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COMPOSTING OF DECIDUOUS TREES LEAVES AND CATTLE DUNG: EFFECT OF TURNING OPERATION IN PROCESS PERFORMANCE

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ABSTRACT

The aim of this study was to evaluate the feasibility of composting fallen leaves and cattle dung and the effect of turning frequency on final compost quality. A bioreactor vessel was designed, manufactured, and situated on the roof of the Agricultural Engineering Department, Faculty of Agriculture, Mansoura University for rapid composting of admixture leaves and cattle dung from November 2008 until June 2010. This bioreactor vessel is conical in shape (right frustum of cone) and made of double layer of stainless steel sheet 1 mm thick with a net volume of 0.1094 m^3. A series of experiments were executed to investigate some engineering factors affecting performance of composting process such as; size of fallen leaves and stirring or turning frequency. Laboratory tests were also carried out to assess and evaluate some physical and chemical properties of raw composting materials, fresh compost, and final compost after curing process. Two different particle sizes of fallen leaves (shredded leaves of 2.0-5.5 mm and complete leaves) and one aeration rate (0.007 m^3/min) were functioned. Two different levels of manual stirring (without and with stirring once every six days) were used. The obtained results revealed that, to maximize the microbial activity and speed up the composting process of admixture materials, they would be aerated by a rate of 0.007 m^3/min, stirred once every six days, and shredded fallen leaves to a smaller particles size. The obtained results also showed that, the final compost contented Nitrogen (N), Phosphorus (P), and potassium (K) of 3.181%, 0.318%, and 3.790%, respectively. They also revealed that, there were no weed seeds found in all treatment samples of fresh and final composts. Rising up the temperature of admixture materials and persisting from the first day until the end of fifth day during the thermophilic phase caused in destructed of pathogens and other organisms.

Keyword: Composting; leaves of deciduous trees; microbial activity; turning frequency

INTRODUCTION

A large amount of municipal solid wastes are annually remained after the harvesting operation of different crops in Egypt. These residues are commonly moved to dumps, where they pose a threat of environmental pollution. Composting is a possible alternative recommended method for treating solid organic wastes and the final products can be reutilized for land application. Composting is a mature technology for converting organic wastes, such as cattle dung and municipal solid waste, into a usable fertilizer or land reclamation materials and is an environmentally friendly and an economically alternative technology (Huang *et al*., 2006).

The persistence of phytopathogenic microorganisms in crop residues is well known. Any composting therefore requires the confirmed capacity of the process to eliminate phytopathogens that might be present in the raw material (Conway, 1996). Microbes mainly contribute to the biodegradation and humidification of organic wastes and the production of composts with high quality. For sustainable use of organic wastes as materials of composts, especially important is that pathogens and other health-related problems must be controlled.

Among the compost able organic matrices, high C/N lignocelluloses wastes are particularly interesting because of their low cost and widespread available. The composting of these materials is slow, but can be significantly enhanced by the addition of N-rich residues, such as animal by-products. Traditionally, manures (from poultry, cattle, and sheep) have been used to decrease the initial C/N ratio of the mixtures and improve the composting process (Li *et al*., 2008). Most studies show that compost application to agronomic soils increases crop production due to its plant nutrient content and moisture retention characteristics. It also improves the physical properties of the soil because organic materials such as agricultural wastes and sewage sludge are degraded into relatively stable compost that can serve as a soil conditioner (Wong *et al*., 1996). Leaves exhibit a relatively slow decomposition rate due to the high content of recalcitrant decomposable compounds such as cellulose and lignin. Therefore, garden residues with relatively high nitrogen content would complement leaves with relatively high carbon content for composting (Wong *et al*., 2001).

Composting has been demonstrated to be a valuable strategy for the recycling of a variety of organic residues, allowing the recovery of degraded soil and the sustainable management of agricultural land (Sanchez-Monedero *et al*., 2001; Ros *et al*., 2006). The addition of animal wastes with differing degrees of Nitrogen availability in the compost starting mixtures is likely to significantly affect the composting process and the quality end products produced. Thus, evaluation of their influence on the chemical, biochemical, and microbiological changes is important since the reliability of composting processes in terms of product quality hygienic safety strongly depends on the optimization of the process (Cayuela, *et al*., 2009). The characterization of a composting process is difficult due to the wide range of physicochemical properties of the starting materials and the complex chemical and biotic interactions during the process. As a consequence, parameters for compost stability and maturity are appropriate only for specific starting materials or process types, and the utilization of a set of methods, addressing different aspects of the process, is highly recommended (Itavaara *et al*., 2002).

Compost maturity and stability are key factors during composting process. Immature compost, when applied to soils, maintains high decomposition activity, which may retard plant growth due to nitrogen starvation, anaerobic acids (Epstein, 1997). In order to promote mature compost production, environmental factors such as temperature, aeration rate, moisture content, and nutrients should be appropriately controlled. Turning frequency is commonly believed to be one of the most important factors affecting compost quality (Michel *et al*., 1996). However, optimum aeration rates vary with the materials and methods of operation, and the effects of turning frequency on a variety of compost parameters are not clearly understood.

The main objectives of this research work were to test and evaluate the following:

(1)The feasibility of composting deciduous trees residues and cattle dung in order to produce quality composting products for organic farming and

(2)to investigate the optimum turning frequency required for rapid composting trees leaves and cattle dung in order to proper aeration for optimum organic decomposition.

MATERIALS AND METHODS

Design of bioreactor vessel

One bioreactor vessel was designed, manufactured, and installed on the roof of the Agricultural Engineering Department, Faculty of Agriculture, Mansoura University in order to study, test and evaluate its performance in rapid composting of admixture leaves and cattle dung from November 2008 until June 2010. This bioreactor vessel is conical in shape (right frustum of cone) and made of double layer of stainless steel sheet 1 mm thick. The gross dimensions of the bioreactor vessel are 54.6 cm in diameter (top base diameter), 30.6 cm in diameter (bottom base diameter) and 74.8 cm deep , with a net volume of 109 433 cm^3 (0.109 m^3), as shown in Fig. (1). The upper base of the reactor was capped using a movable circle iron lid with internal stainless steel layer fixed on it. This cap is divided into 2 parts connected by hinges allow, the first part to open and load or unload content without decoding the second part. The exterior circumference of the bioreactor vessel was insulated using 25 mm thick of fiberglass wool insulation in order to reduce the heat losses (by convection and radiation) from the curved surface area of the reactor into the surrounding environment.

To supply an adequate amount of air (oxygen) for providing and maintaining the presence of oxygen in the composting media, a 2.5 cm diameter hole was drilled on the top base of the bioreactor vessel. Oxygen was usually supplied to the composting media from oxygen cylinder through a control valve fixed on the cover of bioreactor vessel. A preliminary experimental work was carried out to select the best design of the stirring system. The experiment showed that the best design is cross rods (Fig. 2).

This design was consisted of fife different lengths of horizontal cross rods, 20.7, 19.1, 17.4, 15.7, and 14.0 cm (from bottom to top bases). The air during the aeration operation was passed downward through the bioreactor vessel. Driving unit was manually operated and consisted of two bevel gears with reduction ratio of 1:4. Driving gear is mounted and fixed directly on the stirrer. The pinion gear is mounted and fixed on the driving shaft with two bearing units on the top of the bioreactor vessel cover. The two different configurations of stirrers were fixed on the lower base of the bioreactor vessel to provide and maintain allowable free motion for mixed field residues and animal waste easy during the composting process.

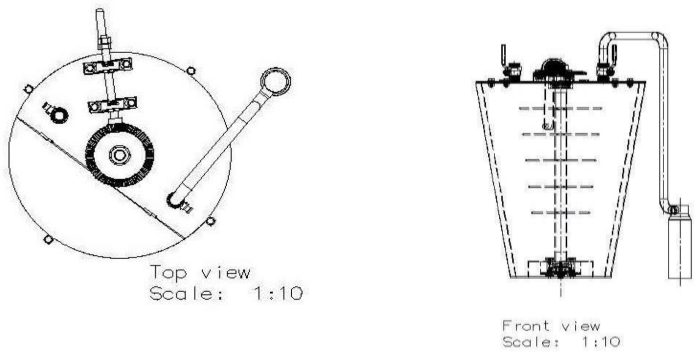

Fig. (1): Top and front view of bioreactor vessel.

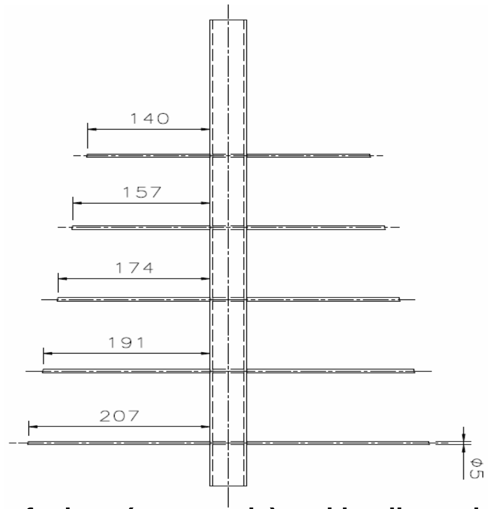

Fig. (2): Diagram of stirrer (cross rods) and its dimensions.

Instrumentation

The temperatures in bioreactor vessel and ambient air surrounding the vessel were measured by the continuous self-recording data logger with K-type thermocouple probe (TM-7XX SERIES, TENMARS ELECTRONICS CO., LTD). The data logger was used to measure the temperature of mixed composting materials at two different locations inside the bioreactor vessel. The acidity (pH) of the admixture composting materials was measured and recorded during the experimental period using pH meter (Microprocessor Pocket-pH/mV, model 323, Germany). To determine and measure the pH of admixture composting material, 5 grams of mixture (shredded leaves and cattle dung) was placed in a glass beaker (50 cm^3) and 30 ml pure water was added and agitated together according to Misra *et al*. (2003). A sample from the bioreactor vessel was taken every two days during the experimental period to test, measure, and adjust the pH of composting materials. The salinity of the raw material (Shredded leaves and cattle dung), fresh compost, and cured compost was measured using electrical conductivity (EC) meter (YEW, model SC5/pocket).

Raw Materials for Composting Process

The first essential step in the overall composting system is to mix manually the raw materials (shredded leaves and cattle dung) in the proper proportions and then load it into the bioreactor vessel. The bioreactor was usually held about 20 kg of composting raw materials. Leaves of deciduous trees were used as one of the raw materials for composting admixture. This raw material was collected and brought from many gardens during autumn season. Leaves and other large objects cannot be composted without size reduction. Downsizing, chopping, or shredding up the fallen leaves is a sound and widely-practised technique. It increases the surface area available for microbial activity and provides better aeration. This technique is particularly effective and necessary for harder materials such as fallen leaves of deciduous trees. Therefore, the leaves were manually broken and shredded when they had moisture content of 4.5 - 5.5 %, w.b. Sieve was used to classify and sort the shredded stalks into two different categories of particles size (2.0 to 5.5 mm), and complete leaves.

The raw materials (shredded leaves and cattle dung) were mixed together with a ratio of 1.5 parts of cattle dung to 1 part of leaves (by weight) to recognize the desirable moisture content of 60 %, w.b. Mixing operation of raw materials was manually executed on a plastic sheet placed on the concrete floor using handle shovels. The admixture of raw materials was weighed at the beginning and end of each test during the experimental period. The physical and chemical properties of the leaves and cattle dung were measured, determined, and listed in Table (1). During the experimental period, the admixture composting materials were situated in the bioreactor vessel just after the mixing operation and adjusted the moisture content for approximately three weeks. After composting period the composted material (fresh compost) was removed from the bioreactor to store under natural conditions (at room ambient temperature) for curing stage.

Carbon/Nitrogen ratio (C/N)

Because of the carbon/nitrogen ratio (C\N) of raw materials (shredded leaves and cattle dung) was very high (Table 1), addition of nitrogen was necessary to achieve the desired C/N ratio. Therefore, amounts of 5 and 14 kg/ton of super phosphate and urea fertilizers, respectively, were added to the mixed raw materials as suggested by Sadaka and Sabbah (1999) and many researchers.

Laboratory Analysis of Raw Materials, Fresh and Cured Composts

All laboratory analyses were carried out according to the ASAE Standard Methods (1997). Sample of 800g was randomly taken from raw materials, mixed materials, fresh compost and cured compost. Also two samples from each vessel were randomly taken at the beginning and end of each experiment. Approximately 800g sample was collected from three arbitrarily selected points at the start and at the end of each run. The moisture content was determined by comparing the weight of a sample before and after drying at 70°C for 48 h, in an electrical oven. The moisture content (MC,%) was determined as follows:

Table (1): Some physical and chemical properties of raw materials

Determination	Cattle dung	Leaves
Bulk density kg/m³	865	178
Moisture content%(wb)	86.05	6.10
Acidity (pH)	8.20	6.88
Volatile solids (VS), %	81.15	95.48
Ash, %	19.25	4.82
TC, %	44.86	52.88
TN, %	0.92	0.72
Carbon/Nitrogen ratio (C\N)	48.76	73.44
Phosphorus (P), %	0.075	0.070
Potassium (K), %	0.35	0.32
Iron (Fe), mg/g	0.773	0.492
Cupper (Cu), mg/g	0.00791	0.0105
Zink (Zn), mg/g	0.0141	0.0187

$$\text{Moisture content, (MC,\%)} = \frac{M_w - M_d}{M_w} \times 100 \qquad (1)$$

Where; M_w, is the weight of the wet sample in g, and, M_d, is the weight of the dry sample, in g. The moisture content of mixed materials at the beginning of each experiment was about 64.84%, wb. Ash content was determined by loss on ignition at 550°C for 8 h (Cayuela, *et al*., 2009). Total organic (TOC) and total nitrogen (TN) were determined by a dry combustion method. Volatile matter content for each raw material and admixture materials was computed according to the method of soil organic content test (Eldridge *et al*., 1993; Vander Gheynst *et al*., 1996).

$$\text{Volatile matter content} = \frac{M_a - M_b}{M_a - M_c} \times 100 \qquad (2)$$

Where; M_a, is the sample and crucible mass, in g, M_b, is the ash and crucible mass after intensive heating at 550°C for 8 h, and, M_c, is the crucible mass, in g. The sample used for moisture content, volatile solids, and fixed solids (ash) determination was also functioned to estimate carbon content. The carbon content was calculated using the following formula:

$$\text{Carbon content} = \frac{100 - \text{Ash}}{1.8} \qquad (3)$$

Nitrogen (N) phosphor (P) and potassium (K) contents of the raw materials, fresh compost, and the cured compost were analysed and determined at the soil department, Faculty of Agriculture, Mansoura University. Carbon to Nitrogen ratio (C/N) was calculated after the amount of carbon and total nitrogen in the composting materials was assessed. Density is calculated by dividing the weight of the substance on the volume that occupies. The bulk weight is expressed in the wet mass of material per unit volume. The bulk density is the dry mass of the material per unit volume of solids and voids occupied by the original material. Bulk density can be found from the following equation (ASAE Standard Methods, 1997).

$$\text{Bulk density} = \frac{\text{Density}(g/cm^3)}{\text{Dry matter}(\%)} \times 100 \quad (4)$$

The weed seeds test was executed after the end of each experimental run to check up the weed seeds in mixed materials (before composting) and the final compost (cured compost). Samples of admixture raw materials (shredded leaves and cattle dung) and final compost were mixed with pasteurized clay soil (same equal amount). Samples were placed in six cleaned plastic pots and situated inside a greenhouse to prevent any weed seeds transfer by wind. The pots were irrigated every 2 days with equal amount of tap water using garden sprayer for 45 days. Also the cured compost was used as an organic material for sweet colour pepper crop which planted inside the greenhouse on the roof of the Department.

Bacteriological analyses

Six samples of admixture raw materials and final compost were randomly selected and collected from each site of run. They were individually wrapped in sterile polyethylene bags for analyzing. An equal volume of cold sterile 15 M phosphate buffer was added using sterile pipette. For getting samples water suspended samples were then serially diluted with sterilized distilled water. One ml suspension was diluted until reached 10^{-7} using seven tubes per each dilution, and then incubated at optimum incubation temperature degree and period. Total aerobic bacterial counts were estimated by pour plate method according to (APHA, 1989). Serially diluted samples were spread onto nutrient agar plates and incubated for 48 hrs at 35°C, as recommended by Vance *et al*. (1987). Total viable count (TVC): This parameter indicates the total microbial contamination of compost samples. Thus, it serves as a useful test in justifying the operating efficiency of various compost processes. The enumeration of total numbers of microorganisms which are multiplying at different temperatures may yield better information about the quality of examined compost. They also provide supporting data regarding the significance of the results of the coli-form test.

The standard plate count technique described by AMARICAN PUBLIC HEALTH ASSOCIATION (APHA, 1989) was used in the determination of (TVA). In this medium, the enumeration of total count is carried out after 48-72 hrs. This medium consists of 3g beef extract, 5g peptone, 17g agar, and distilled water up to one liter, to provide a final pH of 6.8. Plates were incubated at 30°C for 48 h. Values were expressed per 100 ml of the sample. Albeit the above indications of the enumeration of total organisms in compost sample specimen, a more basic knowledge is necessary about the numerical populations of the particular degradation groups of organisms contained in this total enumeration. Consequently, simultaneously with this total enumeration, the levels of the hereunder objectionable microbial groups were quantified. Counts were also calculated for 100 ml of the sample and presented as % of the total count at 30°C, since this group does not grow at 65°C.

Total coli-form counts: Total coli-form counts were determined by pour plate method (APHA, 1989). Serially diluted samples were spread onto fuchsine lactose agar plates (Merck Cat. No. 4044), and incubated for 48 h at 35°C. All red colonies were detected as coli-form or by using MacConkey agar medium as recommended by Vance *et al*. (1987). This medium is used as the selective platting medium for enumeration of E. coli and used for the direct plating of examined compost samples for coli-form counts. Poured plates were incubated at 35°C for 48 hrs. Values were expressed as total coli-form count (TCC)/100ml sample. The contribution of this count to total viable count (TVC) at 35°C was also determined as a percentage. E. coli counts: E. coli counts were also estimated by pour plate method (APHA, 1989). Serially diluted samples were spread onto Fuchsine lactose agar plates (Merck Cat. No. 4044), incubated for 48 hrs at 35°C. The red colonies with permanent metal sheen were detected as E. coli. Fecal coli-form counts: Fecal coli-form counts were estimated by pour plate method (APHA, 1989). Serially diluted samples were spread onto Fuchsine Lactose agar plates (Merck Cat. No. 4044), and incubated for 48 hrs at 38°C. All red colonies were detected as fecal coli-form.

Total Salmonella counts: All procedures were applied according to the FDA-Bacteriological Analytical Manual according to (Islam *et al*., 2004). Samples were serially (10-fold) diluted in sterile phosphate buffer (pH 7.0). Subsequently, 1 ml aliquots or 50 ml aliquots of each sample were pouring plated in or spread plated in or spread plated onto selective S.S agar media in duplicates. Enrichment procedure was used when no colonies were detected in the lowest dilution by direct plating methods. All the mesophilic and thermophilic fungi were isolated by plating small particles of dairy cattle dung compost on potato-dextrose agar (PDA) containing antibacterial agents (streptomycin plus chlortetracycline) at 25-45°C**.**

Experimental Procedures

During this experimental work, the following areas were considered to be very important in rapid composting; (1) all materials were composted (fermented) within 21 days, (2) the experiments were carried out to investigate some engineering parameters affecting development of compost production systems such as particles size of field wastes and turning intervals, (3) aeration rate was fixed at 0.007 m^3/min) throughout the experimental period, (4) laboratory tests were executed to investigate and determine some physical and chemical properties of dried leaves, cattle dung, and admixture compost materials, (5) some macro-nutrients such as NPK elements content of the raw materials and the final compost were determined,(6) curing test, the fresh compost was removed from the bioreactor vessel and its final weight was determined. All fresh composts were stored at ambient air temperature with light perforated cover in plastic containers for curing process within 40 days. The fresh compost was mixed manually and slowly placed in the storage containers using a ram rod in order to provide uniform compacted density of compost. A 0.5 cm perforated screen mesh size were installed 20 cm above the floor to support the compost mass, some physical, chemical, and biological properties of the final compost after curing stage were determined, the percentage of weed seeds in fresh compost and final compost was evaluated of each run, and fresh compost sample was taken from each run for biological analysis in order to determine total viable, total coli-form, total salmonella, and some of pathogenic bacterial and fungi counts.

RESULTS AND DISCUSSION

The engineering parameters affecting composting process (include oxygen and aeration, particles size, turning intervals and compost temperature) were studied and investigated. The temperature rise of the admixture raw materials (leaves and cattle dung) during composting process is considered as an action indicative of the degree of microbial decomposition activity. The temperature giving the optimum activity in samples incubated at a variety of temperature during the assay tended to increase as the composting time progressed. Composting process essentially takes place within the two ranges known as mesophilic phase (10 - 40°C) and thermophilic phase (> 40°C). Although mesophilic temperatures allow effective composting, most experts suggest maintaining temperatures between 43 and 70°C (thermophilic phase). The peak temperatures at constant aeration rate (0.007 m^3/min.), two different levels of particles size, and turning intervals are summarized and listed in **Table (2)**.

Table (2): The peak temperatures at constant aeration rate, two different levels of particles size, and turning intervals

Aeration rate, m^3/min.	Turning Intervals	Particle Size, mm	Peak Temp. °C	Time (day)	Minimum Temp. °C
0.007	Without agitation	2.0 to 5.5 mm shredded leaves	64.8	14	28.1
		Complete leaves	59.5	14	26.2
	With agitation	2.0 to 5.5 mm shredded leaves	65.6	21	30.6
		Complete leaves	62.7	21	29.0

Turning operation of the admixture composting supplies a limited amount of oxygen, but this amount is quickly consumed and must be replenished by passive or forced air movement. Turning operation is mainly required for good aeration. It restores the pore space within the bioreactor vessel so that air moves through raw materials more easily. Fig. (3) shows the temperature profiles of the composting materials without turning and particle size of (2.0 to 5.5 mm). The obtained results indicated that, the composting materials with this treatment reached mesophilic phase, which started from approximately ambient air temperature to 40°C within 12 hours. It attained strains of microorganisms presented in organic waste to decompose the composting materials. The peak temperature of composting materials without turning operation was 64.8°C. The temperature of the composting materials was rapidly increased from mesophilic to thermophilic phases within 3 days. The peak temperature (greater than 60ºC) for treatment of without turning was persisted from the first day until the third day, due to heat generated by ongoing microbial activity during composting process, water vapour, and hot gases were not released from the bioreactor vessel. It then decreased till approached a minimum value of 28.1°C at the end time of day fourteenth, due to the weak or dormant of microorganisms (aerobic bacteria).

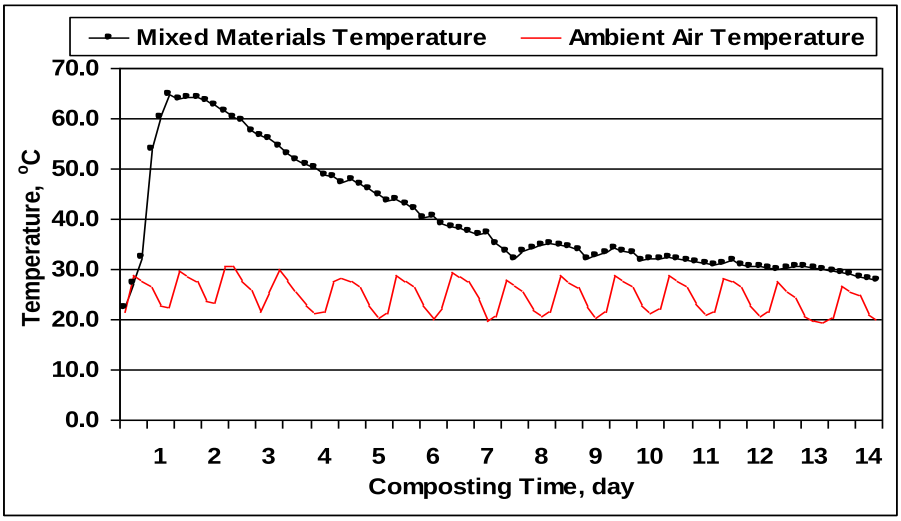

Fig. (3): Temperature profiles of the compost materials and ambient air temperature without turning and particle size of (2.0 to 5.5mm).

Another set of experimental work was carried out to examine the performance of composting system using complete leaves without turning operation as shown in Fig. (4). The obtained data revealed that, the composting materials with this treatment reached mesophilic phase, which started from the ambient air temperature to 40 °C within 12 hours after the admixture materials situated inside the bioreactor vessel, till it reached the peak temperature within 20 hours. The peak temperature of composting materials without turning operation was 59.5°C. The temperature of the composting materials was rapidly increased from mesophilic to thermophilic phases within 3 days. The peak temperature (> 50ºC) for this treatment was remained for approximately 3.3 days, due to the high level of microbial activity in the compost materials, consequently heat generated by these microbial during composting process, water vapour, and hot gases were not released from the bioreactor vessel. After this active time, the temperature of compost materials was dropped rapidly until reached (26.1°C) mesophilic phase again at the end time of day fourteenth, due to the weak or dormant of microorganisms (aerobic bacteria). In the fourteenth day (least day) the temperature of compost materials was dropped and reached to the ambient air temperature and never recovered. This means that, the admixture raw materials were completely composted, and all the microorganisms were died. This is in agreement with the data published by Inbar *et al*. (1993).

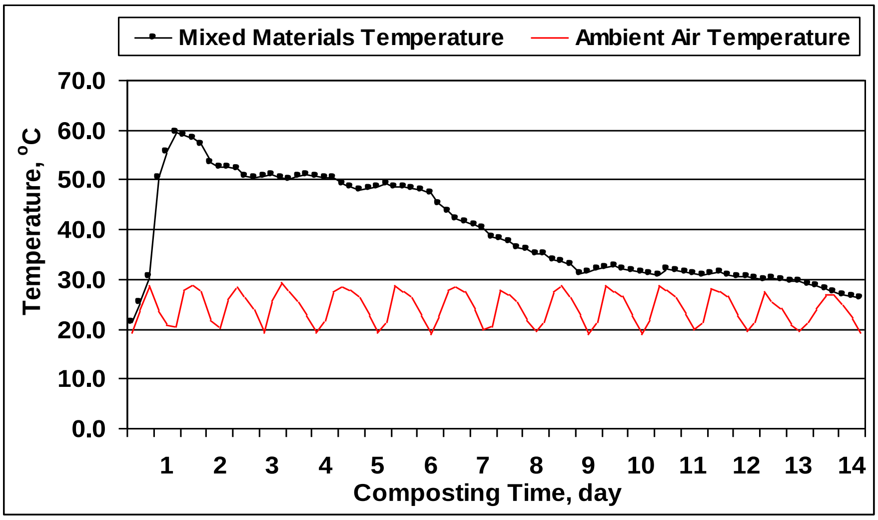

Fig. (4): Temperature profiles of the compost materials and ambient air temperature without turning operations and complete leaves.

To maximize the microbial activity and speed up the composting process, the admixture raw materials were turned three times on a regular basis (once every six days from the beginning of the experiment run). Fig. (5) demonstrates the temperature profiles of the compost materials during composting process when the turning operation was applied three times in twenty one days intervals. It reveals that, the temperature of the compost materials increased rapidly to the thermophilic phase (> 40°C) within 8 hours after the admixture materials were turning inside the reactor vessel, until it reached the first peak temperature of 66.4°C after 24 hours.

The thermophilic temperature with this treatment was persisted from the first day to the beginning of the sixth day. This Figure also shows that, during manual turning (once every six days), the temperature of the admixture compost materials was reduced to about the ambient air temperature because the thermocouple sensors for measuring temperature were inadvertently left outside the bioreactor vessel. After the first turning was accomplished, temperature recovery occurred in about 28 hours and approached to the second peak temperature of 50.8°C. After the turning operation were accomplished (once every six days), the admixture temperature approached to three peak temperatures of 50.8, 48.5, and 46.1°C, respectively. Maximum microbial activity appeared evident during the last one-third of composting period, when the highest frequency of temperature recoveries per unit time occurred. Because of the rapid rate of composting during the first fifteen days (when the temperatures were greater than 40°C), the admixture materials dried out quickly and therefore temperatures of compost materials never fully recovered. The addition of moisture during composting process would be a controllable parameter to consider during further composting research work. Since most of the heat generated by the microbial activity loss in composting process occurs by the evaporation of water, the compost materials should not be allowed to dry below 50% moisture content. Low moisture content increases the chance of reducing high temperatures as well as spontaneous combustion. These obtained data are in agreement with that published by Li *et al*. (2008).

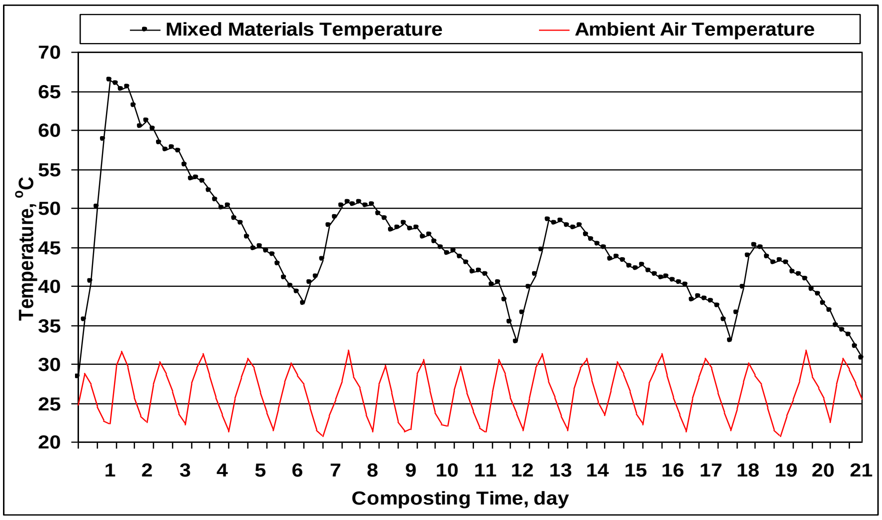

Fig. (5): Temperature profiles of the compost materials and ambient air temperature under turning operation and particle size of (2.0 to 5.5 mm)

Recorded temperature of admixture composting materials histories for complete leaves is shown in Fig. (6). It illustrates the temperature histories for complete leaves as an organic amendment with three turning operations basis (once every six days). The obtained data revealed that, the admixture composting materials with this treatment reached thermophilic phase (62.7°C) in less than 28 hours. The thermophilic phase was persisted from the first day until the end of fifth day due to an increase in microbial activity resulting from an adequate supply of oxygen amongst that aeration rate (0.007 m^3/min), provided more efficient aerobic organisms. The temperature of admixture composting materials was rapidly dropped till reached the minimum value of 33.7°C at the beginning of sixth day as shown in Fig. (6). After that time, the composting materials were stirred; maximum microbial activity appears evident during this active period due to the highest frequency of temperature recoveries per unit time occurred. After the first stirring was accomplished in the sixth day, the temperature of materials recovery occurred within 28 hours and reached to the second peak temperature of 47.3°C. After that, the temperature was decreased and frequented for another six days (from sixth to twelfth day) before it approached the minimum value (29.5°C) at the beginning of eighteenth day. The temperature recovered occurred in about 32 hours after compost was stirred and reached to the third peak temperature of 44.2°C. It decreased rapidly until approached the cooling down phase and never fully recovered.

Variations in temperatures of admixture composting materials can be attributed to two main reasons; the heat energy generated by organic microbial activity which rapidly increased the temperatures above 40°C, otherwise stirring operation and aeration process were accelerated evolving process of thermal trapping, water vapour, and warm gases. This temperature pattern is considered ideal for achieving maximum rate of raw material decomposition (Michel *et al*., 1996). From the temperature frequency of the admixture materials and the oxygen contents of the effluent gas, it can be concluded that, the air supplied with aeration rate of 0.007 m^3/min was adequate rate during active period of decomposition. However, a reduction in air supply rate after peak period of activity would reduce heat loss. This rate of aeration and stirring intervals seemed to be the best conditions to achieve an efficient complete leaves composting. The thermophilic temperatures (40-65°C) are usually desirable because they destroy more pathogens, weed seeds, and fly larvae in the admixture composting materials. Microbial decomposition during composting process inherently release large amount of energy as heat. The self-insulating qualities of the composting materials lead to an accumulation of that heat energy which raises the temperature into the peak level.

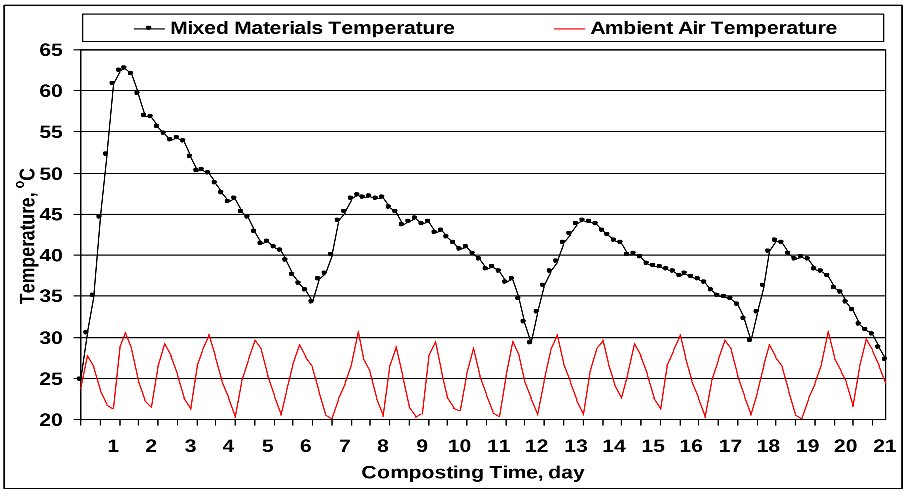

Fig. (6): Temperature profiles of the compost materials and ambient air temperature under turning operations and complete leaves.

Physical Properties of Compost

Moisture content during composting process

Moisture is necessary to enhance the metabolic processes of the microbes. Water provides the medium for chemical reactions, transports nutrients, and allows the microorganisms to move through. Therefore, admixture composting materials should be maintained within a much narrower moisture content range, generally between 50 and 65% w.b. The initial moisture content of raw materials (shredded leaves, complete leaves, and cattle dung) ranged from 58.7 to 66.3% w.b. depending on the composite of the compost materials. The loss in moisture content due to different manual stirrings (without and treble times) was 7.9 and 12.8%, respectively. Consequently, manual stirring operation significantly increased the loss in moisture content by 4.9% as compared with control treatment (without stirring). Most of the heat energy loss during composting process occurs by the water evaporation from the admixture composting materials. As water evaporates particularly in the bottom half layer of the bioreactor vessel, when the temperature of the compost materials always lower than that in the other layer due to evaporative cooling, and as air movement carries away the water vapour and other warm gases, stirring operation with aeration are accelerated the heat losses, accordingly, the moisture content decreased.

Dry matter changing during composting process

The dry matter of fresh compost was always higher than that of raw materials due to loss in moisture content during composting process. The dry matter of cured compost was greater than that of the fresh compost owing to the reduction in moisture content during the curing process. The average dry matter of raw materials, fresh compost, and cured compost during the experimental period, respectively, was 35.55, 45.0, and 53.9%. Accordingly, composting and curing processes resulting in increasing dry matter by 9.45% and 8.9%, respectively. The influence of manual stirring operation on dry matter is evidently observed in the two different particles size resulted from the reduction rate in moisture content during composting process. Therefore, the increasing percentage in dry matter with shredded leaves (2.0 to 5.5 mm) and two different stirring operations (without and with treble times), respectively, was 17.6% and 20.9%. Whereas, the increasing percentage in dry matter with completes leaves and two different stirring operations (without and with treble times) was 16.2% and 18.7%, respectively.

Organic matter changing during composting process

The organic matter of fresh compost was always lower than that of raw materials due to oxidation and conversion of organic matter into carbon dioxide (CO_2), water (H_2O), and new microbial biomass. The organic matter of cured compost was lower than that of the fresh compost. The average organic matter of raw materials, fresh compost, and cured compost during the experimental period, respectively, was 85.98, 75.45, and 67.13%. Accordingly, composting and curing processes resulting in organic matter reduction by 10.53% and 8.32%, respectively. The rate of reduction in organic matter is an indicator of the overall composting rate. The influence of manual stirring operation on dry matter is evidently observed in the two different particles size resulted from the oxidization rate of organic matter during composting process. Therefore, the reducing percentage in organic matter with shredded leaves (2.0 to 5.5 mm) and two different stirring operations (without and with treble times), respectively, was 26.1% and 17.5%. Whereas, the reducing percentage in organic matter with completes leaves and two different stirring operations (without and with treble times) was 20.8% and 11.0%, respectively. The organic matter content was evidently decreased when the compost materials were stirred than in manual stirring treatment, since a substantial loss of total organic matter occurred during composting process.

Dry ash content changing during composting process

Ash of dry matter (dry ash) mainly resulted in a better reference, as it eliminates the natural variations among organic substance contents. The obtained results showed that, the dry ash content of fresh and cured composts was always greater than that of raw substances. The average dry ash content of raw materials, fresh, and cured composts, respectively, was 14.00, 25.05, and 32.87%. Accordingly, the composting and curing processes resulted in increase the dry ash content by an average 11.05% and 7.82%, respectively. This is agreement with the data published by Michel *et al*. (1996); Huang *et al*. (2006); Li, *et al*. (2008). The influence of manual stirring (without and with treble times), forced aeration rate of 0.007 m^3/min, and different particles size (shredded and complete leaves) revealed that, the average dry ash content of the fresh compost increased from 14.6% to 38.3% and from 15.1% to 21.4% for admixture shredded leaves and cattle dung without stirring and with stirring during the experimental period, respectively. Thus, the increasing in dry ash content of fresh compost without stirring and with stirring, respectively, was 23.7% and 6.3%. Whilst, the increasing in dry ash content of cured compost without stirring and with stirring for shredded leaves was 26.1% and 17.5%, respectively. The average dry ash content of the fresh compost increased from 12.3% to 22.8% and from 14.1% to 17.7% for admixture complete leaves and cattle dung without stirring and with stirring during the experimental period, respectively. Therefore, the increasing in dry ash content of fresh compost without stirring and with stirring was 10.5% and 3.6%, respectively. Whereas, the increasing in dry ash content of cured compost without stirring and with stirring (treble times) for complete leaves, respectively was 20.8% and 11.0%.

Reduction in Compost Mass during Composting Process

The admixture compost materials were weighed at the beginning and end of each run and after curing process. The initial mass of raw materials, final mass, mass lost, and percent lost was 20.50, 14.98, 5.52 kg, and 26.93%, respectively. The highest percent lost (27.81%) occurred when used shredded leaves with cattle dung as a raw materials under stirring operation. Whereas, the lowest percent lost (23.56%) occurred when complete leaves with cattle dung are used as a raw materials under unturned operation. Because of the rapid rate of composting process during the first few days (14 days) under unturned operation, the raw materials dried out quickly and therefore temperatures never fully recovered. Consequently, lower rate of mass lost occurred during the experimental period. Whilst, used shredded leaves with cattle dung and stirring operations treble times, the composting process taken time (21 days) longer than that the unturned operations which indicative of the high level of microbial activity. Reduction in initial mass is also dependent on the location within a bioreactor vessel. The top layer of the bioreactor vessel had higher rate of mass lost than the bottom layer, owing to this layer was continuously subjected to the aeration process particularly without stirring operation and shredded leaves. Consequently, manual stirring operation significantly increased the loss in initial mass by 2.55% as compared with control treatment (without stirring). Whereas, under complete leaves and constant flow rate of aeration, the loss in initial mass due to different manual stirrings (without and treble times) was 23.56 and 26.65%, respectively. Accordingly, manual stirring operation significantly increased the loss in initial mass by 3.09% as compared with control treatment (without stirring).

Chemical Properties of Produced Compost

The chemical properties of produced compost are mainly influenced by the raw materials content. Factors affecting chemical properties of compost include; total nitrogen, phosphorus, and potassium (NPK), and electrical conductivity (EC) are the primary nutrients required by the microorganisms involved in composting process. Nitrogen, phosphorus, and potassium (NPK) are also the primary nutrient elements for all the plants and crops. Therefore, their concentrations also influenced the value and quality of the produced. The total nitrogen content of the fresh and cured composts are always more than that of the initial admixture. The average total nitrogen content (N) of raw materials, fresh compost, and cured compost, respectively, was 0.843, 2.667, and 3.181%. Therefore, the composting and curing processes resulted in increasing the total nitrogen content by 1.824% and 2.338% as compared with raw materials. The percentage of total nitrogen content is an indicator of the overall composting rate of raw materials. The percentage of total nitrogen content was evidently increased when the raw materials were turned (stirred treble times) than in unturned treatments. During manual stirring operation, the total nitrogen content of the fresh compost increased from 0.835% to 2.678% as compared with unturned treatment which increased from 0.852% to 2.656%. The obtained results also indicated that the stirring operation was significantly affected total nitrogen content and consequently overall rate of composting. The total nitrogen content of the fresh compost used shredded leaves with cattle dung during composting process increased from 0.866% to 2.965% as compared with complete leaves with cattle dung which increased from 0.821% to 2.369%. Thus, using shredded leaves with cattle dung resulted in increasing the total nitrogen content by 2.099%. The obtained results also indicated that, shredding operation of leaves was significantly effected on the total nitrogen content and consequently on the overall rate of composting.

The phosphorus content (P) of the fresh and cured composts are always more than that of the initial admixture. The average phosphorus content of raw materials, fresh compost, and cured compost was 0.082, 0.259, and 0.318%, respectively. It was increased significantly during each experiment under all treatments. Therefore, the composting and curing processes resulted in increasing the phosphorus of fresh and cured composts content by 0.177% and 0.236% as compared with raw materials. The percentage of phosphorus content was evidently increased when the raw materials were stirred than in unstirred treatments for both leaves (shredded and complete). During manual stirring operation, the phosphorus content of the fresh compost which used shredded leaves increased from 0.088% to 0.365% as compared with unstirred treatment which increased from 0.081% to 0.193%. Thus, manual stirring operation resulted in increasing the phosphorus content by 0.165%. The percentage of phosphorus content was evidently increased when the raw materials contented shredded leaves than the complete leaves under both stirring operations (without and with stirring). During the experimental period under unstirred, the phosphorus content of the fresh compost which used shredded leaves increased from 0.081% to 0.193% as compared with complete leaves which increased from 0.077% to 0.169%. Whereas, under stirred treatment, the phosphorus content of the fresh compost which used shredded leaves increased from 0.088% to 0.365% as compared with complete leaves which increased from 0.083% to 0.307%.

The potassium content (K) of the fresh and cured composts are always more than that of the initial admixture. The average potassium content of raw materials, fresh compost, and cured compost was 0.464, 2.839, and 3.790%, respectively. It was increased significantly during each experiment under all treatments. Therefore, the composting and curing processes resulted in increasing the potassium of fresh and cured composts content by 2.375% and 3.326% as compared with raw materials. The percentage of potassium content was evidently increased when the raw materials were stirred than in unstirred treatments for both leaves (shredded and complete). During manual stirring operation, the phosphorus content of the fresh compost which used shredded leaves increased from 0.444% to 3.670% as compared with unstirred treatment which increased from 0.515% to 2.565%. Thus, manual stirring operation resulted in increasing the potassium content by 1.176%. The percentage of potassium content was evidently increased when the raw materials contented shredded leaves than the complete leaves under both stirring operations (without and with stirring). During the experimental period under unstirred, the potassium content of the fresh compost which used shredded leaves increased from 0.515% to 2.565% as compared with complete leaves which increased from 0.486% to 2.536%. Whereas, under stirred treatment, the potassium content of the fresh compost which used shredded leaves increased from 0.444% to 3.670% as compared with complete leaves which increased from 0.410% to 2.585%. Thus, shredding of leaves under stirring operation resulted in increasing the potassium content by 1.051%. The obtained results also indicated that the stirring operation was significantly effected on the potassium content and consequently on the overall rate of composting. These results and values of phosphorus content are in agreement with the data published by Inbar *et al*. (1993).

Electrical conductivity (EC) changing during compost process

The average electrical conductivity (EC) of raw materials, fresh, and cured composts was 0.362, 0.398, and 0.384 S/m, respectively. The EC values slightly increased during composting process and slightly decreased during curing process. Increasing of electrical conductivity during composting process occurred due to the effect of the concentration of salts as a consequence of the degradation of organic matter (Solano *et al*., 2001). The electrical conductivity of raw materials under unturned and turned operations when shredded leaves were used during the experimental period changed from 0.292 to 0.339 S/m and from 0.354 to 0.414 S/m, respectively. Therefore, manual stirring operation of raw materials (shredded leaves) resulted in increasing the electrical conductivity by 1.18%. Whereas, the electrical conductivity of raw materials under unturned and turned operations when complete leaves were used changed from 0.395 to 0.401 S/m and from 0.406 to 0.436 S/m, respectively. Thus, manual stirring operation of raw materials when used complete leaves resulted in increasing the electrical conductivity by 5.870%. Nevertheless, the curing process of all composts decreased the electrical conductivity till reached 0.384 S/m, an acceptable range of salt concentrations for compost used as soil amendment is 0.42 S/m (Rynk, 1992).

Effect of composting process on weed seeds and microbial content

Because of the temperatures of admixture materials inside the bioreactor vessel were rapidly rose to 66.4°C (thermophilic phase) particularly with shredded leaves and stirring operation, and persisted from the first day to the beginning of the sixth day, there were no any weed seeds contained in the final compost produced under all the treatments. Experimental tests were carried out on the final compost material in order to ensure that there are no weed seeds in the final compost. These tests revealed that, most weed seeds were destroyed during the composting process due to thermophilic temperature (> 40°C). Most weed seeds are mainly destroyed under temperature ranged from 40 to 70°C as shown in Fig. (7). Therefore, the thermophilic temperatures are mainly desirable because they destroy more pathogens, most weed seeds, and fly larvae in the composting materials. This is in agreement with results published by several researchers (Michel, *et al*., 1996; Cayuela, 2009). However, the temperature of admixture materials higher than 70°C for a long time would imply destruction of all organisms in final compost, whereas, temperature lower than 70°C indicates that only selected organisms are killed. Final compost mainly contains, in addition to the harmful disease organisms, many beneficial organisms.

The effect of thermophilic temperature on microbial content of compost materials under different treatments is revealed in Fig. (7). It clearly shows the microbial content of total count (TC), *Salmonella*, and *E-coli* for each treatment and the opposite peak temperature. The thermophilic phase seemed to be the best temperature to obtain an efficient compost production. The experimental techniques used during this research work appeared to be very good tools to study microbial and biochemical mechanisms of composting and to determine the consequences of the variability in raw materials used for compost production. The microbiology of compost is evaluated by methods similar for evaluating soil microbiology. A standard analysis for microbiological content in compost is determined mainly by the concentration of bacteria and fungi. There are many ways to evaluate the concentrations of these organisms in final compost and these serve as an interpretation guide to determine the quality of final compost. An average value total viable count of 25 x 10^6 CFU/g compost was achieved at admixture temperature ranged between 50ºC to 60ºC, comparing with 5.7 x 10^6 CFU/g initial materials (control sample) at temperature of 28.5ºC. Whereas, an average value of 15.1 CFU/g compost was observed at temperature ranged between 60ºC to 66.8ºC. The total count of bacteria was mainly decreased as the mixture temperature increased above 65ºC.

Trace amounts of coli-form bacteria occurred in all samples except only two exhibited relatively high count of coli-forms of fecal origin. The mean reading value of E-coli in the initial compost materials (complete leaves with cattle dung) without stirring was 9.1 x 10^3 CFU/g compost which an enormous value of E-coli content. Due to mesophilic and thermophilic temperatures during composting process as shown in Fig.(7), this value of E-coli content in the finial compost reduced to 5.2 x 10^3 CFU/g compost. While, the mean reading value of E-coli content in the initial compost materials (shredded leaves and cattle dung) without stirring was 871 CFU/g compost. The reduction percentage in E-coli content due to composting process of shredded and complete leaves without stirring, respectively, was 93.6% and 75.0%. While, the reduction percentage in E-coli content due to composting process of shredded and complete leaves with stirring treble times was 98.2% and 90.2%, respectively. The obtained data also revealed that, E-coli reduction percentage, respectively, was 12.0, 66.8, 75.4, 94.8, and 98.4% at temperature ranged from (45 - 50ºC), (51 - 55ºC), (56 - 60ºC), (61 - 65ºC), and (66 - 70ºC).

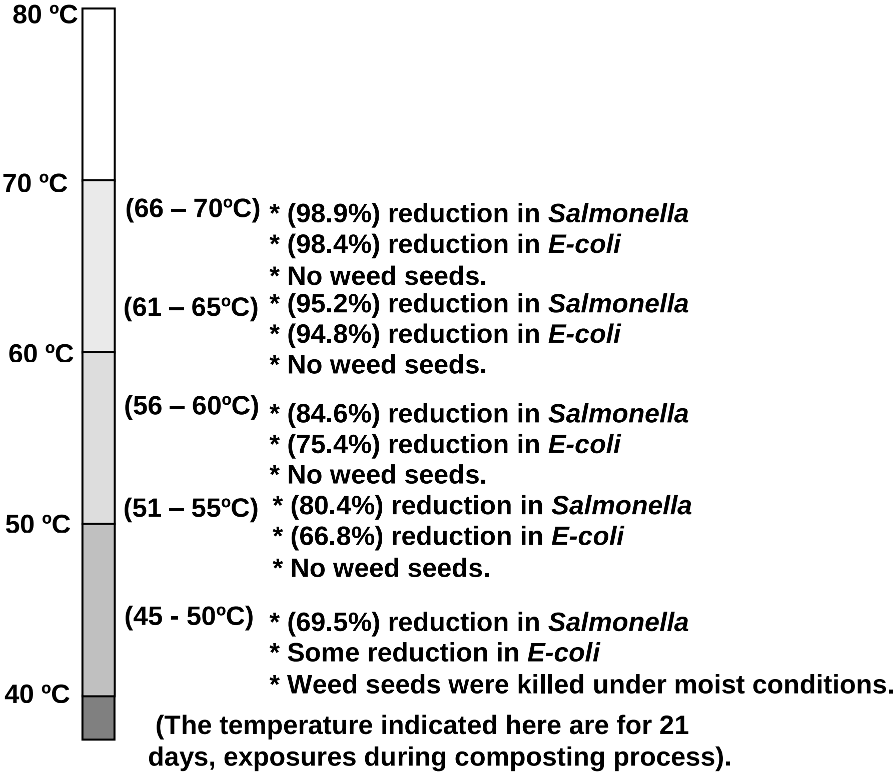

Fig. (7): Temperature of mixture compost materials necessary to kill pathogens, most weed seeds, and other organisms harmful to plants during the experimental period.

Trace amounts of salmonella organism's content occurred due to cattle dung which usually contents high level of these organisms. The trace amount of salmonella organisms in the initial compost materials (complete leaves with cattle dung) without stirring was 2.6 x 10^3 CFU/g compost which an enormous value of salmonella organisms. Due to mesophilic and thermophilic temperatures during composting process, this value of salmonella organism's content in the finial compost reduced to 1.4 x 10^3 CFU/g compost. While, the mean reading value of salmonella organism's content in the initial compost materials without stirring was 440 CFU/g compost. The reduction percentage in salmonella organism's content due to composting process of shredded and complete leaves without stirring was 95.6% and 85.70%, respectively. Whereas, the reduction percentage in salmonella organism's content due to composting process of shredded and complete leaves with stirring treble times was 98.8% and 94.6%, respectively. The obtained data also revealed that, salmonella reduction percentage was 69.5, 80.4, 84.6, 95.2, and 98.9% at compost temperature ranged from (45 - 50ºC), (51 - 55ºC), (56 - 60ºC), (61 - 65ºC), and (66 - 70ºC), respectively, as shown in Fig. (7). The data also shown that, higher level of reduction in pathogenic organisms mainly occurred at higher temperature of admixture materials. Further increase in peak temperatures related to higher microbial activity, increased the reduction of pathogenic microorganisms.

Conclusions

This research work, aimed at the evaluation of bioreactor vessel, compost produced, and energy and water balances. Two treatments were tested, differing in the turning frequency, from a control non-turned vessel to a treble turning of the vessel. The major energy source was the decomposition heat energy of the degraded organic matter. Turning roughly doubled the degradation rate of the organic matter. Water loss was also affected by turning frequency. Turning operation increased water loss due to airflow through the bioreactor vessel. Turning affects both surface evaporation by increasing air conductance and natural airflow by the regeneration of moist surface layer. the thermophilic temperatures are desirable because they destroy more pathogens, most weed seeds, and fly larvae in the final compost composting materials. The final compost material has total nitrogen, phosphorus, and potassium (NPK) of 3.181%, 0.318%, and 3.790%, respectively.

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التخمـــر الهـوائى لأوراق الأشـجار المتسـاقطة والمخلفـات الصـلبة للماشـية: تـأثير عملية التقليب على آداء عملية التخمر الهوائى

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تهدف هذه الدراسة إلى تقييم إمكانية التحلل الهوائى لأوراق الأشجار المتساقطة والمخلفات الصلبة للماشية إلى سماد عضوي مكمور وتأثير عملية التقليب على جودة السماد النهائي. ولتحقيق ذلك تم تصميم وعاء مخمر حيوي وتصنيعه ووضعه على سطح قسم الهندسة الزراعية بكلية الزراعة جامعة المنصورة لتحويل هذا الخليط إلى سماد عضوي وذلك من نوفمبر 2008 وحتى يونية 2010. وعاء المخمر الحيوي على شكل مخروط ناقص قائم مصنع من طبقتين من الاستانلس ستيل سمك الطبقة الواحدة 1 mm وبصافي حجم مقداره $109433\ cm^3$ (أي ما يعادل $0.109\ m^3$). تم إجراء سلسلة من التجارب للتحقق من تأثير بعض العوامل الهندسية مثل حجم أوراق الأشجار المتساقطة وعملية التقليب على أداء عملية التخمر. أيضاً تم عمل إختبارات معملية لتقييم الخصائص الكيميائية والفيزيائية للمواد الخام والسماد العضوى المكمور، وكذلك السماد النهائي الناتج بعد تمام عملية التحلل. تم إستخدام نوعين مختلفين من الأوراق المتساقطة من حيث الحجم (الأوراق المقطعة بأطوال من 2.0 – 5.5 mm والأوراق الكاملة) ومعدل تهوية واحد مقداره 0.007 m^3/min. وكذلك إستخدام مستويين من التقليب اليدوي (بدون تقليب والتقليب مرة واحدة كل ستة أيام).

أظهرت النتائج المتحصل عليها أنه لتعظيم النشاط الميكروبي وللإسراع من عملية التخمر لمواد الخليط يجب أن يتم تهوية الخليط بمعدل 0.007 m^3/min وتقليبه مرة كل ستة أيام وتقطيع الأوراق المتساقطة إلى أجزاء صغيرة الحجم. كذلك تبين النتائج المتحصل عليها ان المحتوى النهائي للسماد من النيتروجين والفوسفور والبوتاسيوم حوالي 3.181%، 0.318%، 3.790% على الترتيب. وأظهرت النتائج أيضاً عدم ظهور لبذور الحشائش في جميع العينات من السماد الأولي والنهائي بسبب إرتفاع درجة حرارة مواد الخليط وإستمرار ذلك من اليوم الأول وحتى نهاية اليوم الخامس أثناء مرحلة إرتفاع درجة الحرارة والتى يمكن أن تقضى على الكائنات الحية الممرضة والكائنات الحية الأخرى.

قام بتحكيم البحث

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