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Resource Conservation by Effective Composting of Municipal Solid Waste in Sri Lanka – Optimum Moisture Range for the Bio-oxidative Phase

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Abstract

Waste is a resource. Municipal solid waste management is a great concern in Sri Lanka due to high water content and heterogeneity of the waste. Composting is one of the important, cost effective methods of management of biological waste in developing countries. This study was performed to determine the optimum moisture range for effective composting, which can be maintained throughout the bio-oxidative phase of the composting process to accelerate the decomposition rate and eventually get a better compost product. Four wind row piles were set up with moisture contents adjusted to 60% ± 10% (Control) for five weeks, 40% ± 10% (Pile A), 60% ± 10% (Pile B) and 80% ± 10% (Pile C) for 8 weeks. Moisture content of the control pile was lowered to a value of 40%± 10% during the last three weeks while other piles were maintained within the experimental moisture ranges for the eight weeks of composting cycle. According to the temperature profiles of the piles, pile B showed the best temperature level for microorganisms. Other physico-chemical parameters were not significantly different between piles. Therefore, moisture content of pile B (60% ± 10%) was selected as the optimum moisture range for the bio-oxidative phase in the composting process. Unskilled labourers can maintain that moisture level easily by performing the squeeze test for the moisture.

Keywords: Meethotamulla; Composting; Biological waste; Bio-oxidative phase; Temperature profile

Introduction

Composting is one of the important methods of controlling biological waste in developing country like Sri Lanka. Passive windrow composting with turning is a widely used strategy to manage the organic fraction of MSW in the country because; MSW of Sri Lanka contains more than 80% (dry weight basis) of organic matter and has moisture content about 60-70% [1]. But there are many problems associated with the composting plants in Sri Lanka. The major problem is bad odour of the compost piles during the bio-oxidative phase. It is really a social problem of those areas where closer to the composting plants. Main reason is that, unskilled and uneducated labourers, who often find the addition of water results insufficient or excess moisture contents inside the piles, maintain composting plants. If water is accumulated faster than it is eliminated via either aeration or evaporation (driven by high temperatures), then oxygen flow is impeded and anaerobic conditions result [2]. This usually occurs at a moisture level of about 65 percent or higher. If the moisture level drops below about 40 to 45 percent, the nutrients are no longer in an aqueous medium and easily available to the microorganisms. Their microbial activity decreases and the composting process slow. Below 20 percent moisture, very little microbial activity occurs [3].

Another reason is that, literature based moisture contents, which have been prescribed for composting are heavily dependent on the composition of MSW, climatic factors of the regions and the turning frequency of windrows. In this study, determine the optimum moisture range in the composting pile was addressed. To achieve it, the performance of the composting process is checked by employing several physic-chemical parameters proposed in literature through which the metabolic activity of the micro-organisms involved in the composting process was evaluated.

Methodology

Preparation of windrow

The study was carried out in the composting plant at Meethotamulla, which is located in a suburb of the capital city of Colombo, Sri Lanka. Passive windrow composting with manual turning for aeration was the technique used in the study. The organic fraction was segregated from mixed MSW at the site. Four rectangular shaped composting piles were prepared with 1m high × 2 m width × 3 m length. Moisture ranges were adjusted to 60% ± 10% at first 05 weeks and then reduced to 40% ± 10% in pile Control, 40% ± 10% moisture maintain in pile A while 60% ± 10% moisture maintained in pile B and 80% ± 10% moisture maintain in pile C by manual moisture addition throughout the 08 weeks of bio oxidative period. Moisture was added to all the piles once a week to ensure that the moisture content was within the experimental range. The moisture range of pile Control (60% ± 10%) was maintained for first five weeks and then reduced to 40% ± 10% for the remaining three weeks of the bio-oxidative phase which is the practice of some composting plants in Sri Lanka. Piles were turned manually once a week to aerate the composting matrix and ensure aerobic conditions within the pile [4]. Homogenous triplicate (1 kg) composite samples were collected from each pile at days 0, 7, 14, 21, 28, 35, 42, 49, and 56 at 50% of the pile height before turning the piles. All the chemical and physical analyses were carried out in triplicate.

Physico-chemical analysis

Ambient temperature and pile temperature at 50% of pile height was monitored using K- Thermocouple before weekly turning of the piles. Heights, lengths and widths of the piles were measured once a week before turning to calculate surface area: volume ratio and volume

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reduction [5]. Samples were analyzed for the moisture content by drying at 105°C for 24 h [6]. pH was measured by mixing with distilled water in a 1/10, (w/v) compost/ water ratio [7]. Total Nitrogen (TN) was determined by Kjedhal method [8] and Total Organic Carbon (TOC) was measured by the wet dichromate oxidation method [9]. Ash content was determined by loss on ignition technique by combusting the materials at 550°C for 5 h [6]. C/N ratio was calculated using the method by Jiménez and García [10]. Cation Exchange Capacity (CEC) was determined using the method by Harada and Inoko [11].

The mean and standard error of mean of three replicates were calculated for all the parameters measured. Linear regression analysis was carried out for surface area: volume ratio, volume reduction, TOC, ash content, TN, C/N ratio, CEC. Slopes of the graphs were compared. All statistical analyses performed were based on the procedures.

Results

Temperature

During the bio-oxidative phase, the ambient temperature fluctuated within a narrow range (from 30°C to 32°C). The temperature profile in the Control and B piles were similar as temperatures had risen to thermophilic levels 55.22 ± 1.21°C and 60.98 ± 2.01°C respectively until day 7 and remained within the thermophilic range with narrow fluctuations until day 49. Pile A followed the same trend of changes like piles Control and B but reached a maximum temperature of 72.39 ± 2.56°C on day 28. Temperature of pile C fluctuated within a narrow range from day 28 to 56 and the maximum temperature observed during the thermophilic stage of pile C is 53.49 ± 1.16°C (Figures 1 and 2).

Surface area: volume ratio and volume reduction

The initial surface area: volume ratio of each pile is 2.67 m^{-1} and increased dramatically as bio-oxidative phase progresses and stabilized during the last three weeks. Pile C showed the highest increase of surface area: volume ratio and reached a value of 4.84 m^{-1} on day 56. But the increase was lowest in pile A and reached a value of 4.43 m^{-1} on day 56. The volume reduction percentage of each pile increased dramatically until day 28 but more gradually between day 28 to 42, to percentages between 70.67% and 76.25% and then leveled off until the end of the bio-oxidative phase. Both the surface area: volume ratio and volume reduction increased in each pile due to the microbial decomposition resulting in evaporation of water and removing carbon dioxide.

Moisture content

Moisture contents remained within the experimental ranges until day 56 (pile A (40% ± 10%), pile B (60% ± 10%) and pile C (80% ± 10%)). The moisture content of pile Control remained at 60% ± 10% until day 35 and then declined to 40% ± 10% until day 56.

pH

At day 0 all piles had more or less same pH values and their pH values dropped until the day 35 and started increasing thereafter.

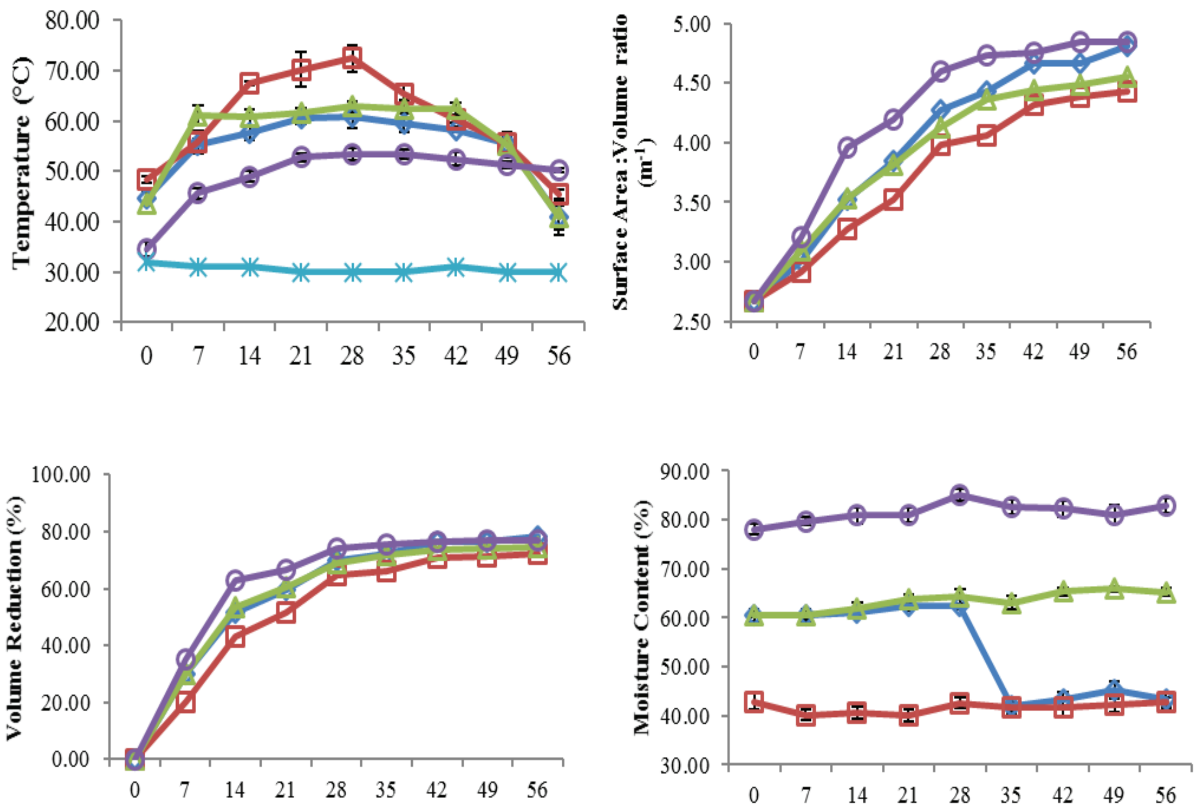

Figure 1: Changes in pile temperature, air temperature (∗) (a), surface area: volume ratio (b), volume reduction (c), moisture content (d), in each pile during the bio-oxidative phase. (◊ = Pile Control, □ = Pile A, △ = Pile B. ○ = Pile C.

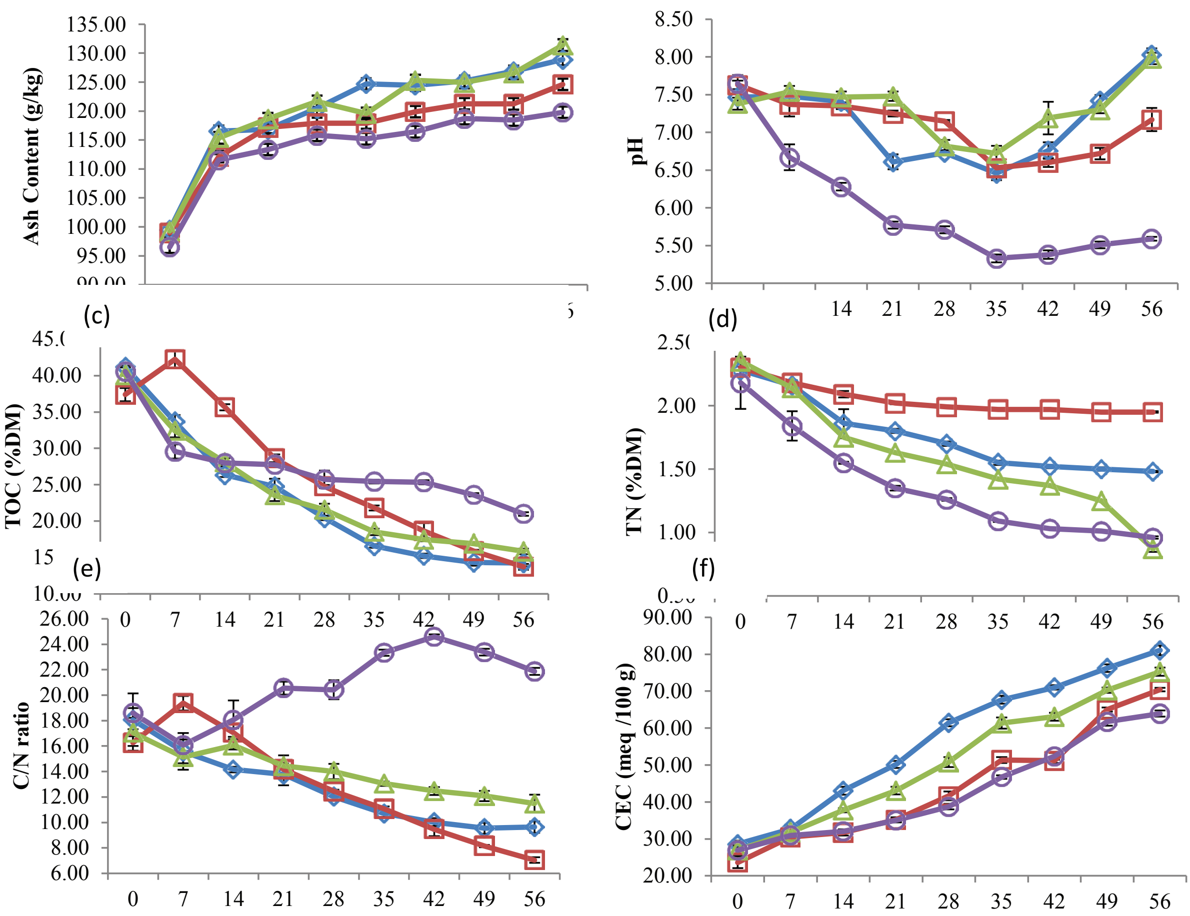

Figure 2: Changes in ash content (a), Ph (b), TOC (c), TN (d), C/N ratio (e) and CEC (f) within each pile during the bio-oxidative phase. (◊ = Pile Control, □ = Pile A, △ = Pile B. ○ = Pile C. Mean and standard deviation of the three replicates are shown).

Ash and TOC

In the present study the decrease in TOC coincided with increase in ash content of each pile. The ash contents of piles Control, A, B and C gradually increased during the bio-oxidative phase as a result of mineralization of organic and nitrogenous compounds. Furthermore, Alexander [12] stated that during composting 20 to 40 percent of carbon substrate in the compost material is eventually assimilated in to new microbial cell. Pile C showed the lowest increase of ash content and reached a value of 119.79 ± 0.27 g/kg at day 56. This could be due to inadequate oxidation of organic carbon and suppression of mineralizing bacteria due to acidic pH values within the pile. TOC in all piles decreased continuously throughout the entire bio-oxidative phase. Pile C showed the lowest decrease of TOC. From days 28 to 42 the TOC of pile C leveled off and there was a gradual decrease from day 42 onwards until day 56. TOC in every pile decreased due to the oxidation of C to CO_2 by the microorganism [13-15].

TN and C/N ratio

TN contents in all piles decreased during the bio-oxidative phase from initial values between 2.18 - 2.35% DM to 0.96 - 1.95% DM by the end of the bio-oxidative phase. That could be attributed to its volatilization as ammonia and by leaching as nitrate after moistening the windrows [16]. The loss of nitrogen from the compost piles also depends on the frequent turning of the windrow [17]. Turning frequency could be a reason for continuous decrease of nitrogen in all piles rather than oxidizing NH_4+-N in to NO3--N and NO2--N. Pile C showed the highest decrease of TN. The reason could be as Carbrera and Chiang (1994) stated that NH_3 volatilization occurs when water content of the material is closer to the water holding capacity. For pile C, water was observed to drip out of the pile when moisture was adjusted to 80% ± 10% and since this is within its water holding capacity, volatilization of NH_3 Could be a cause for the high decrease in TN. But pile C had the lowest temperatures throughout the bio-oxidative phase. High temperatures also result in ammonia volatilization. But the decrease of TN was much lower in pile A which attained the highest temperatures. More over ammonia can be leached out since it is soluble in water. A net decrease of C/N ratio was observed piles Control, A and B. Pile C, as mentioned earlier, due to excessive leaching or volatilization of ammonia, instead of having a decreasing trend of C/N ratio, achieved an increasing trend until day 42 although both TOC and TN decreased over time.

Cation cxchange capacity (CEC)

The initial CEC values of piles were between 28.60 to 23.62 meq/100 g. The values increased gradually until day 7 but more dramatically between days 14 to 56 to values of between 63.95 to 81.07 meq/100 g. The increase of CEC can be explained by the humification process that results in formation of carboxylic and phenolic groups [11]. Harada and Inoku [11] reported that according to Waskaman and Tenny [18] the aerobic decomposition is accompanied by a gradual disappearance of the cellulose and hemicelluloses and an accumulation of the lignin. The increase in CEC during the composting process therefore could be explained not only by increase of carboxyl and/or phenolic hydroxyl groups in the materials but also by the accumulation of materials bearing a negative charge such as lignin. Pile C showed the lowest increase of CEC during the bio-oxidative phase. The reason might be the creation of an anaerobic condition due to inadequate oxygen and resulted in slow humification of organic material.

The progression of bio-oxidative phase was accompanied by the changes in physical parameters such as surface area: volume ratio, volume reduction, bulk density, temperature and chemical parameters such as ash, TOC, TN, C/N ratio, pH and CEC. The slopes of chemical and physical parameters (surface area: volume ratio, volume reduction, ash, TOC, TN and CEC) were not significantly different among the treatments (P>0.05). Therefore, moisture range of the pile A could be taken as the optimum moisture range according to the statistical outcomes since it requires less amount of water than other piles. But the temperatures of pile A exceeded 65°C and that could result in inhibition of microbial activities. Moreover fungus growth (Aspergillus fumigates) could be seen in the pile A which also indicated the lack of moisture. As a solution, temperature could be taken as a tool to determine the optimum moisture range which is independent on the composition and a strong driving force in the succession of microbial communities during composting as the release of heat is directly related to the microbial activity [19-21]. Sandra and Triado [22] stated that most composting takes place at temperatures between 45°C and 65°C. Piles B and C were within the range. Diversity of bacteria increased even when temperature was higher than 60°C [23,24]. Xiao et al. [25] found in a laboratory experiment that more abundant bacterial diversity when the temperature was as high as 64°C. Furthermore highest temperature achieved by pile C was 53.8°C was not sufficient to kill pathogens and weed seeds. Therefore only pile B which contained 60% ± 10% moisture range with maximum temperature of 62.8°C can be taken as the optimum moisture range for MSW composting in Sri Lanka. Liang et al. [26] also reported that many investigators have conducted experiments and identify that 50–60% moisture content is suitable for efficient composting [6,23,27]. FCQAC [28] recommended the squeeze test to determine the moisture content in compost samples. When a handful of compost sample is squeezed, the material should hold together but not exude excess water. This indicates moisture content ~ 60% and can be easily employed by the labourers in the compost plants without any equipment to adjust the moisture contents in the piles.

During this study it has been identified that maintaining particular moisture content was difficult although water was added. This is because windrow composting is an open composting system and the windrows are therefore exposed to the external environment and water loss from evaporation [6]. Besides, ensuring unskilled labor are able to add the right amount of water to ensure a specific moisture content is difficult in the field. Considering that fact, having moisture ranges for the treatments were appeared to be more effective than specifying a specific moisture content. Therefore prescribing a moisture range for the bio-oxidative phase was more practical and achievable in the field than prescribing a particular moisture content.

Discussion

During the composting process, degradable organic matter and nitrogenous compounds in MSW were being broken down by microorganisms. This process resulted in the release of heat so, the temperature inside the piles tended to increase due to biologically generated heat.

Sandra and Triado [22] stated that heat production depends on the size of the pile, its moisture content, aeration, and C/N ratio. This statement was confirmed by the differential heating in piles caused by experimental moisture ranges. Pile C which contained high moisture contents attained low temperatures. This could be due to two main reasons. One reason is that high moisture contents create anaerobic conditions inside the pile and encourage the growth of anaerobic microorganism. Their microbial activity is less intense than the activity of aerobic microbes and generates less amount of heat. The other reason is that, large amount of water was available to absorb the heat produced by the microbes. Every pile except pile C exceeded the optimum temperature ranges (52-60°C) by 1 – 10°C as prescribed by MacGregor et al. [29]. Since the initial C/N ratios and frequency of turning were more or less similar in all experimental piles, they played insignificant roles in differential heating.

Differences in the surface area: volume ratio was another reason for differential heating in compost piles. As mentioned by Michel et al. [30] the piles, with low increase in surface area: volume ratios presumably had less heat loss by convection and thermal diffusion resulting in less cooling, and higher temperatures. This could be another reason for achieving low temperatures by pile C and high temperatures by pile A.

This initial drop of pH in each pile reflected the synthesis of organic acids. De Nobili and Petrussi [31] stated that these organic acids served as substrates for succeeding microbial populations and the subsequent rise, in turn, reflected the utilization of the acids by the microbes and release of ammonia due to the start of proteolytic process. The pH values of pile C fluctuated within a broader range (7.65 ± 0.11 to 5.33 ± 0.05) and its pH values remained lower (acidic) than the pH values of other piles throughout the bio-oxidative phase except at day 0. This may be due to the anaerobic fermentation that developed during bio-oxidative phase due to high moisture levels and resulting anaerobic conditions in the pile. Another reason could be the accumulation of organic acid resulting in the inhibition of bacterial populations because, bacteria prefer a pH between 6 and 7.5, if the pH drops below 6 bacteria, die off and decomposition slows [32]. De Bertoldi et al. [31] suggested that the optimum pH values for composting are between 5.5 and 8.0. All piles except pile C were within the optimum range [33,34].

Conclusion

This study has been done to investigate the optimum moisture level for effective composting. Physico-chemical parameters such as temperature, surface area: volume ratio, volume reduction, TOC, ash content, TN, C/N ratio, CEC were measured while changing the moisture contents in the piles.

60% ± 10% (pile B) moisture range was selected as the optimum moisture range that can be maintained throughout the bio-oxidative phase which also had suitable temperatures for the microorganisms. The squeeze test could be employed by the compost plant laborers to check the moisture content (60%) as it requires no specialized equipment or competent personnel yet gives results that are more accurate. By controlling moisture level at 60%, odour problem and leachate problem also can be solved. Final compost quality also the best in the 60% moisture level. This finding will help to effective composting for resource conservation.

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