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In-vessel Composting System for Accelerated Composting

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ABSTRACT

Low-level microbial activity due to the production of organic acids is a recognized problem during the initial phase of food waste composting. In this study, sodium acetate (NaOAc) was introduced as an amendment to an in-vessel composting system. Sodium acetate was added when the pH of the compost mixture reached a low level (pH < 5), the addition increased pH to 5.8. This had a positive impact on the degradation of organic materials and the formation of methane gas compared to the results without (NaOAc) addition. This also proved that the anaerobic-aerobic in-vessel composting could reduce the large amounts of waste by 33%-30%. However, the addition of NaOAc had no significant influence on the temperature profile, bulk density, electrical conductivity, moisture content, nitrogen, phosphorus, potassium (NPK) and heavy metals during the composting process. To assess the performance of the composting process, two small-scale digesters were used with fixed temperature. Maximum methane content of 68±1% and 75±1% by volume of the generated biogas was achieved in the run without and with NaOAc respectively. The germination index was 84.8% which proved that the stabilized compost obtained in this research is the "mature" kind and satisfactory for agricultural use.

INTRODUCTION

Food waste is the largest component of municipal waste streams after the recyclables are separated. It is associated with high disposal costs (McDonnell 1999). Composting is a promising alternative treatment method for food waste that enables the valuable organic contents of food waste to be reused (Kim et al. 2008).

In recent years, composting has been presented as an environmental friendly and sustainable alternative to manage and recycle organic solid wastes, with the aim of obtaining a quality organic product, known as compost, to be used as an organic amendment in agriculture. When mixed with soil, compost increases the organic matter content, improves the physical properties of the soil, and supplies essential nutrients, enhancing the soil's ability to support plant growth (Iyengar 2006).

Compost can also be applied to the soil surface to conserve moisture, control weeds, reduce erosion, improve appearance, and keep the soil from gaining or losing heat too rapidly (Swan et al. 2002).

Composting may be defined as a biological degradation of organic materials under controlled aerobic conditions. The process may be used to stabilize wastewater solids before their use as a soil amendment or mulch in landscaping, horticulture, and agriculture (Lin et al. 2008). To handle large volumes of municipal waste, the process of decomposition has to be speeded up. The microorganisms in the waste are given an environment, which allows them to grow rapidly and work at peak efficiency in breaking down the waste. To do this, the microorganisms need air, water and nutrients (Iyengar 2006).

When biodegradable organic solid waste is subjected to anaerobic decomposition, a gaseous mixture of methane (CH_4) and carbon dioxide (CO_2) known as biogas could be produced under favourable conditions. The decomposition of the waste materials is mainly done by the fermentation process, which is carried out by a different group of microorganisms like bacteria, fungus, actinomycetes, etc. (Swan et al. 2002).

Due to the presence of short-chain organic acids that are not only produced from raw materials, but also generated during the initial phase of batch composting, pH will be lowered inhibiting microbiological activity (Nakasaki et al. 1993, Beck-Friis et al. 2001, Reinhardt 2002, Beck-Friis et al. 2003 and Lin et al. 2008). Therefore, inhibiting the adverse effect of organic acids, i.e., controlling pH during the initial composting phase, is the primary issue to be resolved.

Anaerobic composting, while accepted elsewhere, has failed in our country primarily due to the odour nuisance, the time involved in producing a stable product and space requirements. While the aerobic process is characterized by a minimum odour problem and rapid decomposition when compared to the older anaerobic process. Still, the aerobic process has not yet been proven satisfactory, and as of this date, no installations are using this process in operation in this country, except on an experimental or pilot plant basis.

In this research, an amendment material, sodium acetate (NaOAc), is introduced to the food waste composting process to resolve the difficulties noted above. NaOAc as a buffer salt combined with the acetic acids produced in the first composting process can form NaOAc/HOAc, a buffer solution in the composting reactor. Buffer solutions are potentially pH control amendments because of their capability to resist change in ambient pH and maintain it at the desired level (Liang et al. 2006).

However, very few studies have examined the use of buffer salts for regulating the pH of the composting process. Also, the effect of pH control amendments on the production of biogas has also been investigated. Therefore, the objective of this research is to examine the effect of NaOAc on the food waste composting process under controlled experimental conditions, quality of the final compost, as well as estimating the percentage of biogas generated due to organic solid waste degradation.

The process starts with the oxidation of readily degradable organic matter; this first phase is called decomposition. The second phase, stabilization, includes not only the mineralization of slowly degradable molecules, but also includes more complex processes such as the humification of lignocellulosic compounds. From a technical point of view, the composting process is stopped at a phase in which the remaining organic matter present is relatively in large quantities (more than 50 % of the starting amount); otherwise, the process would continue until all of the organic components are completely mineralized. The primary product is called compost, which may be defined as the stabilized and sanitized product of composting, compatible, and beneficial to plant growth (Diaz et al. 2007).

MATERIALS AND METHODS

Raw sample: The food waste (FW) was collected from daily regular kitchen waste. FW was mainly food remaining in plates after lunch consisted of potatoes, carrots, beef, steamed rice and cooked soybean. Leaves were added as a bulking agent and as a source of nitrogen, while garden soil was added to provide more desired microorganisms (Lin et al. 2008).

In-vessel composting reactor: The composting system consisted of a cylindrical vessel metal tank (200 L) with an easy mechanism for turning the compost, as shown in Fig. 1. A perforated steel screen was installed 10 cm above the reactor bottom, to recover leachate formed in the lower section and through an opening valve.

Fig. 1: In-vessel composting reactor.

A pressure gage was installed in the top of the reactor to measure the pressure of the gasses produced while temperature and humidity sensors with the platinum probe were installed in the centre of the reactor. All the raw materials were minced into pieces of < 5 mm in diameter using a food processor, and mixed well before the reaction began. To compare and analyse the effects of NaOAc on the composting processes, two experimental treatments were carried out in sequence. In Run B, NaOAc salt was added to the compost mixture; Run A was conducted as a control treatment without NaOAc addition. The detailed composition of raw materials for the composting processes is summarized in Table 1.

The digester cell was filled with 66.67 kg of different simulated food waste and 0.6 kg of sodium acetate as a buffer. The digester cell was operated anaerobically from day 1 to 5, and then air was introduced on day 6 to start the aerobic process.

Table 1: Raw material for the compositing processes in the vessel.

Item	Run A (kg)	Run B (kg)
Potato	8.46	8.46
Carrot	13.06	13.06
Meat	2.34	2.34
Soybean	13.06	13.06
Steamed rice	13.34	13.34
Soil	13.34	13.34
Leaves	3.06	3.06
Water	4.66	4.66
NaOAc	0	0.60

For Run B, 600 g of NaOAc, was added to the compost mixture on day four immediately after sampling, when the pH had decreased to a relatively low level (pH < 5) (Giannis et al. 2012).

Temperature, pH, and moisture content were taken at regular intervals throughout the composting period. Also, germination tests, NPK, and heavy metal analyses were carried out for examining the quality of the composted product for each run. Two replicates were conducted for each study.

Mixing was achieved by turning the arm of the screw by hand to ensure sufficient contact between bio-waste and the bacteria inside the digester (Donovan et al. 2012). Composting is essentially completed when mixing no longer produces heat in the pile (Giannis et al. 2012).

At the end of each composting trial of 20-25 days, the finished product was collected from the bottom layer of the bioreactor and spread outside to form a pile. Six representative samples were collected from different points within the collection. The final sample was formed after mixing the six samples together to form a homogeneous material. From the similar material, two samples were selected from which a series of parameters were evaluated (TMECC 2002).

Analytical procedure: The standard methods followed for testing and evaluating compost and composting feedstock material were according to the Test Methods for the Examination of Composting and Compost (TMECC 2002).

Laboratory analyses included measurements of moisture content, pH, volatile solids, water soluble total Kjeldahl nitrogen (TKNW), NH_4^+, NH_3, phosphorus as P_2O_5 and PO_4^{-3}, potassium, electrical conductivity, heavy metals, and germination test.

Samples from the compost of about 50 g were collected and dried in an oven at 105°C for 24 h; the loss of weight was taken as the moisture content. The oven-dried sample was further heated at 550°C for 2 h for the determination of volatile solids. The pH of the clear supernatant was measured for the top clear liquid of the sample with a pH meter.

The water-soluble extract was prepared by mixing 10 g of sample with 100 mL of deionized water, then shaken for two hours, and centrifuged at 3000 rpm. The supernatant was then filtered through a filter paper Whatman No. 1 (TMECC, 2002). Nitrogen as total N, NH_3, NH_4^+, potassium, and phosphorus as P_2O_5 and PO_4^{-3} were analysed using the Multi Direct Photometer for multi-parameter analyses. The electrical conductivity of the compost was investigated once daily using EC meter.

Heavy metals of water-soluble extract samples were analyzed by Atomic Absorption Flame Emission Spectrophotometer (GBC Scientific Equipment Sens AA).

Germination test was performed for 48 h at 25°C in the dark with 20 radish seeds placed on a 9 cm filter paper Whatman No. 1 soaked with 4 mL of compost extract and put in a Petri dish (Bertran et al. 2004). Moreover, the germination test was repeated with deionized water as a control, and extract of commercial compost. The following equations were used to calculate the relative seed germination, relative root growth, and germination index (GI) (Zucconi et al. 1981 and Tiquia et al. 1996).

$$\text{Relative Seed Germination (\%)} = \frac{\text{number of seeds germinated in compost extract}}{\text{number of seeds germinated in compost control}} * 100 \quad ...(1)$$

$$\text{Relative Root Growth (\%)} = \frac{\text{mean root length in compost extract}}{\sqrt{\text{mean root length in compost control}}} * 100 \quad ...(2)$$

$$\text{GI (\%)} = \frac{(\text{Relative Seed Germination}) * (\text{Relative Root Growth})}{100} \quad ...(3)$$

Two plastic bottles, 1 L each were modified and used as digesters. The mouth of each was supplied with an airtight rubber stopper and an outlet to permit gas collection in a suitable glass bottle filled with 0.1 M of NaOH. Each digester was setup at several combinations of environmental conditions that play the leading role in the efficiency of the anaerobic digestion process and biogas production. These conditions were temperature, starting pH and moisture content.

The temperature of the biodigesters was maintained at a constant value in a water bath (50°C), thermostatically controlled as shown in Fig. 2.

Biogas formed was measured by "liquid displacement method." The schematic diagram of the experimental laboratory setup is shown in Fig. 3.

Sampling proceeded until the composting temperature was almost near ambient temperature and stand still (Gumaa 2009). Laboratory analyses included measurements of moisture content and temperature of the composted materials, which were recorded daily during the composting period. Composition of food samples used in the study is presented in Table 2.

The biogas is a mixture of carbon dioxide, methane, hydrogen sulfide and nitrogen (Liang et al. 2006). The amount of hydrogen sulfide is less than 1% (Kaparaju et al. 2008). The amount of nitrogen is hard to estimate although it can be measured with gas chromatography (GC) (Juanga

Fig. 2: Laboratory batch digesters of anaerobic digestion to estimate the generated biogas.

Fig. 3: Gas collection by displacement.

Table 2: Raw materials for batch digesters lab-size.

Item	Run A (kg)	Run B (kg)
Potato	74.1	74.1
Carrot	114.3	114.3
Meat	20.4	20.4
Soybean	114.3	114.3
Steamed rice	116.7	116.7
Soil	116.7	116.7
Leaves	26.8	26.8
Water	41	41

et al. 2005 and Bonn 2008).

Laboratory simulation: To study the influence of NaOAc addition on biogas production, two laboratory biodigesters in series were investigated. In digester B, NaOAc salt was added to the mixture; digester A was conducted as a control without NaOAc addition. The procedures held were as follows: The raw material mixture; composition of biogas was measured by taking a 50 mL of biogas sample in a large syringe, and pushing the biogas slowly (over 10 minutes) through a 0.5 L glass bottle liquid, displacement system containing a stable solution of NaOH (4 g/L). As the biogas passes through this high pH solution, the CO_2 of the biogas is converted to carbonate and absorbed into the liquid; only the methane passes through the solution, and an equivalent volume of alkaline solution is pushed out of the glass bottle as shown in Fig. 3.

The volume of alkaline solution that pours out of the bottle divided by the amount of biogas injected is equal to the fraction of methane in the biogas (Juanga et al. 2005, Bonn 2008 and Gumaa 2009).

RESULTS AND DISCUSSION

Results are based on parameters used to assess the anaerobic-aerobic mixed solid waste conversion, NaOAc addition, and methane gas production.

Temperature profiles: The temperature of the composting mixture in both the runs rose soon after beginning the experiment and reached 63 ± 2°C within 20 to 25 days, corresponding to an average increase rate of 2°C/day as shown in Fig. 4.

The temperature increased to the thermophylic level (above 50°C) within 13 and 7 days in Run A and Run B respectively, indicating that the indigenous microorganisms could easily utilize the organic materials in the amended food waste.

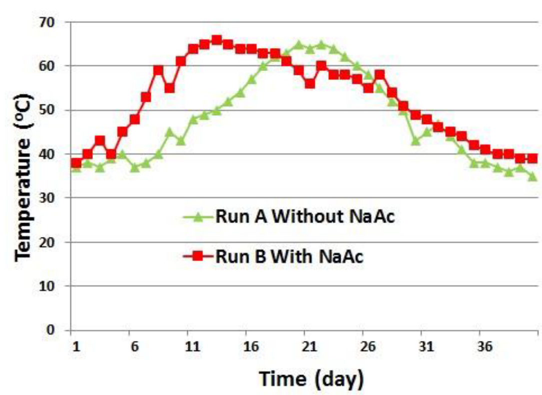

Fig. 4: Temperature profiles through composting process.

The thermophylic phase lasted more than 15 days in Run A and 20 days in Run B, and then the temperature slowly dropped to an average level. The duration of the thermophilic phase in Run B was relatively longer than that in Run A. The increase in temperature with time is consistent with previous reports of Benson et al. (2007).

The overall average ambient temperature during this study was 40±3°C, indicating that exothermic reactions in the digester contributed much beneficial heating. For the batch digester, the system was located in A water bath adjusted at 50°C. This relatively high temperature would be expected to facilitate digestion. It also shows that the cell is capable of retaining heat that is generated during decomposition to withstand sudden electric cut-off.

It is clearly shown that the composting proceeded more rapidly in the laboratory plastic biodigesters than in the large tank in both runs A and B due to the relatively optimal conditions i.e., under control and suitable surrounding environment. Temperature profiles for run A and run B are shown in Fig. 5.

The changes of pH: The changes of pH are shown in Fig. 6. The pH had its lowest value at day 4 in all the runs. The addition of NaOAc raised the pH value in Run A because NaOAc is an alkaline salt that forms a buffer solution through combining with acetic acids present in the composting material. This partially neutralized the acids and tended to maintain a relatively stable pH (5-5.8) level. However, maximum pH values in the reactor with the addition of NaOAc were around 9.1, while in the control reactor they were about 7.0.

Moisture content: The moisture content tended to decrease due to the combination of high temperature levels and aeration during the thermophilic phase and was controlled by applying water (humidifying) to the compost mass. The initial moisture content 63.5% of the wet weight was reduced in all the experiments to reach an average moisture content of 40±5% of the wet weight, remaining above the minimum moisture content of 40% suggested by Liang et al. (2003) and Petric et al. (2009) for optimal composting conditions. After that, no significant changes in parameters have been observed.

Electric conductivity: Fig. 7 shows the variation of electrical conductivity with time. The electrical conductivity slightly increased on day 1. Since decomposable compounds were easily released in the solution, the soluble ions in the water extract may increase slightly at the beginning of the composting process. The electrical conductivity was in the range of 2 to 3 dS/m during composting.

The initial EC increase could be caused by the release of

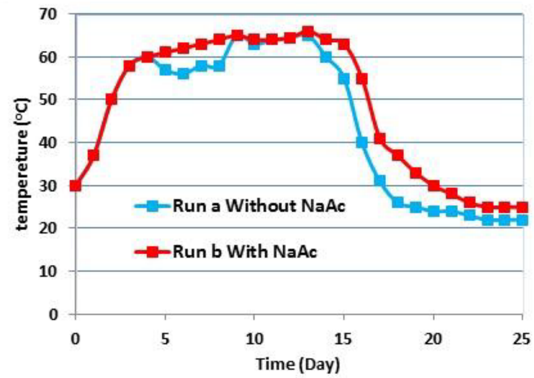

Fig. 5: Temperature profiles in simulated digester.

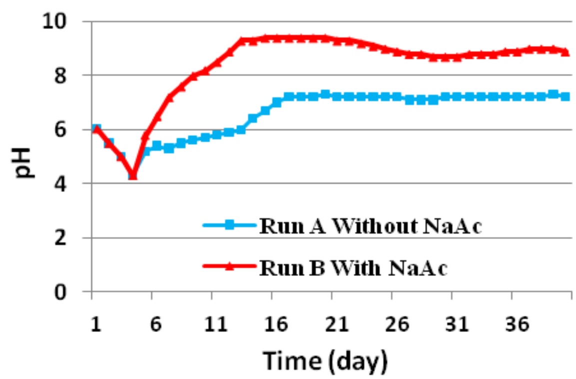

Fig. 6: pH profiles of the composting processes.

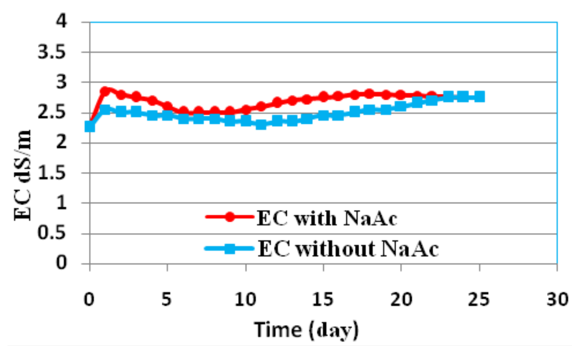

Fig. 7: Variation of electrical conductivity during composting.

mineral salts such as phosphates and ammonium ions through the decomposition of organic substances (Fang & Wong 2000). As the composting process progressed, the volatilization of ammonia and the precipitation of mineral salts could be the possible reasons for the decrease of EC at the later phase of composting (Beck et al. 2003).

Evolution of Compost Characteristics

Organic matter loss: Dry matter losses mainly occurred during the first 13 days (TMECC 2002) but varied among composting runs, with a mean loss of dry matter of 32 ± 9% and a coefficient of variation of 15.6%.

Compost quality: The concentration of nitrogen was very low in the final compost suggesting that nitrogen was lost during composting upon opening the digesters. Losses of nitrogen in this composting process were governed mainly by volatilization of ammonia due to high pH (that is because of the addition of NaOAc) and high temperature values of the substrate. Agitation and aeration rate may have also affected the rate of ammonia volatilization (Beck et al. 2003). However, as composting was developing the nitrate concentration, presented a significant increase which can be explained by the activity of autotrophic nitrobacteria which oxidize ammonium compounds into nitrates in the presence of oxygen-rich environment (Benson et al. 2007 and Chroni et al. 2009).

Nitrates reached 0.6 mg/L and 2.84 mg/L on the 40th day of the process, for Run A and B respectively, which can be considered as an indicator of a high degree of compost stabilization. Phosphorus as P_2O_5 reached 3.1 and 4.5 mg/kg on the 40th day of the process, for Run A and B respectively, which are higher than the recommended levels, while potassium as K_2O reached 3.12± 0.03 mg/kg for both the runs. Results of Run A are expressed in Table 3.

Heavy metals: Metal concentrations were below the maximum permissible levels of organic farming recommended by the Japanese Ministry of Agriculture. The maximum allowable levels for organic farming in Japan are 2 mg/kg mercury, 5 mg/kg cadmium, 50 mg/kg arsenic, 600 mg/kg copper, and 1800 mg/kg zinc (Japanese Ministry of Environment 2005). As may be concluded, the quality of the current compost meets the requirements of USDA and US, Composting Council, TMECC 2002 as given in Table 4.

Germination test: Maturity of compost may be evaluated with the use of the cress seed germination bioassay, which is sensitive to excessive salinity or the presence of phytotoxic simple organic acids or phenol compounds (Chroni et al. 2009 and Donovan 2012). One of the most significant germination tests is that reported by Zucconi et al. (1981, 1985) and many following tests were developed from this.

The results of germination show 86.5% relative seed germination and 98% root growth; the calculated value of germination index (GI) is 84.8% which is better than the suggested value of 60% for cross reported by Diaz Diaz et al. (2007). On the other hand, poor relative seed germination of 50.9%, root growth 16.4%, and GI 8.3% values were observed upon analysing a commercial compost extract.

Table 5 gives values for very mature, mature and immature composts (TMECC 2002), which shows that the obtained compost can be classified as a mature compost.

Table 3: Characteristics of run A compost and compost quality.

Heavy metal (mg/kg dry weight)	Run A compost	TMECC 2002 Max
Pb	110	150
Zn	-	1400
Cu	28	750
Ni	35	210
Cd	0.54	2
Moisture content, %	40.2	30-60
Electrical conductivity (EC) dS/m	2.75	4.7
Available nutrients (NPK) mg/kg	1.1 N 3.1 P_2O_5 3.12 K_2O	1.6 N 2.57 P_2O_5 8 K_2O
C/N	20/25	20/30

Table 4: Outcome of germination.

Parameter	Compost extract of in-vessel lab-scale reactor	Commercial compost extract
Total seeds	75	75
Germinated seeds	45	33
Mean root length (cm)	0.98	0.85
Relative seed germination %	86.5	50.9
Relative root growth %	98	16.4
Germination index %	84.8	8.3

Table 5: Compost maturity indices, TMECC (2002).

Method	Units Rating		
	Very Mature	Mature	Immature
NH_4-N : NO_3-N ratio	< 0.5	0.5-3.0	> 3
Total NH_3-N ppm, dry basis	< 75	75-500	> 500
Seed Germination %	> 90	80-90	< 80
Plant trials of control %	> 90	80-90	< 80

Gas Production and Composition

It was impossible to assess the impact of NaOAc addition on methane production in both runs A and B in the large tank; therefore, two-laboratory biodigesters of two litres each were used spontaneously as biodigesters (A and B). In digester B, NaOAc salt was added to the raw material mixture; digester A was conducted as a control treatment without NaOAc addition. Experiments were held in the Environmental Engineering Department Laboratory in Baghdad University.

The largest fraction of gas probably had been lost from the compost by volatilization. The total volume of methane produced was 68±1% of the total gas produced in the absence of NaOAc, where the production reached 75±1% for the NaOAc-amended compost, indicating that the addition of NaOAc had effectively increased the extent of methane gas production due to efficient material degradation.

Biogas production is very slow at both, the beginning and the end period of observation. This is predicted due to the biogas production rate in the digester is directly corresponded to the specific growth rate of methanogenic bacteria in the biodigester (Nopharatana et al. 2007). After 27 days observation, biogas production tends to decrease due to the stationary phase of microbial growth. The rate of methane gas produced agreed with other results of researchers (Lo et al. 1984, Nopharatana et al. 2007 and Kaparaju et al. 2008).

CONCLUSIONS

The characteristics of the wastes composted and the temperature profiles obtained indicate that composting is a suitable technology to treat food wastes and to recycle them into stabilized and sanitized soil amendment. The final compost produced in this study was satisfactory for its agricultural application regarding pH, electrical conductivity as a salt content index, germination test, and heavy metal contents.

The main findings were:

1. In-vessel composting can process significant amounts of waste without taking much space or cost as other solid waste management methods. Besides, it can accommodate virtually any organic waste (e.g., meat, animal manure, biosolids, food scraps). The length of the composting process was 35 days in the vessel and two weeks of curing out of the vessel. The residuals after composting were about 33% of the original weight for run A and slightly less (30%) for run B, i.e. the 66.6 kg turned to be 20.7 kg in the vessel B, indicating successful reduction. The bulk density of the composting materials was 750 kg/m^3 at day 1, and kept on decreasing after each mixing trial to reach 390 kg/m^3 on day 12, almost equal for both the runs.
2. The temperature of the composting mixture in both the runs rose soon after beginning the experiment and reached 63±2°C within 20 to 25 days, corresponding to an average increase rate of 2°C/day. The duration of the thermophilic phase in Run B of 20 days was slightly longer than that in Run A of 15 days.
3. It was clearly shown that composting proceeded more rapidly in the laboratory plastic biodigesters than in the large vessel due to the relatively optimal conditions, i.e., under control and suitable surrounding environment.
4. Final pH levels in reactors B was around 9.1, while the control reactor was about 7.
5. Electrical conductivity slightly increased on day 1, as the composting process progressed, the volatilization of ammonia and the precipitation of mineral salts caused EC reduction at the later phase of composting. Overall, electrical conductivity was in the range of 2 to 3 dS/m for both runs.
6. The initial moisture content (63.5% of wet weight) was reduced in all experiments to reach an average moisture content of 40±5% of the wet weight.

Compost maturity was evaluated using certain indices; the levels of indices were relatively stable in the latter part of the composting period, and they remained constant.

1. Nitrates reached 0.6 mg/L and 2.84 mg/L on the 40th day of the process, for Run A and B respectively, which can be considered as an indicator of a high degree of compost stabilization.
2. Phosphorus as P_2O_5 was 3.1 and 4.5 mg/L on the 40th day of the process, for Run A and B respectively, which are higher than the recommended levels. Potassium as K_2O reached 3.12±0.03 mg/kg for both the runs that are within the recommended level of the USA compost quality standard.
3. The metal concentrations in this study were below the maximum permissible levels for organic farming recommended by the Japanese Ministry of Agriculture, Japanese Ministry of Environment, 2005 and the recommended levels of the USDA and US Composting Council standards.

In all the cases, a peak in gas emissions was observed in coincidence with the thermophilic stage. In fact, gas emissions may be proposed as an indicator of the biological activity of composting materials. The results showed:

1. Biogas production is very slow at the beginning and the end period of observation.
2. The total volume of methane produced was 75±1% of the total gas produced in run A and 68±1% of the total gas produced in run B, indicating that the addition of NaOAc had effectively increased the extent of methane gas production due to efficient material degradation.

The results showed that relative seed germination = 86.5%, relative root growth = 98%, and GI = 84.8%. The obtained compost can be classified as mature compost. This stabilized compost can be finally considered very satisfactory for agricultural use.

REFERENCES

Beck-Friis, B., Smàrs, S., Jonsson, H. and Kirchmann, H. 2001. Gaseous emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes. Journal of Agricultural Engineering Research, 78(4): 423-430.

Beck-Friis, B., Smàrs, S., Jonsson, H., Eklind, Y. and Kirchmann, H. 2003. Composting of source-separated household organics at different oxygen levels: Gaining an uderstanding of the emission dynamics. Compost Science and Utilization, 11(1): 41-50.

Benson, C., Barlaz, M., Lane, D. and Rawe, J. 2007. Practice review of five bioreactor/ recirculation landfills. Waste Management, 27(1): 13-29.

Bertran, E., Sort, X., Soliva, M. and Trillas, I. 2004. Composting winery waste: Sludges and grape stalks. Bioresource Technol., 95: 203-208.

Bonn, Jonas 2008. Improved techniques for sampling and sample introduction in gas chromatography. Royal Institute of Technology.

Chroni, C., Kyriacou, A., Manios, T. and Lasaridi, K.E. 2009. Investigation of the microbial community structure and activity as indicators of compost stability and composting process evolution. Process Evolution Bio. Resource Technology, 34: 103-110.

Diaz, L.F.M. de Bertoldi, W. Bidlingmaier and E. Stentiford 2007. Compost Science and Technology. Waste Management Series 8, British Library Cataloguing in Publication Data.

Donovan, S. M., Bateson, T., Gronow, J. R., and Voulvoulis, N. 2012. Characterization of compost-like outputs from mechanical biological treatment of municipal solid waste. Centre for Environmental Policy, Imperial College London, United Kingdom.

Fang, M. and Wong, J.W.C. 2000. Effects of lime addition on sewage sludge composting process. Water Research, 15: 3691-3698.

Giannis, A., Makripodis, G., Simantiraki, F., Somara, M. and Gidarakos, E. 2012. Monitoring operational and leachate characteristics of an aerobic simulated landfill bioreactor. Waste Management, 28(8): 1346-1354.

Gumaa, Nadhem Haydar 2009. Effect of some factors on anaerobic biodegradation of organic solid wastes and biogas production. Proceedings of 3rd Scientific Conference of the College of Science, University of Baghdad, 24 to 26 March 2009.

Iyengar, S.R. 2006. In-vessel composting of household wastes. Waste Management, 26: 1070-1080.

Japanese Ministry of the Environment 2005. Available at http://www.env.go.jp/recycle/waste_tech/ippan/h17/index.html

Juanga, J.P., Kuruparan, P. and Visvanathan, C. 2005. Optimizing combined anaerobic digestion process of organic fraction of municipal solid waste. Environmental Engineering and Management, Asian Institute of Technology.

Kaparaju, P., Buendía, I., Ellegaard, L. and Angelidaki, I. 2008. Effects of mixing on methane production during thermophilic anaerobic digestion of manure: Labscale and pilot-scale studies. Bioresour. Technol., 99: 4919-4928.

Kim, J. D., Park, J. S., In, B. H., Kim, D. and Namkoong, W. 2008. Evaluation of pilot-scale in-vessel composting for food waste treatment. Journal of Hazardous Materials, 154(1): 272-277.

Liang, C., Das, K.C. and McClendon, R.W. 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. Bioresource Technology, 86: 131-137.

Liang, Y., Leonard, J.J., Feddes, J.J.R. and McGill, W.B. 2006. Influence of carbon and buffer amendment on ammonia volatilization in composting. Bioresource Technology, 97: 748-761.

Lin, Y.P., Huang, G.H. and Lu, H.W. 2008. A simulation-aided factorial analysis approach for characterizing interactive effects of system factors on composting processes. Science of the Total Environment, 402(2-3): 268-277.

Lo, K.V., Whitehead, A.J., Liao, P.H. and Bulley, N.R. 1984. Methane production from screened dairy manure using a fixed-film reactor. Agricultural Wastes, 9(3): 175-188.

McDonnell, E.M. 1999. Process characterization, and stability and maturity testing of forced air, static pile processed food scrap and wood chip compost. Ph.D. Thesis, Cornell University, United States.

Nakasaki, K., Yaguchi, H., Sasaki, Y. and Kubota, H. 1993. Effects of pH control on composting of garbage. Waste Management and Research, 11(2): 117.

Nopharatana, A., Pullammanappallil, P.C. and Clarke, W.P. 2007. Kinetics and dynamic modeling of batch anaerobic digestion of municipal solid waste in a stirred reactor. Waste Management, 27: 595-603.

Petric, I., Sestan, A. and Sestan, I. 2009. Influence of initial moisture content on the composting of poultry manure with wheat straw. Biosystems Engineering, 104: 125-134.

Reinhardt, T. 2002. Organic acids as a decisive limitation to process dynamics during composting of organic matter. Microbiology of Composting, 177-188.

Swan, J.R.M., Crook, B. and Gilbert, E.J. 2002. Microbial emissions from composting sites. Issues Sci. Technol., 18: 73-101.

Tiquia, S.M., Tam, N.F.Y. and Hodgkis, I.J. 1996. Effect of composting on phytotoxicity of spent pig-manure sawdust litter. Environ. Pollut., 93: 249.

TMECC 2002. Test Methods for the Examination of Composting and Compost, USDA and US. Composting Council, Bethesda, MD.

Zucconi, F., Monaco, A., Forte, M. and de Bertoldi, M. 1985. Phytotoxins during the stabilization of organic matter. In: Composting of Agricultural and Otherwaste, J.K.R. Gasser, Elsevier Applied Science, London, pp. 73-85.

Zucconi, F., Pera, M.A., Forte, M. and Bertoldi, M de. 1981. Evaluating toxicity of immature compost. Biocycle, 22: 27-29.