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# A SEQUENTIAL BATCH COMPOSTER FOR THE MANAGEMENT OF KITCHEN AND GARDEN WASTE IN RESTAURANTS AND GUEST HOUSES

Wijetunga S and Karunarathne RSP

Department of Agricultural Engineering, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka

## Abstract

**The disposal of solid waste is the last operation of solid waste management. Composting can be considered as an attractive onsite waste disposal option for the management of organic solid wastes. The medium scale waste generators (25-50kg/day) do not have proper, adaptive technology for the production of compost. In this study, it was attempted to design, construct and evaluate a composting bin system for the management of organic waste in restaurants and guest houses. The composting structures designed were installed in Kataragama town. Kitchen and garden waste was used as raw material. The first composting system is composed of six bins while the second system had only four bins. The six bins system was operated using only six bins for the total composting period while other was operated using four bins. Kitchen and garden waste mixture (3:1) was used for the composting. Waste in the first week was added to the first bin and then degrading waste in first bin was transferred to the next bin in second week. This procedure was followed until the completing the compost production. Temperature is recorded daily while pH, EC, nitrogen and organic carbon were measured once in a week. Selected physical and chemical parameters of the compost were also determined. The quality parameters in both rotation systems are almost similar to the compost standards given by Sri Lanka standard institute. The four bin rotation system is quite complex than the six bin rotation system and therefore, six bin rotation system can be recommended since it can be operated easily. Based on the results of the study, the designed composter can be successfully used for the production of compost from kitchen and garden waste.**

Keywords: Compost, Compost bins, Kitchen waste, Restaurant waste

## INTRODUCTION

Waste generation in various human activities is an ever increasing process due to the increase of population with the demand of new necessities of the people. The urbanization of people seeking more facilities intensifies the municipal solid waste (MSW) disposal problem in cities of the local authorities since the waste disposal is to be disposed in environmentally safe approaches. The municipal solid wastes refers to the materials that have no value to the concerned person and that cannot be discharged through the drainage lines and they are generated domestically, commercially, industrially and through health care and gardening activities (Vuai, 2010). The composition of waste and the rate of generation are changed with the economic status of the residents, geographical location, social and cultural habits, and climate of the area. The safe disposal of MSW having different materials is a big challenge for local authorities (Gunaruwan & Gunasekara, 2016). Even though methods have been developed and are being developed for the management of MSW, it is not possi-

*Corresponding author: swije@ageng.ruh.ac.lk

ble to apply the same method for all locations where wastes are generated. The suitable methods should be selected or developed based on the quality and quantity of wastes, economic statues of the local authority, technical knowhow of the management personals and climatic and geographical conditions of the area.

The total estimated waste generation in Sri Lanka is 10,768 tonnes per day in year 2013 (JICA, 2016) and now it may be more than 15000 tonnes per day according to the population and economic growth rates. The waste generation rate in the local authorities of Municipal Council, Urban Council and Pradeshiya Sabhas (smallest administrative unit of local authority) is not equal and it varies depending on several factors. However, it is estimated that the waste generation potential in Sri Lanka in 2015 was 1.297 kg/person/day and is being increased due to economic growth of the country (JICA, 2016). Across Sri Lanka there are 297 local authorities and they are the responsible agencies for the management and disposal of solid wastes in their purview. The most prevalent final waste disposal method practice in the most of the local authorities in Sri Lanka is open dumping due to low cost, easy to practice and less technology involved. The open dumping of wastes creates the detrimental effects on environment and health hazards for flora and fauna. However, the dumping of collected wastes in the places which are richer in biodiversity such as river banks, road sides, wetlands and marshes are frequently practiced by local authorities in Sri Lanka (Gunawardana, Basnayake, Shimada, & Iwata, 2009).

The degradable component of MSW in the most of developing countries is comparatively higher than the developed countries (Bhada-Tata, 2012). It has been observed that about 90% of MSW in Sri Lanka are degradable organics in nature (Menikpura, Ariyawansha, Basnayake, & Tharinda, 2007). However, the quality and the rate of waste generation in different parts of Sri Lanka have considerably been changed in recent past, due to rapid urbanization and economic conditions.

The biological approaches, aerobic and anaerobic degradation, are considered as most popular methods for the management of organic fraction of municipal solid wastes (OFMSW) at present (Tchobanoglous *et al*.,1993). Aerobic digestion or composting is natural process by which degradable organic matter is transformed into complex stable compounds; carbon dioxide and water by aerobic microorganisms, and no readily degradable materials are found in final stable product called compost (Gomez, 2006; Iyengar and Bhave 2006). The separation of organic fraction from MSW is to be performed at first instance for the composting. The non-degradable materials such as glass particles, plastic fragments and elevated trace metals are not suitable for composting. The separation of OFMSW after collection of mixed waste is difficult and not feasible than the separation of waste at the places where waste is originated. More organic degradable waste generates from residencies, restaurants, guest houses, hotels and food stalls and on-site composting can be used for the management of degradable organic waste at such places (Hwang *et al*., 2002). Composting bins are more popular for the waste management in residencies where a little amount of wastes are generated and the different composting bins have been developed and practiced in Sri Lanka (Premachandra, 2006). In on-site bin composting, the separation of waste is very easy and the compost can easily be produced in a little effort (Papadopoulos et al., 2009; Kalamdhad and Kazmi, 2007). However, those composting bins cannot be used for the production of compost in restaurants and guest houses since the amount of waste generated in such places are considerably higher than that of residencies. Therefore, it is necessary to develop a suitable composting method for such places for the management of organic waste through the production of compost. In this study we attempted to design, construct and evaluate a composting bin system for the management of organic waste through the production of compost in medium scale waste generators (25-50 kg of wastes per day) such as restaurants and guest houses.

## MATERIALS AND METHODS

The location of the study was selected considering the availability of guesthouses and restaurants. At the beginning of the study, the waste generation rate of the restaurants and guesthouses were estimated. Based on the composition and waste generation rate, a sequential composter waste designed. The designed composter was established and operated in the selected guesthouses. The important parameters for the evaluation of the process of composting were monitored and the quality parameters of compost were also determined at the end of the study for the evaluating the quality of compost for agriculture.

### Geographical location of the study

The location of the study is Kataragama which is situated in Monaragala District in Uva Province of Sri Lanka and its geographical coordinates are 6° 25' 0" North, 81° 20' 0" East. The distance from Colombo, capital of Sri Lanka is 228 km. It is a religious town where *Ruhunu Maha Kataragama devalaya*, a shrine dedicated to *Skanda-Murukan*, a famous shrine and ancient Buddhist temple are located. Therefore, different religious groups visit the area during annual festival season as well as the holidays and weekends. Although Kataragama was a small village during past, today it is a fast developing town.

Kataragama belongs to low-country dry zone and annual rainfall is about 1500 mm. The nearby river (*Manik Ganga*) is the only water source and almost all other reservoirs are seasonal. The population of Kataragama divisional secretariat for year 2007 was 20,945 individuals in 5482 families. Its floating population increases tremendously greater than 20 times its inhabitants during festival season. It also becomes crowded at that time with many businessmen, transitory merchants, security persons, beggars and other service providers. And also there are many guesthouses and restaurants in Kataragama. As such, the waste disposal is one of the major problems in the town.

### Site selection for composter

Easy access, availability of water and sufficient space for loading and unloading of waste were considered for the selection of suitable places for the construction of Sequential Batch Composters (SBC). Ceybank Resort (CR) and Elder's Residency (where elder are living by the government donations) at Kataragama town were selected for the construction of the SBCs.

Ceybank resort has 26 rooms and six halls which can be utilized to provide lodging facilities for approximately 175 persons per day. In addition to guests, 12 more persons work at Ceybank resort and approximately 150 kg of kitchen waste and 50 kg of garden waste was generated per week. Land area of the resort is about 0.2 ha.

Elder's Residency (ER) has the capacity of 45 regular residents and 7 employers and the land area is about 0.6 ha, where approximately 200 kg of kitchen waste and 60 kg of garden waste per week are generated. SBCs were established at the very corner of the land in both locations to avoid unpleasant odors if any.

### Design and construction of sequential batch composters

Sequential batch composters having six compartments were designed to install in above two locations. The approximate volume of single compartment of the SBC is about 0.65 $m^3$. The plan of the SBC and the construction being carried out are shown in figure 1 and 2, respectively.

The sequential batch composters were constructed using bricks, cement and sand while the roof was made out of metal sheets. The dimension of a compartment was 1.35×0.9×0.45 m (lower side); 60 m (upper side). Concrete basement was also used to avoid any leaking out of leachate from the SBC into nearby soil. Two and half centimeter holes (diameter) were made on the walls of the each compartment to facilitate the aeration and to avoid possible anaerobic digestion of waste. A wooden sliding doors and metal roofs (folding) for each compartment were made to easy loading and unloading of waste.

**Physical and chemical analysis**
The physical and chemical parameters of raw material (compostable organic waste) before the composting, during composting and end the end of the composting process were determined for the monitoring of the composing process in SBCs and to determine the final quality of compost. Temperature was recorded using a digital thermometer (Tenma test equipment, 72/7712) while air temperature was recorded using standard thermometer. Grab samples were taken from the each compartments of SBC and mixed together, dried and powdered for the determination of total organic carbon, total Kjeldahl nitrogen, total phosphorus, electrical conductivity (EC), pH, and heavy metals. Organic carbon was determined by Walkey and Black method while TKN was determined by micro Kjeldahl method. Phosphorus was determined by acid digestion outlined in standard methods (Clesceri, Greenberg, & Eaton, 1999). Twenty grams of dried, powdered samples were taken and diluted with 40 mL of distilled water and shaken, kept for about one hour and measured the pH and EC (Gupta, 1999). Heavy metals (Cd, Cr, Cu, Zn and Pb) were determined by an Atomic Absorption Spectrometer (5100 PC Spectrometer; Perkin-Elmer).

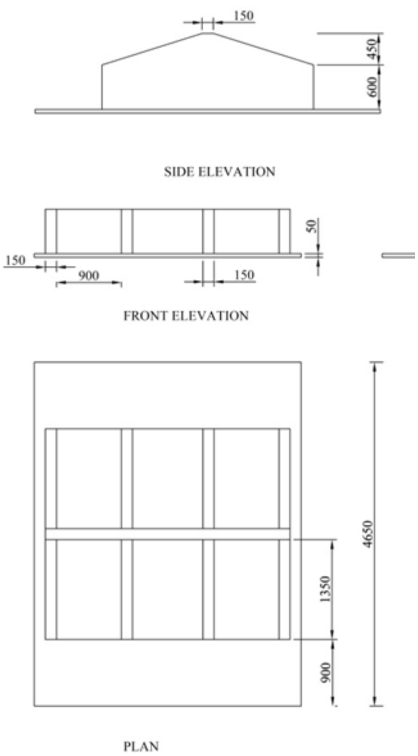


**Figure 1: Plan of the SBC**

**Figure 2: SBCs are being constructed**

**Experimental Procedure**
The designed and constructed SBC were evaluated by following the two types of feeding techniques at ER and CR. The waste generation in CR was quite low during the study period. Therefore, we followed the four bin rotation (FBR) system while the six bin rotation (SBR) system was followed for ER.

In the four bin rotation system, first, waste was fed to the first bin of the composter for one week, and they were kept in the second bin during the second week. The waste coming from the second bin at the end of the second week was kept in the third bin for 1 to 3 weeks. Then, at the end of the fifth week, the wastes in the third bin (3, 4 and 5 weeks old) was transferred to the fourth bin and kept there for 6-7 weeks until the compost was matured. During the transferring of compost from one bin to another, waste was properly mixed and therefore, no additional mixing was required. However, the moisture of waste in bins was checked and water was added if required during transferring and mixing. The mixing of degrading wastes in the third and fourth bins was practiced in once a week since the waste are kept for more than one week in those bins.

The waste was kept only one week in each of first three bins of SBC during the six bin rotation system. During the fourth and fifth weeks, partially degraded wastes was kept in the fourth bin and then they were transferred to the fifth and sixth bin after keeping them only one week in each bin. In the sixth bin partially composted waste was kept for about 6-7 week to complete the composting process. In this rotation procedure, all the six bins of the SBC were used while in the FBR system, only the first four bins are used for the composting process. The four bin rotation system is suitable for the places where waste generation quite law (<25kg/day). If the amount of waste is low in bins, it is difficult to maintain the proper moisture content suitable for composting. During the composting process, the volume of degrading waste is reduced due to microbial degradation, and therefore, to maintain proper moisture condition waste in two bins is needed to be mixed. Kitchen and garden waste are mixed together (3:1) to maintain the suitable C/N ratio before feeding to the composters. Moreover, garden waste plays the role of bulking agent.

## RESULTS AND DISCUSSION

### Composition of waste

Waste composition of two places where the SBCs is to be installed was determined. Kitchen waste generation was higher (75%) than the garden waste (25%) at Ceybank rest. Kitchen waste was comprised of rice (56%), fruits (20%) and vegetables (24%) while dried leaves (68%) and fresh leaves (32%) were the main waste components.

Composition of waste in ER was almost similar to that of CR. Kitchen waste generation was 77% of total waste generation and the rest was garden waste (23%). Rice, fruits and vegetables accounted for 60%, 14% and 26%, respectively. Sixty five percent of dried leaves and 35% of fresh leaves were found in garden waste. It appears that waste in two places is very good for composting with respect to the biodegradability.

### Quality parameters of collected waste

Selected physical and chemical parameters that are important for the microbial degradation of waste were determined in the two selected (ER and CR) places where SBCs are to be installed. Samples were collected separately as garden and kitchen waste and were analyzed for organic carbon, nitrogen, moisture content and organic matter (Table 1).

Carbon to nitrogen ratio which is very important for the composting was also calculated. The general optimum C/N ratio of raw material for composting is 25:1, higher ratio reduces the degradation rate and lower material increases the nitrogen loss (de Bertoldi, Val-

**Table 1: Quality parameters of collected waste**

| Parameter | Ceybank Rest | | Elder's Residency | |
|---|---|---|---|---|
| | Garden waste | Kitchen waste | Garden waste | Kitchen waste |
| Moisture (% ) (wb) | 52.70 | 78.51 | 23.90 | 69.64 |
| Organic carbon % (db) | 54.43 | 51.36 | 55.74 | 51.79 |
| Nitrogen % (db) | 1.91 | 2.41 | 1.6 | 1.96 |
| Organic matter % (db) | 93.83 | 88.55 | 96.08 | 89.29 |
| C:N ratio | 28:1 | 21:1 | 35:1 | 26:1 |

lini, & Pera, 1983). Mixing of two types of raw materials gives approximately proper C/N ratio for composting and it will help to maintain the proper moisture content also.

**Variation of temperature during composting process in SBCs**

Temperature variation during the composting process shows the microbial activity, by which ultimate quality of compost will be decided. Temperature variation of the compost indicates the existing degradation phases of composting process. Three major temperature ranges of composting process have been identified by Gomez (1998) as mesophilic (10-40° C), thermophilic (40-60°C) and cooling (40-10°C) phases. Variation of temperature in two SBCs and air are shown in figure 3.

Temperature in two composting systems is almost similarly varied during the composting process and there is no significant difference (*p=0.98*) in temperature variation among the two types of rotation. The maximum temperature in ER where the SBR followed and in CR where the four bin rotation was practiced were 61.7°C and 61.4°C, respectively. However, minimum temperature was similar (27.6°C) in two locations. Temperature profile of this study has not followed the typical pattern (Adrian *et al*., 2002). It appears that initial mesophilic phase was only a few days in two composting bins. Similar pattern of

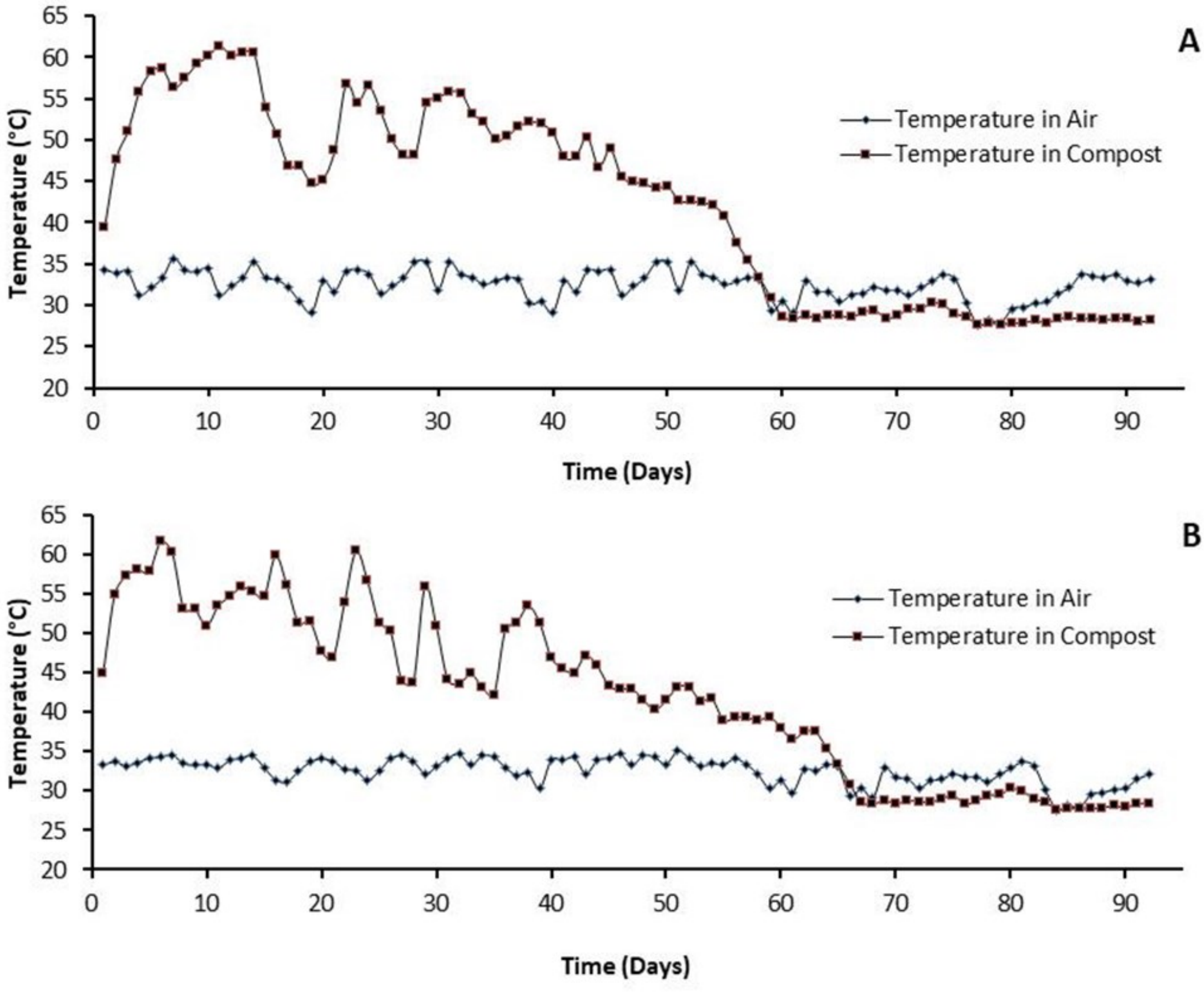


**Figure 3: Temperature variation during the composting process in SBCs at four bin rotation (A) and six bin rotation (B) processes.**

temperature variation has been observed when kitchen waste is used as feeding material (Arslan *et al.*, 2009). Kitchen waste contains a lots of food materials that are easily degradable. Therefore, the rate of microbial activity is prominent from the inception of the composting. Then, the temperature reached quickly to thermophilic phase and continued up to 55 days. The waste used for the composting has the garden waste, which contains organic matter having cellulose that is quite resistant microbial degradation. Therefore, longer thermophilic phase is a good indicator for converting cellulose (resistant material) to compost by microbes involved in composting process (Bustamante *et al*. 2008; de Bertoldi *et al*. 1983). The cooling phase of composting process occurred until the end of composting process from 55 days onwards. Quite constant temperature was noted during this period showing the compost being matured. The sudden temperature drops were observed when transferring the degradation waste from one bin to another in both SBCs (Figure 3). Moreover, during transferring of waste, water was also sprayed when required and it also caused to the reduction of temperature.

**pH of waste during composting**

The variation of pH of composting waste SBCs (FBR and SBR) were recorded and shown in figure 4. The pH of the degrading waste varied in between 6.8 and 8.7 in SBR composter while, it was in between 6.6 and 8.3 in FBR system. The optimum values of pH should be 5.5 to 8 (de Bertoldi et al., 1983). In this study, a little high pH vaues than the optimum values were observed and it is basically due to the presence of food materials containing more proteins.

Generally pH at the beging of composting is reduced due to the activity of acid forming bacteria who break down of complex organic materials to organic acids and their intermedites (de Bertoldi et al., 1983). However, in this study, from the inception of composting, pH tends to increase. This is basically due to the high temperature (figure 3) which causes the volatilization of amonia through the nitrogen loss. High pH values were recored during fourth week of the feeding in both rotation systems and it is due to the accumilation of ammonia compounds in composting materials due to decomposition of proteins in wastes (Pagans et al., 2006). High pH values observed in SBR system were significant over FBR system (*p=0.011*). High pH in SBR may be due to nutrient content of waste material. However, pH gradually decreases with time indicating the reduction of ammonia release towards end of the composting process.

**Electrical conductivity in waste during composting**

EC reflects the salt content of the composting products and their suitability for plant growth. Soil amendments having high EC is not suitable for plants since plants experience water absorption difficulties because of the osmosis effect and moreover, they are phytotoxic (Lasaridi et al., 2006).

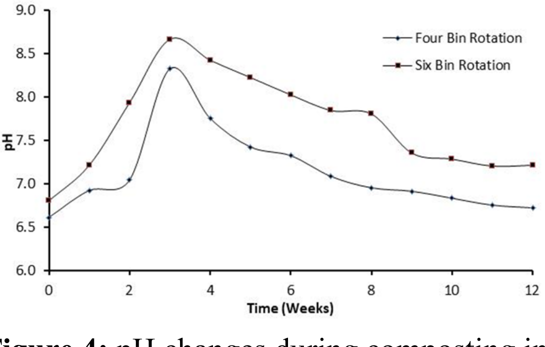


**Figure 4:** pH changes during composting in two SBCs

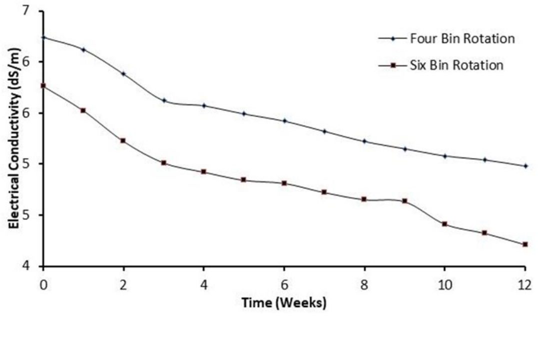


**Figure 5:** Variation of electrical conductivity during composting in SBCs

Electrical conductivity was gradually reduced in both rotation systems during composting process (Figure 5). Electrical conductivity of the samples varied in between 5.22 and 6.24 dS/m in FBR, and 4.65 and 5.76 dS/m in SBR. Electrical conductivity in low in decomposing waste in SBR system compared to FBR system (*p=0.001*). It indicates the soluble material is low in SBR system. It appears that more soluble salts may have been removed from the compost in SBR system.

**Carbon and Nitrogen ratio in decomposing waste**

Organic carbon in waste is gradually reduced from ~54 % to ~39 % in both rotation systems during the composting process due to the degradation of waste by aerobic microorganisms. Reduction of carbon during composting is basically attributed to the mineralization of organic matter resulting in the release of organic carbon as carbon dioxide (Said-Pullicino et al., 2007). Energy required for microbial growth and development was taken by the oxidation of organic matter and heat also generated resulting the increasing the temperature. Therefore, organic carbon content should be gradually reduced. The reduction of organic carbon was observed as expected (Figure 6). Even though, two rotation systems show the different percentages of organic carbon, the changes are not significant (*p=0.12*).

**Nitrogen in decomposing waste**

Nitrogen content of waste is one of the most important nutrients for the success of the composting process. Organic nitrogen existed as part of the structure of proteins is mineralized to ammonia and nitrate by ammonification and nitrification reactions (Silva *et al.*, 2007). At the early growth stages of the microorganisms, carbon utilization is high. Therefore, the carbon content was rapidly decreased at early stages of the composting process. Loss of nitrogen from waste as ammonia is considerably less when compared with carbon and it causes to rapid decrease of dry weight of the waste, resulting the increase of the nitrogen content. Therefore, nitrogen content of the degrading waste should generally be increased as observed (Arslan *et al.*, 2009). However, in this study, nitrogen content of degradation waste is initially increased and then decreased (Figure 7). Nitrogen reduction may be due to the removal of nitrogen from degrading wastes as leachate.

**Variation of C: N ratio**

At the first stages of the composting process, C: N ratio is gradually decreased because of the reduction of the carbon content over nitrogen. Later stages, C: N ratio is increased basically due to the reduction of nitrogen (figure 7). Finally C:N ratio of compost reached to around 19-22 in two types of rotation systems

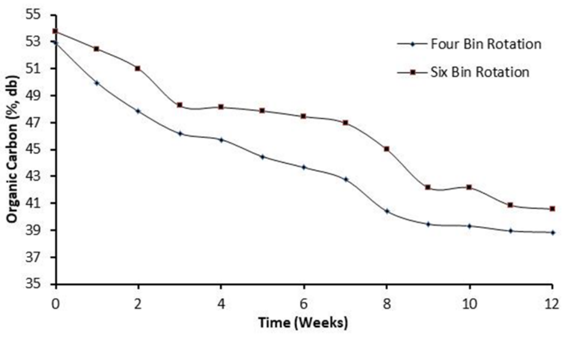


**Figure 6:** Changes of organic carbon during the composting of waste in two types of rotations in SBCs

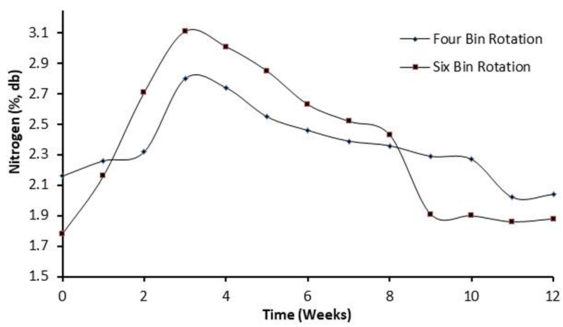


**Figure 7:** Changes of organic carbon during the composting of waste in two types of rotations in SBCs

(figure 8) complying with recommended values of matured compost (Sri Lanka Standard 1246, 2003). The reduction of C/N ratio during composting is an indicator for the stabilizing the compost. However, the final C/N ratios depend up on the characteristics of the feeding material (Silva et al., 2007). Usually, compost is considered stable when the C/N ratio is approximately 17 or less, unless lignocellulosic material remains (Silva et al., 2007). It seems that the C/N ratio of this study is greater than 17 indicating the instability of compost. However, Forster et al. (1993) reported that the C/N ratio is not a good indicator for the determination of maturity of compost. The compost production systems having pH over 7, the C/N ratio may change a very little during composting because of the carbon and nitrogen loss simultaneously as carbon dioxide and ammonia (Sullivan & Miller, 2001).

**Quality of compost**

After maturation of compost in SBCs, samples were taken and determined the selected quality parameters. The determined values of quality parameters were compared with the standard values outlined by Sri Lanka standard institute (Sri Lanka Standard 1246, 2003). Color, moisture content, pH, nitrogen, C/N ratio, and organic carbon content of the final compost were in the range of standard compost while EC and particle sizes are different from the standard values. Available phosphorous from the compost in SBR was within the recommended level while it was not in the recommended range in compost taken from the FBR composter. Table 2 shows the quality parameters of compost produced in SBCs and the standard values of compost produced from domestic waste.

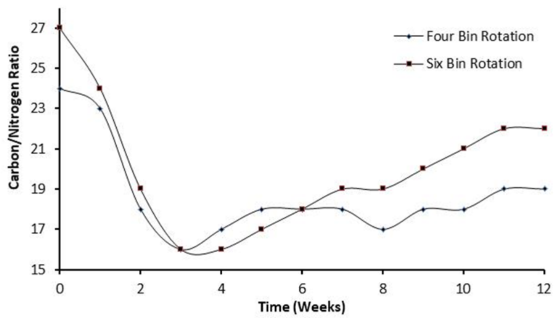


**Figure 8:** Changes of Carbon to Nitrogen ratio during the composting of waste in two rotation systems in SBCs

**Table 3:** Selected physical and chemical properties of compost

| Properties | Standard Value | Four Bin Rotation | Six Bin Rotation |
|---|---|---|---|
| Color | Brown / grey to dark black | Brown / grey to dark black | Brown / grey to dark black |
| Moisture content (% in db*) | <25 | 24.68 | 20.27 |
| pH | 6-8 | 7.34 | 7.21 |
| EC (dS/m) | 0.5-4 | 4.98 | 4.21 |
| Nitrogen (% in db) | >1.0 | 2.04 | 1.89 |
| C:N ratio | 10-25 | 19:1 | 22:1 |
| Phosphorous (% in db) | >0.5 | 0.38 | 0.62 |
| Organic Carbon (% in db) | > 20 | 38.85 | 40.58 |
| Cadmium (mgkg$^{-1}$) | <10 | Not detected | Not detected |
| Chromium (mgkg$^{-1}$) | <1000 | 12.47 | Not detected |
| Copper (mgkg$^{-1}$) | < 400 | 4.96 | 2.4 |
| Zinc (mgkg$^{-1}$) | <1000 | 48.24 | 95.99 |
| Lead (mgkg$^{-1}$) | < 250 | Not detected | Not detected |

*Dry basis

## CONCLUSION

The design and constructed SBC was evaluated for the production of compost using kitchen and garden wastes generated from medium scale restaurants. The composter is comprised of six bins where waste generated in different days can be accommodated and transferred to bin to bin according to the degree of degradation until compost is produced. When the amount of waste generation is low, FBR system can be practiced successfully. The quality parameters, which are used for the evaluating the compost quality, in both rotation systems (FBR and SBR) are almost similar to the compost standards given by Sri Lanka standard institute. The electrical conductivity of compost in two systems is slightly higher than that of recommended. Standard germination and growth tests have not been performed in this study to determine the phytotoxic effect. However, we suppose that phytotoxic effects may not arise since the feed stocks are not mix with municipal solid waste. The four bin rotation system is quite complex than the SBR system and therefore, SBR system can be recommended. However, if the availability of waste is low, FBR system can also successfully applied. Based on the results of the study, the designed SBC can be successfully used for the production of compost from kitchen and garden waste generated from medium scale restaurants.

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## REFERENCES

Adrian J. Whittle, & Alex J. Dyson. 2002 The fate of heavy metals in green waste composting. The Environmentalist 22: 13–21.

Arslan E, İpek U, Öbek E, Topal M & Baykara O 2009 IN-VESSEL COMPOSTING: I. KITCHEN WASTES. Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 14(2): 33– 46.

Bhada-Tata DH and P 2012 What a waste: A global review of solid waste management. Urban Development & Local Government Unit World Bank 1818 H Street, NW Washington, DC 20433 USA.

Clesceri LS, Greenberg AE & Eaton AD (Eds.). 1999 Standard Methods for the Examination of Water and Wastewater (20$^{th}$ ed.). American Public Health Association, American Water Works Association, Water Environment Federation.

de Bertoldi M, Vallini G & Pera A 1983 The Biology of Composting: A Review. Waste Management & Research, 1(1): 157–176.

Forster JC, Zech W & Würdinger E 1993 Comparison of chemical and microbiological methods for the characterization of the maturity of composts from contrasting sources. Biology and Fertility of Soils, 16(2): 93–99.

Gomez A 1998 The evaluation of compost quality. TrAC Trends in Analytical Chemistry, 17(5): 310–314.

Gomez RB 2006 The use of respiration indices in the composting process: a review. Waste Management & Research, 24(1): 37–47.

Gunaruwan TL & Gunasekara WN 2016 Management of Municipal Solid Waste in Sri Lanka : A Comparative Appraisal of the Economics of Composting. NSMB Journal of Management, *2*(1): 27–45.

Gunawardana EGWW, Basnayake BFAA, Shimada S & Iwata T 2009 Influence of biological pre-treatment of municipal solid waste on landfill behaviour in Sri Lanka. Waste Management & Research : The Journal of the International Solid Wastes and Public Cleansing Association, ISWA, 27(5): 456–462.

Gupta P 1999 Soil, plant, water and fertilizer analysis. Agro Botanica. Retrieved from https://scholar.google.com/scholar?

cluster=12325990296094730332&hl=en&as_sdt=2005&sciodt=0,5

Hwang EJ, Shin HS & Tay JH 2002 Continuous feed, on-site composting of kitchen garbage. Waste Management & Research, 20(2): 119–126.

Iyengar SR, & Bhave PP 2006 In-vessel composting of household wastes. Waste Management, 26(10): 1070–1080.

JICA 2016 Data Collection Survey on Solid Waste Management in Democratic Socialist Republic of Sri Lanka. Retrieved from http://open_jicareport.jica.go.jp/pdf/12250213.pdf

Kalamdhad AS, & Kazmi AA 2007 Rotary Drum Composting of Mixed Organic Waste based on Different C/N Ratios. In Proceedings of the International Conference on Sustainable Solid Waste Management: pp. 258–265. Chennai, India.

Lasaridi K, Protopapa I, Kotsou M, Pilidis G, Manios T, & Kyriacou A 2006 Quality assessment of composts in the Greek market: The need for standards and quality assurance. Ournal of Environmental Management 80: 58–56.

Menikpura SNM, Ariyawansha SWGRTK, Basnayake BFA, & Tharinda YGWGM C 2007 Design and Development of Biofilters for Controlling Odor Emissions from Composting of Municipal Solid Waste. In Proceedings of the International Conference on Sustainable Solid Waste Management: pp. 250–257. Chennai, India.

Pagans E, Barrena R, Font X, & Sánchez A 2006 Ammonia emissions from the composting of different organic wastes. Dependency on process temperature. Chemosphere, 62: 1534–1542.

Papadopoulos AE, Stylianou MA, Michalopoulos CP, Moustakas KG, Hapeshis KM, Vogiatzidaki EEI, & Loizidou MD 2009 Performance of a new household composter during in-home testing. Waste Management, 29(1): 204–213.

Premachandra HS 2006 Household Waste Composting & MSW Recycling in Sri Lanka. In *Asia 3R* conference. Tokyo. Retrieved from https://www.env.go.jp/recycle/3r/en/asia/02_03-3/08.pdf

Said-Pullicino D, Erriquens FG, & Gigliotti G 2007 Changes in the chemical characteristics of water-extractable organic matter during composting and their influence on compost stability and maturity. Bioresource Technology, 98(9): 1822–1831.

Silva MTB, Menduíña AM, Seijo YC, & Viqueira FD 2007 Assessment of municipal solid waste compost quality using standardized methods before preparation of plant growth media. Waste Management & Research, 25(2): 99–108.

Sri Lanka Standard 1246. 2003 *Specification* for compost from municipal solid waste and agricultural waste. Sri Lanka Standard Institution, Colombo, Sri Lanka.

Sullivan D & Miller R 2001 Compost Quality Attributes, Measurements, and Variability. In Compost Utilization In Horticultural Cropping Systems. In P. J. Stoffella & B. A. Kahn (Eds.), Compost utilization in horticultural cropping systems. Lewis Publishers is an imprint of CRC Press LLC.

Tchobanoglous G, Theisen H, & Vigil S. 1993 Integrated solid waste management, engineering principles and management issues. New York, USA: McGraw-Hill Book Company.

Vuai SAH 2010 Characterization of MSW and related waste-derived compost in Zanzibar municipality. Waste Manag Res, 28 (2): 177–184.