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Fluctuations of temperature and *Stratiomyidae* larval density in domestic waste management: Experimentation for biological treatment

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ABSTRACT

Solid waste management is a tedious process in developing countries. Unscientific disposal of solid wastes leads to severe environmental disasters and health problems. The states which have a burden over the environment and public health are considering environment-friendly and cost-effective mechanisms for solid waste management. The solid waste management issues have already become very severe in cities and towns as the disposal facilities are geared to a large amount of waste generated. The explored mechanisms include vermicomposting and organic waste digestion by the larvae of black soldier fly. As the composition of decayed matter varies due to physicochemical and biological components, the physicochemical and biological parameters in decomposing solid waste are important. A vast number of studies were already carried out recently on solid waste management in the western region. Hence, the present study is focused on exploring fluctuations of temperature and Stratiomyidae larval density of composting in a tropical climate. The research was carried out in 2 stages. In the first stage, a preliminary study was conducted to find out whether the addition of garden waste to composting kitchen waste has affected the dipteran larvae that colonize the compost. The preliminary study showed that with the addition of garden leaves into the unit the abundance and the diversity of fly larvae go down drastically. Therefore, in the second stage, the proper study was carried out without adding any garden wastes and using kitchen waste only. It is concluded that the increase in temperature leads to microbial activity while fly larval activity indirectly enhances microbial activity which promotes composting.

Key words: Solid Waste, Physicochemical Parameters, Biological Parameters

Introduction

Management of solid waste in low and middle-income countries is a challenging issue. The waste components such as glasses, metal, papers consist of only negligible fractions when compared to organic waste, which is around 80% of total solid waste malpractices (Diener et al., 2011). Thus organic solid waste mismanagement emits around 6.8% of greenhouse gases such as CH_4 due to anaerobic decomposition (Couth & Trois, 2009). Solid wastes generated by domestic activities are often assimilated disposed of. This is well learned with the incidence of Meethotamulla in Sri Lanka.

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Unscientific disposal of such wastes leads to severe environmental disasters and health problems (Dienner, Zurbrugg, & Tockner, 2009). These problems have already become very severe in cities and towns as the disposal facilities are geared to a large amount of waste generated.

Heaps of household wastes dumped at every nook and corner of roadsides are a ubiquitous sight in cities. Furthermore, household waste collected by those providing a garbage disposal service ends up as landfills. Open dumping of household and other wastes provides breeding grounds for disease vectors such as flies, mosquitoes, cockroaches, rats, and other pests.

However, the states which have a burden over the environment and public health are considering environmentally friendly and cost-effective mechanisms for solid waste management.

The explored mechanisms include vermicomposting and organic waste digestion by the larvae of black soldier fly. Interestingly, insects can convert around 1.3 billion tonnes of biowaste per year into insect biomass, which can be utilized as animal feed (Pastor et al., 2015). Thus, the physicochemical and biological parameters in decomposing solid waste are essential. A vast number of studies were already carried out recently on solid waste management in the western region.

Hence, the present study is focused on exploring fluctuations of temperature and Stratiomyidae larval density of composting in tropical climates.

Literature Review

Composting is one of the methods of household waste or garbage utilization. It is defined as the decomposition of complex organic matter by a mixed microbial population in the moist, warm and aerobic environment. These micro-organisms convert organic wastes into compost which has a significant value in agricultural farming. Moreover, some insects such as ants, flies, beetles, and earthworms are also associated with compost and play vital roles in the process. Especially the larval stages of flies break down waste into smaller particles by their feeding activity, thereby increasing the surface area. Particles of compost with larger surface areas provide more opportunities for microbes to contribute to composting. In addition to improving soil fertility, compost can act as a natural bio filter where the organic pollutants in the waste dissolve in water and are converted into simple atoms by microorganisms (Moretti, 2002).

Bio- wastes were composted in open windrows as stated by Kojyula et al., (2000). Adequate aeration of the windrows was guaranteed when the initial height of the window was less than 1.5 m and the blending ratio for biowaste and a bulking agent was one tonne of biowaste to one cubic meter of wood chips. The temperature rose to 85°C in these windrows. Carbon concentration increased slightly during 64 weeks of composting, while the hydrogen ion concentration decreased. The pH and the ash content also increased during composting.

Several studies on the faunal diversity of composting heaps have been carried out. According to Odegaard & Tommeras (2000), household compost heaps are rich in arthropod fauna. Their survey reviewed the changes in the composition of beetle fauna in compost heaps in the Nordic countries during the 20^{th} century and shows that a total of 34 alien beetle species have been established in compost heaps; 12 of these are also established in natural habitats. More interestingly, some of the previous studies were entirely on dipteran fauna itself. Calyptrate fly populations were monitored with sticky traps at the following 4 sites in Hampshire: UK (from August to November 1998) a landfill and composting site (Paulsgrove), a site adjacent to this landfill (Port Solent), a site with no landfill nearby (Gosport), and a composting site with no landfill nearby (Goulson et al., 1999). Housefly *Musca domestica* (L.) and lesser house fly *Fannia spp*. were not important constituents of the dipteran catch, while bluebottles (*Calliphora spp*.) and greenbottles (*Lucilia spp*.) comprised approximately 12% of the total. Very large fly populations were found at the two composting sites, and it seems likely that these provide ideal breeding grounds for a range of fly species since they offer an abundance of warm decaying organic matter. Furthermore, the study stated that more flies emerged from one-week-older than from two-week-old household waste.

Household composting

Household composting in one's backyard is an age-old method that has been practiced around the world including in Sri Lanka (Shanthini & Walgama, 2003). Household composting bins differ in shape and size. In today's urban settlements, land available for a typical household is limited. Accordingly, it is necessary to use compact units to dump compostable household waste. The barrel becomes the simplest and the most convenient composting unit in urban households. However, rather than using a barrel itself where corrosion can occur, it is best to use an aluminum composting unit. The construction and setting up of a household composting unit has been outlined and demonstrated by R. Shanthini (personal communication).

During composting, kitchen waste changes physicochemical characteristics due to microbial activity that finally results in a biodegraded mass commonly referred to as compost. The composition of kitchen waste consisting largely of organic matter changes markedly during this process. Under aerobic conditions, microbial decomposition of organic matter results in the production of CO_2, H_2O, nutrients, and a large amount of heat. In the absence of sufficient O_2 or under anaerobic conditions foul-smelling gases such as H_2S are produced. Hence, maintaining the composting unit with kitchen waste under aerobic conditions as well as maintaining the composition of the compositing mass in a manner conducive to microbial activity becomes important.

Mature compost is a soil conditioner and also acts as a natural fertilizer. In composting, physical features such as the texture, structure, aeration, temperature and moisture content, chemical characteristics such as pH and nutrient content of the composting mass become important (Radojeric & Bashkin, 1999 and Nawarathna, 1977). Composting is a biological decomposition process in which micro-organisms play a vital role. In addition to the microfauna, macrofauna, especially dipteran larvae are associated with composting waste (Shanthini & Walgama, 2003).

Physical and biological parameters of compost

To express the composition and the quality of the composting mass and its final conversion into compost several physicochemical and biological parameters are used. Among them, certain parameters are most critical to the process of composting by microorganisms and to its final product as a soil-enriching medium. These parameters include temperature, bulk density, water content, pH, organic carbon, adult dipterans and dipteran larval density (Kojyula et al., 2000; Odegaard & Tommeras, 2000; Koening, 2003).

Temperature

Aerobic composting is a biological decomposition process where micro-organisms convert organic matter into CO_2 and H_2O in the presence of oxygen (Shanthini & Walgama, 2003). As a result, a great deal of energy is released in the form of heat where composting mass shows a gradual increase in temperature. High temperatures within the composting heap indicate good aerobic conditions that favor microbial activity.

A recent study on household composting using aluminum composting units was carried out by Shanthini & Walgama (2003) in hill country of Sri Lanka. The study was conducted over 160 days with the frequent turning of composting mass upside down and adding of dried grass clippings which topped the kitchen waste in the composting unit. The study revealed that after 160 days the composting kitchen waste reduces its volume by two-thirds and the temperature of the compost mass varies from 40 to 50°C when the ambient temperature is 15 to 25°C.

Macro organisms in compost

Compost is a rich source of nutrients for plants, insects and other invertebrates that inhabit it (http://www.ibiblio.html). A large number of insects inhabit compost heaps where ants, beetles and flies play an important role in the composting process. The predominant species of flies encountered in composting will vary with the location and the type of waste material. The variety of kitchen and other waste materials available for composting offers satisfactory breeding conditions for many different species (http://www. urbangardencenter.com).

In addition to invertebrates, vertebrates such as rats, porcupines and pigs are also attracted to fresh compost systems (Shanthini & Walgama, 2003). Furthermore, mature compost attracts earthworms that indicate the suitability of compost as a soil conditioner.

Dipterans associated with compost

Certain families of Diptera feed on decomposing plant matter in their larval stages (Borror et al., 1992). They are included in the families` Mycetophilidae (fungus gnats), Cecidomyiidae (gall midges), Bibionidae (march flies), Psychodidae (moth flies and sand flies), Trichoceridae (winter crane flies), and Scatopsidae (minute black scavenger flies). In addition, Family stratiomyidae (Soldier flies), Family Drosophilidae (Pomace flies or small fruit flies), and Family Lonchopteridae (Spear-winged flies) are associated with compost.

Adult of the Family Stratiomyidae (Soldier flies) is about 18 mm in size and usually found on flowers (Borror et al., 992). Most soldier flies are dark-colored and with or without light markings. The members of this family are more easily recognized by their wing venation. The larvae live in a variety of habitats; some are aquatic and feed on large algae, decaying material or some small aquatic animals, some live in dung or other decaying materials. Furthermore, black soldier flies (*Hermetia illucens* L.) commonly breed in outdoor toilets, poorly managed compost and in poultry manure (http://ipm.ncsu.edu.htm). Larvae occur in the greatest densities in moist media. Soldier fly larvae are scavengers and thrive on many kinds of decaying organic matter including carrion, manure, plant refuse and the waste products of beehives.

In addition, some researchers have revealed the advantages of fly populations in compost heaps. The promising research work in Sustainable Agriculture Research and Education (SARE) (2004) pointed out that the black soldier fly (*Hermetica illucens* L.) driven manure management system reduced the volume of poultry droppings by more than half and practically eliminated house fly populations. Thus, conversion of organic waste by black soldier fly larvae is a popular recycling technology for organic waste (Diener et al., 2011)

Materials and Methods

Study plan

The study on composting of kitchen waste was carried out in stages. In the first stage, a preliminary study or pilot study was conducted to find out whether the addition of garden waste to composting kitchen waste affected the dipteran larvae that colonized the compost. According to observations of Shanthini et al. (personal communication), when dry leaves and dried cut grass were added to kitchen waste during composting no-fly larvae were observed. To confirm this observation a preliminary study was carried out for two months where in addition to kitchen waste, garden waste (dry leaves) was added to the composting mass of kitchen waste. The composting unit was located in a household in the University premises.

The preliminary study showed that with the addition of garden leaves into the unit the abundance and the diversity of fly larvae go down drastically. Therefore, the proper study was carried out without adding any garden wastes and using kitchen waste only.

Initial study

The composting unit used in the preliminary study was emptied of its contents, cleaned and used for further studies. The unit was fed weekly with kitchen waste for a period of 6 months. Temperature and biological parameters (Radojevic &. Bashkin, 1999) were measured. The need to replicate and validate the work by running at least two more household composting units arose. Also, replication cannot be achieved in the same household as kitchen waste was sufficient for two composting units was not generated in a single household.

Replicate study

Hence, during the third stage of the study two composting units were run simultaneously in two different households. One of these composting units was run at the same household where the pilot study and the initial study were conducted. A second household and a second composting unit was selected as the other replicate.

Setting up of the Composting Unit

Initial study

The aluminum composting unit used in the study was made to specification (30 cm in diameter and 75 cm in height) and was held upright inside a wooden frame. At the household where the study was carried out, the composting unit was placed outdoors on level ground in an open area receiving diffused sunlight. The wooden frame holding the unit was balanced on the ground. The composting unit had a lid in order to keep the rainwater away and the entry of large flying insects and animals. The lid also helped to retain the heat that was generated during aerobic composting. The sides of the aluminum composting unit had minute holes of about 2 mm diameter arranged in an irregular manner in order to provide good aeration. Four additional holes of 1.2 cm diameter were made along a vertical line on the sides of the unit. These holes were15 cm apart. The base of the unit was filled with dry saw dust up to 20 cm height (which included the 10 cm space between the base and the ground) from ground level. A layer of bricks placed around the base of the composting unit helped to contain the sawdust in place.

Feeding the composting unit

The composting unit was fed once a week with kitchen waste (collected over the week). Kitchen waste was weighed before adding into the unit. Certain items in kitchen waste like coloured paper, cardboard, batteries, medicines, pesticides, insecticides, coconut shells, and shells of certain fruits ("beli” and woodapple) were removed prior to feeding the unit. The composting unit was fed weekly in this manner with kitchen waste for a period of 25 weeks. Several selected parameters of compost were measured during this period.

Replicate study

After the initial run of the composting unit for 25 weeks, the need to verify the repeatability of the household composting system that was used. To verify the repeatability of the performance of the composting unit, two additional composting units were set up. The composting unit that was initially run for 25 weeks was emptied of its contents, cleaned and restarted according to the procedure given in Section 2.3. This was labeled as composting Unit 2 (with reference to the initial run which would be referred to as Unit 1) and was located at the same household (C-33 in the campus premises).

Another composting unit was newly constructed to the same specifications as the earlier one and was labeled as Unit 3. Unit 3 was located at the household at C-81, Meewathura (within the campus premises).

Composting Units 2 and 3 were run simultaneously for 19 weeks. The same parameters of compost measured using Unit 1 were repeated with composting Units 2 and 3. The composting Units 1, 2 and 3 were used as three replicates in the study.

Parameters of Compost Measured

The physical and biological parameters such as Height of the composting mass or level of top surface of composting mass, amount of compost formed (as a measure of height reduction), temperature and fly larval density of Stratiomyidae flies of the composting mass in Units 1, 2 and 3 were measured using the methods given under each parameter.

Physical Parameters Measured

Measures of the Composting Mass

Overall height of composting mass

The height of the composting mass in the composting unit was measured prior to each addition of kitchen waste and after the addition of fresh kitchen waste. A graduated stick of 1 m length marked at 5 cm intervals was used for measuring the compost height. This stick was inserted in to the bin from above to reach the top surface of the composting mass. By subtraction of the length from 0.85 m the level or height of the composting mass in the unit was determined.

Volume of composting mass

Volume of the composting mass in the Unit was determined using following formula.

Volume of composting mass $m^3(l) = \pi r^2 h$

Where π|= 3.142, r is the radius of the Unit (0.15 m) and the height of composting mass in meter.

Amount of compost formed

Amount of compost formed was determined in relation to the reduction in height of the Composting mass. Calculations were carried out using the following formulae.

Height reduction R (cm) = H_2- H_1 Where, H_1, is the height (cm) of waste before adding waste in week 2, H_2 is the height (cm) of waste in the unit after adding waste in week 1.

Height reduction (%) = R/ H_2 *100

Where, R is the height reduction in the composting mass and H_2 is the height (cm) of waste in the unit after adding waste in week 1.

The height reduction per unit weight of waste was also calculated using the following formula.

Height reduction per unit weigh t = H_2— H_1* 10^4/ W

Where, H_1 is the height (cm) of waste before adding waste in week 2, H_2 is the height (cm) of waste in the unit after adding waste in week 1 and W (g) is the weight of waste added in week.

Measurement of Temperature

The temperature of the composting mass in the unit was measured at three different heights (bottom, middle, top). The bottom height (0 cm) and the middle height (15 cm) are reached by the composting mass. However, the topmost height of the composting mass (fixed at 30 cm) where measurements are to be taken is not reached if the overall height of the compost mass does not exceed this height. Under such conditions, no temperature measurements were made at a middle level of the composting mass but just below the top surface of the compost mass.

Temperature measurements using a thermometer (graduated up to 100 °C) were made before opening the lid of the unit. The temperature of the composting mass was determined by inserting the thermometer into the composting mass at specific heights. In order to introduce the thermometer into the composting mass at a given height, the metal case of the thermometer (which is 15 cm long and 1.2 cm diameter) was first pushed through the corresponding hole in the unit into the composting mass. Thereafter, the case was pulled out leaving a space behind in the compost. Then the thermometer was inserted into the space allowing the thermometer bulb to come in contact with the composting mass. The thermometer was left in this position for 3 minutes and the temperature was recorded. Three measurements of temperature were taken at each height in each unit.

The ambient temperature was also recorded by taking the air temperature just outside the unit. Temperature of the composting mass was measured in this manner at weekly intervals over the entire duration of each unit.

Biological parameters

Monitoring of Fly Larvae Density

To determine fly larval density, compost samples were removed at three heights (0 cm, 15 cm and just below the top surface level) using the corer, the volume of the compost sample removed was determined using following equation.

Volume of composting mass removed = $\pi r^2 h$

Where, π = 3.142, r is the radius of the corer (1.1 cm) and h is length (cm) of the removed composting mass in the corner Radius was determined by taking the circumference and using the formula of $C = 2\pi r$,Where C is Circumference (cm), π is 3.142 and r is radius (cm) of the corer.

The number of larvae in the removed sample of compost was counted by spreading the compost on a white tray and visually counting the larvae present. Then the larval density was determined per quantity of compost removed. The value thus obtained was multiplied by 10 and the density expressed as No. of larvae per cm^3 as indicated in the equation below.

Larval density = Number of larvae / Volume of compost (V cm^3) removed x 10

The values obtained for larval density was multiplied by 10 to get rid of decimal numbers and the density of larvae were expressed as per cm^3 of compost. Species identification was done by removing live fly larvae at intervals (once a week) from compost and raring them to adulthood in the laboratory. Adults that emerged were identified. Taxonomic keys and reference collections were used to identify the adult flies up to family level.

Results

The data obtained for composting unit 1 with respect to the 2 parameters is presented initially. Thereafter the data from all 3 composting units with respect to the same 2 parameters were compared using the two-sample t-test (Bluman, 1997) where data from unit 1 was compared with unit 2, unit 2 with unit 3 and unit 1 with unit 3. Based on the t- values obtained (at 95% significance) it was found that there was no significant difference in the three composting units with respect to temperature and larval density. Hence, the three composting units were considered as three replicas and the data from all three units were used for determining relationship between the different parameters.

Data obtained for composting unit 1

Quantity of Kitchen Waste Added

The amount of kitchen waste added weekly into the compost unit over the 25-week period. The amount added varied remarkably with higher amounts being added on weeks 6, 15 and 24. The highest amount of waste of 6.7 kg was added in week 7 while the lowest amount of 1.15 kg was added in week 1. On the average 3.6 kg of waste was added weekly into the compost unit.

Maximum height of waste attained (level of top surface)

Depending on the amount of kitchen waste added weekly into the compost unit the overall height or the top level of the composting mass in the unit varied. An overall average compost height of 21.9 cm was recorded during the first 16 weeks. Thereafter, a reduction in the compost height was observed over the next 9 weeks resulting in a very low height of 10 cm in weeks 23 and 24.

Height reduction as a measure of compost formed

The kitchen waste added weekly in to the compost unit changes to compost after several weeks due to the action of microbes and other organisms in composting mass. With the conversion of waste into compost, a reduction in volume of the composting mass can be observed. This reduction in volume is accompanied by a reduction in height of the composting mass in the unit. Therefore, height reduction can be taken as a measure of compost formation. Further the compost formation (as a measure of height reduction) can be measured by taking into consideration:

i. Volume of the composting mass (as the circumference of the compost unit is constant, height variations would reflect change in compost volume)

ii. Weight of kitchen waste added.

The height reduction was considered in terms of the overall compost height reached on adding kitchen waste and was expressed as a percentage. The percent height reduction although fluctuated indicated an overall gradual increase over the 25 weeks of the study.

Furthermore, the height reduction in the composting mass per unit weight of waste added can also be taken as a measure of compost formation. Thus the amount of compost formed will not be affected by the weight of waste added immediately. As the weekly height reduction per unit weight obtained is very small, this ratio was multiplied by 10000.

A sharp reduction in the ratio (of % height reduction per unit waste added) was first obtained at week 7 inferring the commencement of compost formation. The highest ratio of 0.0048 cm/g obtained at 23 weeks is indicative of more compost formation.

Temperature variations in the composting mass

A difference in the temperature of the composting mass at the three heights (0, 15 and 30 cm) was observed throughout the study period. The temperature of the composting mass at the three heights changed from 26 - 39.5 °C with a mean of 30.5 °C.

The pattern in temperature fluctuation at the three levels was similar during most part of the study except at the middle level where a marked increase in temperature was seen especially from weeks 3 and 19. This difference was more pronounced at weeks 6 and 16 where temperatures of 39.0 °C and 39.5 °C was registered respectively. Thus, the composting mass at the middle level recorded the maximum weekly temperature through most part of the study.

Maximum temperature attained by composting mass

The maximum temperature of the composting mass (irrespective of the height) remained above the ambient temperature during most of the study period; between weeks 3 and 19, Between weeks 1-3 and 19 -25 the temperature of the composting mass remained at the ambient temperature which is considered as temperature of the surroundings. A marked increase in temperature (39 °C and 39.5 °C) of the composting mass was much higher than the ambient temperature recorded at week 6 and16. The highest maximum temperature recorded in the composting mass was 39.5°C with a mean of 32.5 °C.

Relationship between temperature of compost and height of composting mass

The fluctuations in maximum temperature of compost followed a pattern similar to that of the maximum height attained by composting mass in different weeks. Thus, an increase in compost height was accompanied by an increase in temperature and vice versa.

A correlation analysis was carried out to see whether there is a relationship between the height of the composting mass and the maximum temperature attained.

The correlation analysis showed that there is a relationship between overall height of compost and the maximum temperature (as $p = 0.000 < a = 0.005$, reject H_o; H_o = there is no relationship between maximum temperature and height of composting mass). Moreover, Pearson Correlation Coefficient of 0.794 indicated a positive relationship between the height of composting mass and maximum temperature. Therefore, it can be concluded that with the increase in overall height of the composting mass the maximum temperature of the composting mass increases.

Biological parameters

Variation in Larval density

The dipteran larvae found in the composting mass belonged to the Family Stratiomyidae. The larvae were reared in the laboratory and the adults that emerged were collected. As no keys and reference Specimens for this group are available the descriptions of soldier flies given in the web (http://ipm.ncsu.edu.htm) were compared with features of soldier flies obtained through rearing. Accordingly, the descriptions fitted the species *Hermetica illucens* L. (the black soldier fly). Eggs of this fly were not laid on the composting unit but were found on the outside of the bucket in which kitchen waste was collected. Thereafter, the first instar larvae moved into the bucket and on to the kitchen waste. It is likely that with the kitchen waste the larvae moved into the compost unit.

The newly laid eggs were creamy white and darken with time, the larvae were slightly flattened and creamy white when newly hatched. The later instar larvae were reddish brown in colour. Pupae developed within a darkened skin or pupal case. After about five and half months since oviposition adults emerge.

Larval density at different heights of the composting mass

Stratiomyidae larvae were observed in compost only after the 10^{th} week and they disappeared from compost after about the 23^{rd} week. During the intervening period several peaks in larval density was recorded specially at the top level of composting mass. The highest larval density of 93 larvae/10 $cm^3$was recorded at 17 weeks at the top level. The larval density ranged from 0 - 93 with a mean of 16.3 larvae per 10 cm^3.

Comparison of data from the three units using two sample
T- TEST
The data obtained from the 3 composting units on temperature and Stratiomyidae larval density obtained over a period of 25 weeks for unit 1 and 19 weeks for units 2 and 3 were compared using the two sample t-test.

Table 1 t-values obtained following comparison of the three composting units with respect to the different parameters of compost measured

Parameter	Unit 1 & Unit 2	Unit 2 & Unit 3	Unit 1 & Unit 3
Temperature	t= 0.09 P= 0.93	t= 0.27 p= 0.78	t= 0.18 p= 0.85
Larval Density (Stratiomyidae)	t= 0.61 P= 0.62	t= 0.89 P= 0.89	t= 0.60 P= 0.61

As shown in Table 1, temperature and larval density of compost obtained from the three units did not show a significant difference at 95% significance level. Therefore, the three units were considered as replicates and the data from all three units were used for determining the relationship between the different parameters.

Comparison of the three studies

Variation in Quantity of kitchen waste added

The amount of household waste added weekly into the 3 compost units differed widely. The amount of waste added depended on the kitchen waste generated by each household during the study period. Kitchen waste generated depended on the food habits and the number of occupants in the household. Even in the same household the amount of waste generated varied with time.

The composition and quality of kitchen waste added too was varied. Much of the kitchen waste consisted of fruit peelings, vegetable, green leaf and coconut refuse. Refuse from fish and meat formed only a small component. It is important to note that garden refuse (fallen, fresh leaves or dried leaves) was not added into compost units. Prior experience indicated that adding garden refuse led to the reduction in the fly larval population. A similar finding has been made by Shanthini & Walgama (2002).

The weight of waste added weekly into the 3 units indicates that Unit 1 received more waste on a weekly basis than units 2 and 3. Also, the maximum and minimum amount of waste added during the study period was much higher in Unit 1 compared to Units 2 and 3. Individual mass input into three Units given below are the details on weight of waste added weekly in to the three units (Table 2).

Table 2 Mean and Range of waste added weekly

Unit	Mean weight of waste added/week (kg)	Range of weight of waste added/week (kg)
1	3.6	1.1- 6.7
2	1.9	0.8- 4.3
3	2.0	0.9- 5.4

The cumulative weight of waste added weekly was calculated for each unit for the period they were run. The cumulative waste input in unit 1 showed a higher value compared to the other two units. Units 2 and 3 were fed with similar amounts of waste while Unit 1 received more waste.

Overall height of waste attained (Level of top surface)

The amount of kitchen waste added determined the height of the composting mass. Even with weekly addition of kitchen waste, in certain weeks there was no increase in compost height. On the other hand a reduction in compost height was observed in certain weeks even with the weekly addition of waste (week 17 in Unit 1 and week 13 in Unit 2).

A reduction in the height of the composting mass results from the conversion of waste in to compost. The amount of kitchen waste added to the three units at weekly intervals differed depending on the waste generated in each household. In to Unit 1 the total weight of waste added over the 25 weeks was 90.4 kg and the final height reached at 25 weeks was 24 cm. Units 2 and 3 were fed with 41 and 38 kg and reached a final height of 13 cm and 14 cm respectively.

The total height of all three composting units is 75 cm. The total volume of a composting unit is 52 L (calculated using the diameter (30 cm) and the total height (75 cm) of the composting unit). Similarly, the volume of the composting mass was calculated using the diameter of the unit and the height of compost reached in each week. The final volume (highest volume) attained by the composting mass differed in the three units (Unit 1: 17 L, Unit 2: 9 L and Unit 3: 10 L).

Height reduction in composting mass

The height of composting mass measured just prior to adding fresh waste weekly in to the units was considered as the height of the composting mass in that week. The final height of the composting mass determined the level of the top surface of the composting mass. Height of the top surface of the composting mass varied with the amount of waste added weekly. The top surface of unit 1 was maintained much above those of units 2 and 3 due to the differences in the amount of waste added. The mean and range in compost height recorded for the three units are given below (Table 3).

Table 3 Mean and Range in height of compost

Unit	Mean height of compost /week (cm)	Range of height of compost /week (cm)
1	21.9	10- 29
2	8.3	2- 20
3	12.9	2- 21

The kitchen waste added after several weeks gets converted into compost. With the formation of compost, a reduction in height of the composting mass is observed. Hence, height reduction can be taken as a measure of compost formed in each unit.

Height reduction as a percentage of overall height

Height reduction as a percentage of the means of height, after adding fresh weight was calculated using the following formula.

% Height reduction = $(R/ H_2)100$

Where R= Height reduction (cm) and H_2= Height, after adding fresh waste to unit in week 1(cm)

Height reduction as a percentage of unit weight

Height reduction per unit weight is a measure of the amount of compost formed during the preceding period. Furthermore, according to the formula, height reduction taken here is not affected by the Amount of waste. The ratio of the difference in height per unit weight has been multiplied by 10, 000 as the reduction per unit weight is very small. Of the three unit's height reduction was more pronounced in Unit 2.

Analysis of the data obtained using One- Way ANOVA confirms that there is no significant variation in height reduction per unit weight of waste added to each with time (Table 4).

Table 4 One-Way ANOVA for Height reduction per unit weight versus Time One-way ANOVA: Height reduction per unit weight versus Time Analysis of Variance for Height reduction per unit weight

Source	DF	SS	MS	F	P
Weeks	18	9924	551	0.87	0.615 (NS)
Error	38	24112	635		
Total	56	34036			

Variation in Maximum Temperature

An increase in temperature of the composting mass is an indication of microbial activity that is responsible for compost formation. A marked increase in temperature in all three units was seen around week 6 (Fig. 1). After 6 weeks a reduction in temperature was observed and this temperature was maintained during the proceeding weeks.

It is important to note that in Units 2 and 3 the compost did not reach the 30 cm height. The highest temperature of 43 °C was recorded in Unit 2 at 6 weeks, while in Units 1 and 3 the highest temperatures of 39.5 °C and 36 °C were recorded at 6 weeks respectively (Table 5).

Fig. 1 Variation of maximum temperatures in three units with Time

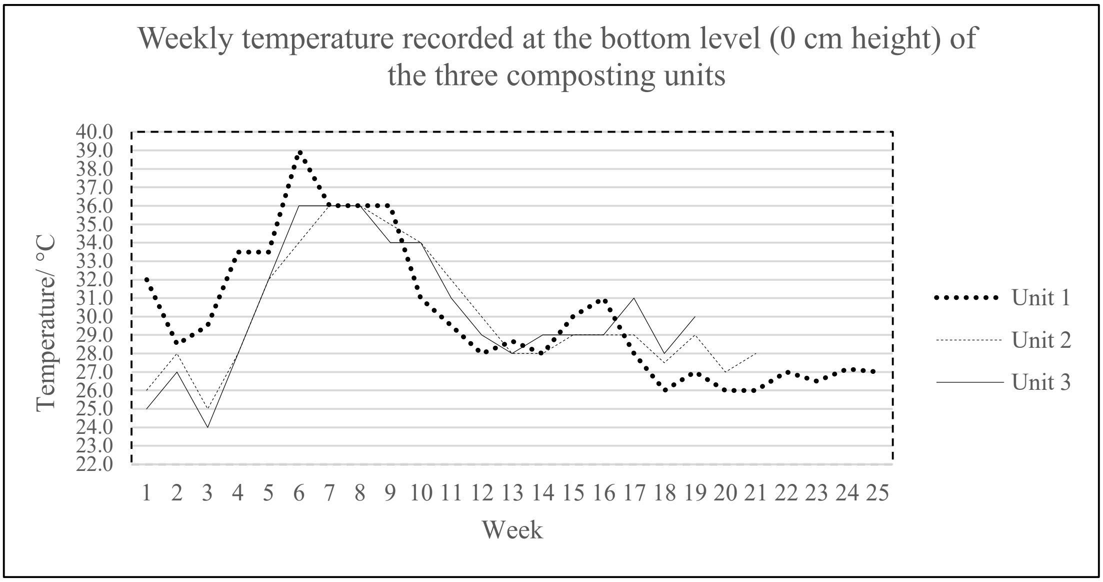

Table 5 Mean and Range in maximum temperature of compost

Unit	Mean Temperature of compost /week	Range in Maximum Temperature of compost /week °C
1	32.5	27- 39.5
2	30.8	26- 43.0
3	30.8	25- 36.0

A similar fluctuation pattern in temperature (between 20 °C and 40°C) was seen at the bottom level of composting mass in the three units. A marked increase in temperature was seen from week 3 to week 6. The temperature at bottom level then fluctuated between 25.0°C and 32.0 °C from week 11 onwards. The mean and the range in temperature at bottom level are 30.1 °C and 25- 39 °C. Temperature at the top level of the composting mass in the three units showed a somewhat similar fluctuation pattern and varied between 25.0 °C and 43.0 °C. with a gradual increase from week 2 - 6. Thereafter, a gradual decrease in temperature was seen until week 17. The mean and range in temperature at the top level of compost were 29.3 °C and 25-43 °C respectively.

Further, the Two-Way ANOVA (Table 6) confirms that there is a significant variation in temperature of composting mass with time as well as with compost height.

Two-way ANOVA: Temperature versus Time (week), Height (cm) Analysis of Variance for temperature

Table 6 Two-Way ANOVA for Temperature with Time and Height of composting mass

Source	DF	SS	MS	F	P
Time	18	659.82	36.66	9.58	0.000 (S)
Height	1	36.61	36.61	9.57	0.003 (S)
Interaction	18	98.30	5.46	1.43	0.143
Error	76	290.74 3.83			
Total	113	1085.47			

Variation in fly larval density

The larvae found in compost belonged to the Family Stratiomyidae. The maximum larval density in compost obtained at three different heights over the entire study period is shown in Fig. 2. Stratiomyidae larvae appeared in compost only after 8 weeks and disappeared from compost after about the 24" week. The maximum larval density of 93, 84 and 62 were recorded respectively in Units 1, 2 and 3 at week 17 with a mean of 18.4 during the study.

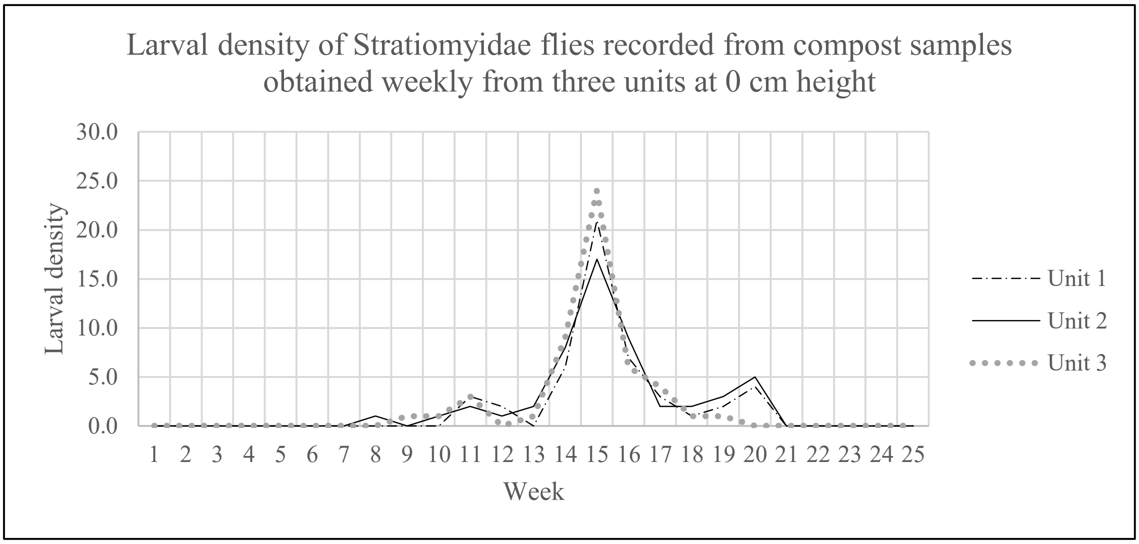

Fig. 2 Maximum larval density of compost in three units

Mean maximum fly larval density in Unit 1	25.7
Range of maximum fly larval density in Unit 1	0- 93
Mean maximum fly larval density in Unit 2	15.25
Range of maximum fly larval density in Unit 2	0-84
Mean maximum fly larval density in Unit 3	13.4
Range of maximum fly larval density in Unit	0-62

During the intervening period several peaks in larval density were recorded specially at top level while bottom level showed the lowest larval densities.

Unit 1 recorded a highest larval density of 93 larvae/10 cm^3 at 17weeks at top level. Units 2 and 3 at a similar time (at 17 weeks) reached the highest larval density of 84 and 62 larvae/ 10 cm^3 respectively at top level. However, the Two-Way ANOVA (Table 7) indicates a significant variation in Stratiomyidae larvae density with both time and height of compost.

Table 7 Two-way ANOVA for Fly larval density with Time and HeightTwo-way ANOVA: Fly larval density versus Time (week), Height (cm)
Analysis of Variance for Stratiomyidae larvae

Source	DF	SS	MS	F	P
Time 0.000 (S)	9	14806.2	1645.1	52.12	
Height 0.000 (S)	1	3952.8	3952.8	125.22	
Interaction 0.000	9	9368.0	1040.9	32.97	
Error	40	1262.7	31.6		
Total	59	29389.7			

Discussion and Conclusion

The quantity and quality of kitchen waste generated would vary from household to household and would depend on the number of occupants in the household and their food habits. This fact was reflected in the study where a total of 90 kg was fed to unit 1, 41 kg to unit 2 and 38 kg to unit 3 over a period of 19-25 weeks. In a similar study conducted by R. Shanthini (unpublished) the cumulative kitchen waste input was 177.5 kg over a period of 160 days.

With the weekly addition of kitchen waste into a unit an increase in the height and the accompanying volume of the composting mass was expected but this was not consistently observed. This observation is explained on the basis that kitchen waste undergoes decomposition due to bacterial activity and feeding by dipteran larvae resulting in a gradual change into compost. This gradual change in the composition of the kitchen waste during composting is reflected in the reduction in height (volume) as well as in many other parameters that characterize compost. The formation of compost (accompanied by a marked reduction in height) with the weekly addition of kitchen waste was first evident during the 6 week of the run. This reduction in the compost height in the three units gradually increased with time till the 16" week, inferring continuous production of compost. A previous study by R. Shanthini (unpublished) demonstrated a 58 cm height increment in moist compost after adding of about 177.51 kg of kitchen waste and 10 kg of dried grass clippings.

As pointed out by Sustainable Agriculture Research and Education (SARE) (2004), the black soildier fly (*Hermetica illucens* (L.) driven manure management system reduced the volume of poultry droppings by more than half and practically eliminated house fly populations. A similar idea was generated in the study by Shanthini (Unpublished), where high temperatures killed a considerable number of fly eggs resulting in a reduced larvae population. This led to the low consumption of incoming waste. However, the larval density in the present study showed a negative relationship with height reduction which - may be due to the intraspecific competition for food by the larval stages.

Aerobic composting is a biological decomposition process in which microorganisms break down organic matter in the presence of oxygen (Shanthini, Unpublished). In this aerobic biodegradation, organic matter is converted into CO_2 and H_20 and a great deal of energy released in the form of heat. According to studies of Shanthini and Walgama (2003) the temperature of compost varies from 40 to 50 °C when the ambient temperature is 15 to 25 °C. Bio-waste composted in open windrows by Kjyula et al (2000) resulted in an increase in temperature to 85 °C. The highest temperature reached during the present study was 43°C at a compost height of 15 cm at 6 weeks (in Unit 2) when the ambient temperature was 32°C.

At 15cm height, the composting mass is subjected to low water clogging, good aeration which is ideal for the activity of microorganisms. All three composting units showed a gradual increase of temperature after the 4th week and reached a peak at 6th and 12th week. The microorganisms that associate with composting take time to stabilize within the system. The duration that takes for stabilization is recorded as nearly 6 weeks by other researchers (Shanthini and Walgama, 2003) which was seen in the present study too. The increase of temperature shows the stability of microorganisms that are thermophilic and release of energy as heat (Shanthini and Walgama, 2003).

Composting sites provide ideal breeding grounds for a range of fly species since they offer an abundance of warm decaying organic matter (Goulson *et al*, 1999). In present study too at 30 cm height or top level of the composting mass Stratiomyidae larval density was high. The recent study by R. Shanthini (Unpublished) recorded similar results. According to this study the top surface of the Composting mass, being cooler than the interior composting mass, harboured a large number of larvae which contributed to the breakdown of fresh waste to a certain degree for microbial degradation. According to Goulson *et al (*1999) a household composting site with a nearby landfill resulted in a large number of Calypteran flies; bluebottles *(Calliphora* spp.) and greenbottles *(Lucilia* spp.). However, according to their study, the house fly *(Musca domestica* (L)) and lesser house fly *(Fannia* spp.) were not an important part of the dipteran catch in the composting system. Similar conditions were observed during this study where three different dipteran fly families were observed in the three compost units. They are flies of the Family Stratiomyidae, Drosophilidae and Lonchopteridae. Only the larval stages of Stratiomyidae flies were recorded from the composting mass while adults of Drosophilidae and Lonchopteridae flies were present in the sweep net catches. However, the larval stages of Family Drosophilae and Family Lonchopteridae were not recorded through naked eye observations. As the flies of these two families are very small, the eggs and larval stages are indeed very minute too. Moreover, the diversity and density of flies were found to vary depending on the suitability of the composting mass for breeding.

Black soldier fly is commonly found in tropical and warmer temperate regions (Diener *et al*, 2011). According to current study density of Stratiomyidae larvae was high during the 13th and 19th week. According to Goulson*et al* (1999) a mean number of 0.43 (per kilo) adults calyptrate flies emerged from one week-old waste. Zheng (2012) pointed out that 1000 black soldier fly larvae per 1 kg of solid residual is the best option in waste management. Since large quantities of waste are delivered to landfills daily, a substantial increase in the local population of calyptrate flies can be expected. During the present study the fly larval density in the three composting units showed an increase from 13th -22nd week where the larval density ranged from 25-84 (#/ 10cm^3) with a peak at 15th week. Moreover, the larval density of present study peaked at top level while bottom level showed the lowest larval densities. This can be due to the fresh mass input of kitchen waste in the top level.

As Shanthini (unpublished) pointed out with the increase of top surface level of composting mass the maximum temperature attained by the composting mass also increased. The present study also confirmed it as Units 1 and 3 showing a positive relationship between the highest temperature and the top surface level of the composting mass.

Conclusion

Evidence of microbial activity as inferred from high temperatures, when bulk density was low (with more pore space) was recorded after 6- 7 weeks and continued for 16-17 weeks. The colonization of the composting mass by fly larvae results in conditions conducive to microbial activity. The increase in temperature that follows is attributed to microbial activity. Hence fly larval activity indirectly enhances microbial activity promoting composting.

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