content of nitrogen as ammonium and as nitrate and total nitrogen was determined by kjeldah method. The compost temperature was measured at regular time intervals throughout the composting duration, using a digital thermometer. Another set of temperatures were measured in different parts of the bioreactor until the termination of the composting trial. An average value was accepted as the temperature of the composting material.
Ten grams of sample were weighted and strewed into Erlenmeyer flask, 100 ml of distilled water was added. Auto shaked for 30 min to measure the pH of samples extract using a pH meter. Moisture content (gravimetric, wet basis) was determined by drying at 105 °C for 24 hours.
Total phosphorous as P_2O_5, total potassium as K_2O, magnesium as MgO, calcium as CaO and heavy metals concentrations (Cd, Cr, Cu, Ni, Pb, Zn) were analyzed using Atomic Absorption Spectrophotometer (Perkin Elmer 2380, AAS-EM). To estimate the reduction of the pathogenic microorganisms, biological analyses have been performed to evaluate their density prior and after the composting processes. The analyses evaluated the density of the total and faecal coliforms and helminthes eggs in the compost produced for each trial.

3. RESULTS AND DISCUSISSION

3.1 Characterization of Raw Materials

From **Table 2,** the drying bed SS is characterized by high moisture content of an average value of (72.60) % and low C/N ratio (17.79). The C/N ratio of MSW is about 30 and is optimal for composting as it can be composted alone with the addition of water **Ogunwande et al., 2008; Huang et al., 2011;** and **Al-Zubaidi, 2013**.
The initial pH values of MC, OFMSW and SS were measured to be 6.3, 8.5, and 6.5 for respectively as shown in **Table 2**. The presence of high concentrations of heavy metals such as Zn and Pb were the trace-elements acquiring the highest concentrations in SS used in this study.

3.2 Physicochemical Parameters

3.2.1 Mass loss

The starting weight of 10 kg raw material turned to be 3.3kg, 3.75kg and 4kg through 40 days of composting for E1, E2 and E3 respectively indicating successful reduction in mass quantities.

3.2.2 Mineralization or (Organic matter degradation)

Mineralization is the decomposition or oxidation of the chemical compounds in the organic matter into plant accessible forms **Girovich, 1996**.

The mineralization process which took place in the composting bioreactor resulted in lowering organic matter content of the substrate. Organic matter content of the substrate at the initial stage of composting on the 1st day dropped from 60.24% to 38.34% for E1, 58.83% to 42.58% for E2 and 56.84% to 45.36% for E3 at the end of the composting process (40 days) as shown in **Fig.2**. Organic matter was subjected to an overall reduction of 36% throughout E1composting process, 28% reduction throughout E2 and 20% throughout E3, while the remaining carbon content at the end of each process was 21.3%, 23.65% and 25.2% respectively, which is considered to be a good value referring to **Brinton, 2000** and is expressed in **Table 3**.

3.2.3 Temperature

Temperature followed a typical temperature profile for composting (mesophylic-thermophylic-mesophylic), **Fig.3.** In each pile the temperature increased from ambient temperature to more than 50 °C within 2-5 days, and showed rapid initiation of the compost process, due to the appropriate C/N ratio besides the process is exothermic. The substrates passed from an initial mesophylic phase (<40 °C) to a thermophylic phase after the 2nd day for E1, the 3rd day for E2, and the 5th day for E3. Comparing the piles, it seems that higher temperature was achieved in the mixture of E1 (3:1:1), confirming the assumption that self-heating ability is closely correlated to the waste characteristics. Temperature may increase up as a result of biological degradation of organic materials in solid waste or other organic matter in first days of composting process. High moisture content and low amount of composting material mass may not produce enough heat and may lost the heat it produced easily **De Guardia et al., 2010**.

As the organic compounds were degraded, the piles become richer in the more stable compounds which were less accessible to the microorganisms and as a result the corresponding temperature begun to decrease gradually reaching almost ambient temperature. The temperature reached a second mesophylic phase on the 6th day of E1, the 4th day of E2, and on the 8th day of E3 while the maturation process took place during this last stage of composting as shown in **Fig. 3**. Similar temperature profile was observed in related pilot scale bioreactor composting experiments held locally **Al-Zubaidi, 2013; Talib, 2014** and globally **Tang et al., 2007; Lu et al., 2008;Elango et al., 2009;** and **Gao et al.,2010**. Reaching high temperatures may participate actively for accomplishment of compost stability and reduction of retention time in the bioreactor **Elango et al., 2009**. Finally, the temperature of each pile approached the ambient temperature at day 30-40. Elevated temperatures (>50 °C) were maintained in the bioreactor for five continuous days (2^{nd} to 6^{th} day) for E1, two days (3^{rd} to 4^{th} day) for E2 and one day (7^{th} day) for E3, which is sufficient time for the sanitation of the substrate in E1 and E2 to get rid of pathogenic microorganisms that exist in SS mainly, while one day for E3 may indicate low compost stability. Many researchers reported that the temperature range for optimal composting is between 52 to 60◦C **Boch et al., 1984; Elango et al., 2009; Huang et al., 2011;** and **Al-Zubaidi, 2013**.

3.2.4 pH.

As shown in **Fig.4**, the pH values increased during the initial stage of anaerobic composting (9.7 on the 3^{rd} day, 8.8 on the 4^{th} day, and 9.9 on the 5^{th} day for E1, E2 and E3 respectively, probably this is due to rapid activity of bacteria which release ammonia as organic matter decays. Thereafter, through ammonia volatilization and its oxidation to nitrates by the action of nitrobacteria and trapped air, ammonia content decreased and thus the pH value drops to around 7 at the end of the process. The pH of the mature compost was near neutral (6.3–7.6) indicating a good quality compost that is within the suggested range of (6–8.5) **TMECC, 2002** .This finding was closely related to **Sánchez- Mondero et al., 2001;** and **Huang et al., 2011**.

3.2.5 Moisture content (Mc)

Moisture content is the single most important factor that promotes and accelerates the decomposition process. The initial substrates were prepared to have relative high moisture content (78.0%, 72.0% and 70.0 % for E1, E2 and E3 respectively) to sustain thermophilic phase **TMECC, 2002**. At final stages of composting moisture content decreased gradually reaching 45%, 34% and 30% at the final day of the process (40th), for E1, E2 and E3 respectively as shown in **Fig.5**. Final low water content reduces the intensive microbiological activity and at the same time, reduces the transportation costs of mature compost as it occupies less volume.

3.2.6 Nitrogen content

Nitrogen content was measured at the end of each trial i.e. on the 40th day, it was found to be 1.75%, 1.40% and 1.05% for E1, E2 and E3 respectively, as shown in **Table 3.** During composting, nitrogen is metabolized mainly to ammonium while the non-soluble complexes of nitrogen decompose to soluble nitrogen forms that are readily available for metabolic activities.

Losses in nitrogen gas during composting occur mainly as ammonia but may also occur as nitrogen and nitrates oxides **Eklind and Kirchmann, 2000**. On the other hand, in terms of dry weight, there is an increase in total nitrogen concentration due to the mineralization of organic matter and consequent loss of weight in the mass being composted through losses of CO_2 and H_2O **Banegas et al., 2007**. According to **Table 3**, initial substrate acquired a 19.50,18.32and30.42 C/N ratio, for E1, E2, and E3 respectively, due to carbon consumption at the end of the process the C/N ratio had decreased to12.17, 16.90 and 24.00 for E1, E2 and E2 trials respectively which are qualified as good quality compost and thus can be applied in agricultural land. Maintaining C/N ratio after composting is an important factor to determine the value of finished compost as soil amendment for crops.

Researchers have suggested various ideal C/N ratios from more than 12 to lower than 25 **Brewer and Sullivan, 2003; Rihani et al., 2010;** and **Al-zubaidi, 2013** but the optimal value is often dependent on the initial feedstock. Therefore the ratios obtained in this study for E1, E2 and E3were considered satisfactory.

C/N of E3 mixture was the highest of three ratios. Significantly high losses of N occurred during the composting process, and the losses of N increased when the amounts of SS in the mixtures increased (3:3:1). The degree of stability of the compost is also strictly related to the nitrification index (N-NH4/N-NO3).For the 3:1:1 mixture, the C/N was the lowest of the three ratios. However, a higher N content (1.75%) was found in the final composting which contribute to the reduction of the nitrification index (N-NH_4/N-NO_3) during compost maturation and can be considered as an indicator of a high degree of compost stabilization **Brinton, 2000; Abouel wafa et al., 2008;** and **Huang et al.,2011**.The appearance of significant quantity of nitrates at the final day (968.4, 1230.8 and1350.7 mg/kg) in conjunction to low ammonium concentration (200.7, 340.5 and 420.3 mg/kg) are shown in **Table 4.** In his study, the acquired ratio was 0.2, 0.28 and 0.31, for E1, E2, and E3 respectively, where ratios less than 0.5 are the better for mature compost **Brinton, 2000**.

3.2.7 Nitrogen, phosphorous and potassium (NPK)

Levels of NPK value in the finished compost are also important in determining the quality of compost, since those elements are essential nutrients for plant growth. **Iyengar and Bhave** in **2006** reported that the nitrogen, phosphorous and potassium (NPK) contents for compost should be more than 1% each. The total N% found to be 1.75%, 1.4% and 1.05% for E1, E2 and E3 respectively as forementioned in **Table 3**.The results shown in **Table 5** revealed that initial values of nutrient P as percentages decreased to 0.98, 0.86, and 0.56 for trials E1, E2, and E3 respectively, while the amount of P in the original heaps were 1.68, 1.48, and 0.96 as percentages respectively. This reduction may be attributed to consumption of phosphoric compounds in cell growth and reduction in total mass. The amount of K values increased to 1.99, 1.83, and 1.82 as percentages for the three trials. According to the aforementioned literatures and the data obtained from E1,E2 and E3 trials, the nutrients level of the end-product composts appeared to be sufficient for plant growth for E1(3:1:1) only.

3.2.8 Heavy metals

High levels of heavy metals such as Cd, Cr, Cu, Pb, Ni and Zn in the composts represent an obvious concern if they were to be applied to food crops. Heavy metals do not degrade throughout the composting process, and frequently become more concentrated due to the microbial degradation and loss of carbon and water from the compost **Richard and Woodbury, 1992**.

The heavy metals concentrations in the final composts were generally low and did not exceed the suggested European Union states and USA limits presented in **Table 6**. In addition compost produced from E1, E2 and E3 trials may be classified as first class compost based on the metal quality standards for compost and stabilized bio-waste **Brinton, 2000**. Total metal contents in compost are of concern when repeated applications to land occur. Field trials involving MSW compost application to soil have all reported an increase in soil and plant metal concentrations. Generally, increasing the overall heavy metal burden of the soil may be undesirable. Yet the risk of metal contamination from MSW-derived composts is of similar magnitude to that posed by bio solids application to land which is now a widely accepted practice.

3.2.9 Pathogenic microorganisms

One of the problems posed by direct use of sewage sludge in agriculture is the risk of plant and human contamination by pathogens. According to **Stentford** in **1996**, temperatures more than 55 ^{o}C favor sanitation, values between 45 and 55 ^{o}C favor degradation, and 35 and 40 ^{o}C favor microbial diversity. The maximum temperatures during the present composting process were ranged between (51and 58) ^{o}C. These temperatures, which were maintained for several days during the process, ensured that the composting process followed was suitable for stabilizing organic matter and suppressing pathogenic microorganisms. The development of microbial populations, which cause numerous physicochemical changes within the mixture, could influence the metal distribution through release of heavy metals during organic matter mineralization or the metal solubilization by the decrease of pH, metal bio sorption or metal complexation with the newly formed humic substances **Zorpas and Loizidou, 2008**.

To estimate the reduction of the pathogenic microorganisms, analyses have been performed to evaluate the density of total coliforms, faucal coliforms and helminthes eggs prior and after composting processes as shown in **Table 7**. The elimination or inactivation of pathogenic microorganisms in composts depends on the time/temperature conditions maintained during composting. In this study, elevated temperatures (>55 ºC) were obtained for approximately four continuous days (2^{nd} to 5^{th} day for E1), above 50 ºC for two days (3^{rd} to 4^{th} day for E2) and equal 51ºC for one day (7^{th} day for E3), as shown previously in **Figure 3**. Therefore, it can be inferred that the composting trial for E1 had been performed successfully with respect to the sanitization of bio solids since the levels of pathogenic microorganisms detected at the end of the process in E1 was significantly lower than E2 and E3.However, a quite difference has been observed between E1, E2 and E3 trials for total and fecal coliforms in the final compost due probably to different ratio of SS. While in all cases, data comply with the guidelines for the safe reuse of fecal sludge **USEPA, 1993; WHO, 1996;** and **Brinton, 2000**.

3.2.10 Germination test

The compost obtained from E1 trial, after 40 days at 70% moisture and C/N ratio of 12.17 was chose to carry out the germination test, to check the phytotoxic effect on plant growth.

The outcomes of the germination test are given in **Table 8** that shows 86% relative seed germination and 90% relative root growth; the calculated value of germination index (GI) is 77.4%. On the other hand, poor relative seed germination (60%), root growth (68%) and GI (40.8%) values were observed for the commercial compost extract, this is an indication that the commercial compost was probably immature. The following equations were used to calculate the relative seed germination, relative root growth, and germination index (GI) **Marek et al., 2003**:

$$Relative\ seed\ germination\ (\%) = \frac{Number\ of\ seeds\ germinated\ in\ compost\ extract}{Number\ of\ seeds\ germinated\ in\ control}\ x\ 100 \quad (3)$$

$$Relative\ seed\ germintation\ (\%) = \frac{43}{50}\ x\ 100 = 86\%$$

$$Relative\ rootgrowth(\%) = \frac{Mean\ root\ length\ in\ compost\ extract}{\sqrt{Mean\ root\ length\ in\ control}}\ x\ 100 \quad (4)$$

$$Relative\ rootgrowth(\%) = \frac{0.90}{\sqrt{1}}\ x\ 100 = 90\%$$

$$GI\ (\%) = \frac{(Relative\ seed\ germination\ )x(Relative\ root\ growth)}{100} \quad (5)$$

$$GI\ (\%) = \frac{(86)x(90)}{100} = 77.4\%$$

There is a potential concern that the applicability of these results could be limited because; the data used are not suitable measurements for the quality of the compost in land application.

4. CONCLUSIONS

1. Composting provides a critical step in the treatment of MSW as mass reduction. The residuals after composting is about 33.0%, 37.5 %, and 40.0 % of the original weight for the three trials respectively indicating that E1 (3:1:1) is the best trial for reducing weight.

2. The present study has shown that E1 was superior to E2 and E3 during composting, especially for moisture-content due to its ability to accumulate and retain heat and to achieve high organic matter degradation. The organic matter was subjected to an overall reduction of 36% throughout E1, 28% reduction throughout E2 and 20% throughout E3, while the remaining carbon content at the end of each process was 21.3%, 23.65% and 25.2% respectively, which is considered to be a good value**.**

3. The temperature of each trial elevated above 50 °C, and were maintained in the bioreactor for five continuous days, for E1, two days for E2 and one day for E3, which is sufficient time for the sanitation of the substrate in E1 and E2 for the destruction of pathogenic microorganisms that exist in SS mainly.

4. The changes in temperature and chemical parameters of different OFMSW: SS: MC ratios indicate that the E1 (3:1:1) is the best for maintaining the highest N content in the final composting product.

5. Nitrogen content measured at the end of each trial was found to be 1.75%, 1.4% and 1.05%for E1, E2 and E3 respectively, which proved all to be satisfactory. Due to carbon consumption at the end of the process the C/N ratio has decreased to12.17, 16.90 and 24,00, for E1, E2 and E3 trials respectively that is still within the recommended range.

6. The acquired ratios of nitrification index ($N\text{-}NH_4/N\text{-}NO3$) were 0.2, 0.27 and 0.31, for E1, E2, and E3 respectively. Biomass with lower than 0.5 nitrification ratio is considered as mature compost.

7. The P percentage values decreased to 0.98 %, 0.86 % and 0.56 % for trials E1, E2, and E3 respectively.

8. The amount of K values increased to 1.99, 1.83, and 1.92 as percentages for the three trials.

9. The nutrients level NPK of the end-product composts appeared to be sufficient for plant growth for E1 (3:1:1) only.

10. All of the heavy metal concentrations were relatively low when compared with the allowable limits.

11. Composting trial E1 had been performed successfully with respect to the sanitization of bio solids since the levels of pathogenic microorganisms detected at the end of the process in E1 was significantly lower than E2 and E3.

12. The obtained GI for E1 trial was 77.4 %, which can be classified as mature compost since GI is almost near the recommended level.

13. In conclusion, a 3:1:1 mixture of OFMSW:SS: MC is recommended for agricultural application in terms of pH, high organic degradation, low heavy metal contents and satisfying content of nutrients, germination index, and pathogens concentrations reduction.

5. RECOMMENDATIONS

1. It is recommended that segregation for MSW should be carried out at the household level in terms of achieving highest efficiency for compost production.
2. Further studies are recommended to use composting technology to solve organic pollutants.
3. The system could be used by municipalities to conduct composting trials of their yard waste and organic residues.
4. It is recommended that further pilot study should be carried out to investigate the effect of different food wastes on the composting process.
5. Following the production of bio solids a field study is recommended to assess the effects of land application of bio solids on crop yield and soil quality, the heavy metal accumulation in soil, crop and also groundwater. This kind of collaboration makes the use of sludge in agriculture more reliable.

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NOMENCLATURE & ABBREVIATIONS

BMW= biodegradable municipal waste
C/N = carbon to nitrogen ratio
GI = germination index
LOD = levels of detection
MBT= mechanical biological treatment

MC= mature compost
Mc= moisture content
MOA= ministry of agriculture
MSW= municipal solid waste
NPK= nitrogen, phosphorus and potassium content.
N.R= no reduction
OFMSW = organic fraction of municipal solid waste
SS= Sewage sludge
TKNW= water soluble total kjeldahl nitrogen
TMECC= test methods for the examination of composting and compost
TS= total solid

Table 1. OFMSW components.

Item (kg)	MSW
Potato	1.27
Carrot	1.96
Broad beans	1.96
Meat	0.34
Steamed rice	2.00
Soil	2.00
Leaves	0.46
Water	0.70
Total	10

Table 2. Physicochemical parameters of raw materials

Parameters	MC	MSW	SS
Organic matter%	40.87	84.42	44.83
Moisture content%	67.90	68	72.60
O.C%	22.71	46.9	24.91
N%	1.40	1.87	1.40
C/N	16.22	25.0	17.79
K%	3.06	1.91	1.00
P%	0.21	2.04	0.17
pH	6.30	8.50	6.50
Cd mg/kg	<LOD*	<LOD*	<LOD*
Cr mg/kg	36.0	<LOD*	77.0
Cu mg/kg	34.0	23.0	108.0
Ni mg/kg	25.0	25.0	112.0
Pb mg/kg	65.0	30.0	125.0
Zn mg/kg	513.0	202.0	928.0

***LOD**: level of detection

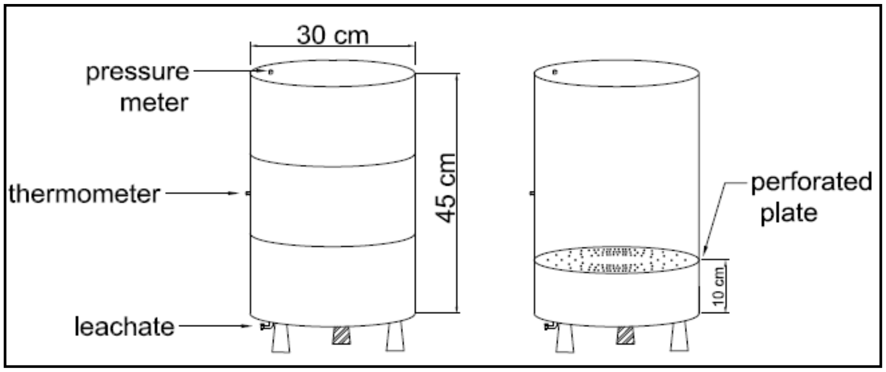

Figure.1. Schematic diagram of the bioreactor.

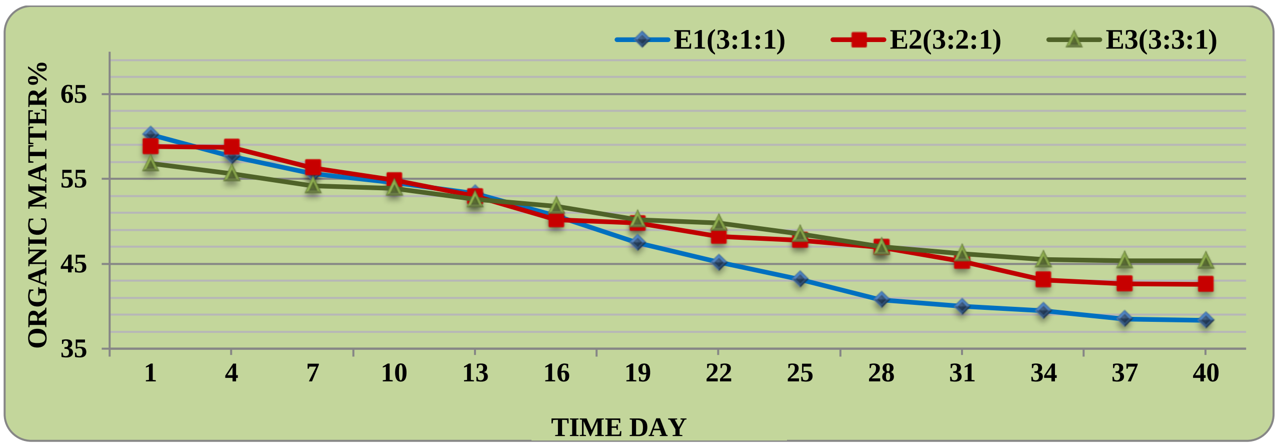

Figure 2. Organic matter variations through the composting processes.

Table 3. Properties of initial and final compost.

Trials	O.M%		%Red	O.C.%		%Red.	N%		%Red.	C/N%	
	Initial	Final		Initial	Final		Initial	Final		Initial	Final
E1 3:1:1	60.24	38.34	36.35	33.47	21.30	36.5	1.72	1.75	N.R*	19.50	12.17
E2 3:2:1	58.83	42.58	27.62	32.68	23.66	27.6	1.78	1.40	21.3	18.32	16.9
E3 3:3:1	56.84	45.36	20.19	31.58	25.20	20.20	1.04	1.05	N.R	30.42	24.0

N.R: no reduction

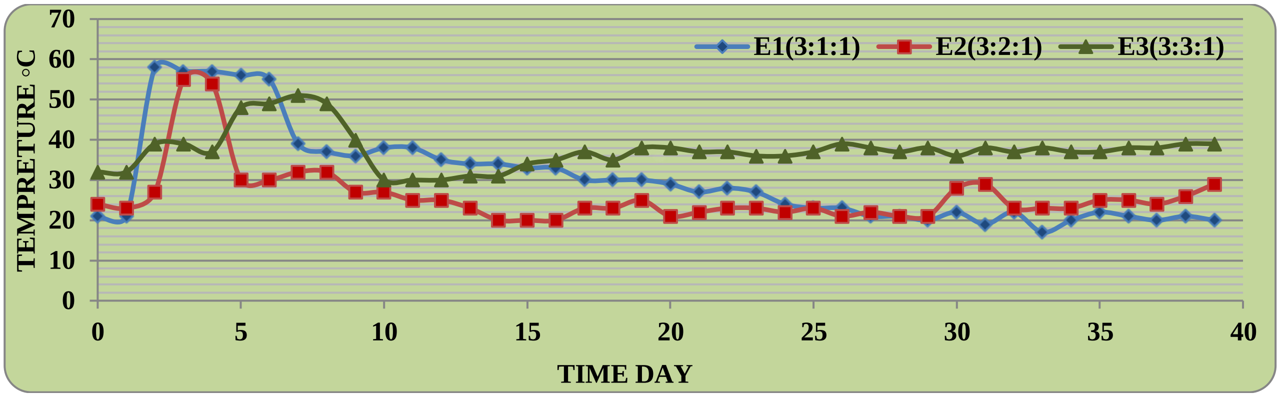

Figure 3. Temperature variation through the composting processes.

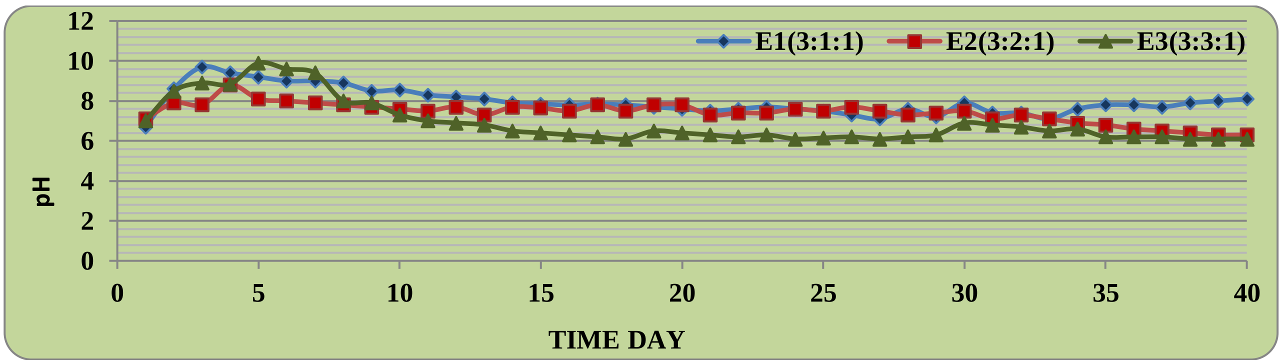

Figure 4. pH variation through the composting processes.

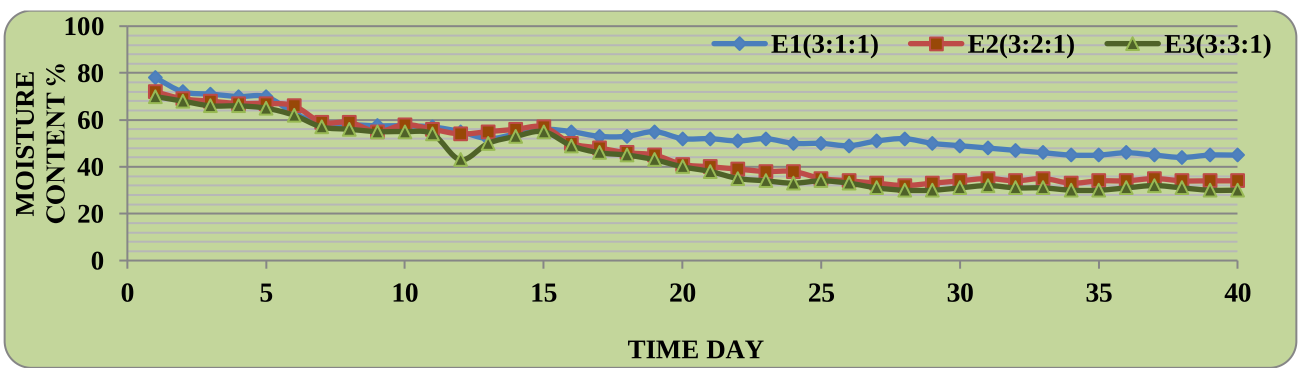

Figure 5. Effect of the proportion of municipal solid waste, mature compost and sewage sludge on moisture contents**.**

Table 4. Nitrification index for the concerned proportions.

mg/Kg	E1(3:1:1)	E2(3:2:1)	E3(3:3:1)
NH_4^--N	200.70	340.50	420.30
NO_3^+-N	968.40	1230.80	1350.70
NH_4^--N/ NO_3^+-N	0.20	0.28	0.31

Table 5. P and K levels in initial proportions and in final composts.

Initial (Final)	E1(3:1:1)	E2(3:2:1)	E3(3:3:1)
P%	1.68 (0.98)	1.48 (0.86)	0.96 (0.56)
K%	1.96 (1.99)	1.79 (1.83)	1.88 (1.92)

Table 6. Heavy metals concentration in the 3 trials and quality standards of stabilized bio-waste Brinton, 2000.

Metal mg/Kg	EU	USA	E1(3:1:1)	E2(3:2:1)	E3(3:3:1)
Cd	0.7	32	<LOD	<LOD	<LOD
Cr	70-200	1200	<LOD	59	176
Cu	70-600	1500	16	64	35
Hg	0.7-10	17	<LOD	<LOD	<LOD
Ni	20-200	420	<LOD	49	80
Pb	70-1000	300	30	79	48
Zn	210-4000	2800	326	857	306

Table 7. Bio solids pathogen concentrations.

Initial →	E1(3:1:1) (final)	E2(3:2:1) (final)	E3(3:3:1) (final)
Total coliforms*	5.34 (0.2)	9.89 (0.9)	12.42 (1.8)
Fecal coliforms*	4.64 (<0.1)	7.63 (0.3)	10.82 (0.5)
Helminthes eggs /10 g	20.27 (<1)	25.85 (<1)	29.73 (<1)

* Log10 MPN/10 g ds.

Table 8. Outcomes of germination test.

Item/ parameter	Control test	Compost extract of in-vessel lab-scale reactor	Compost extract of Commercial compost
Total seeds	50	50	50
Germinated seeds	50	43	30
Mean root length cm	1	0.90	0.68
Relative seed germination (%)	-	86	60
Relative root growth %	-	90	68
Germination index %	-	77.4	40.80