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Performance Evaluation of a Static Composting System Using Date Palm Residues

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Abstract: The performance of a static composting system (bioreactor) was evaluated using date palm residues. Date palm residues (DPR, 80% dry matter) was mixed with broiler chicken manure (BCM, 63.34% dry matter) as a nitrogen source. Four mixtures were prepared by using 4 ratios (v/v) of 2:3, 1:1, 3:2 and 7:3 (DPR:BCM). The C/N ratios were 25.0, 26.0, 27.5 and 30.0 for mixture 1, 2, 3 and 4, respectively. Total volume of the mixture was $0.03m^3$. Moisture content was adjusted to 60% at the start of the experiment and not controlled during the reaction. A constant airflow was continuously supplied at a rate of 10 L/min to the bottom of each bioreactor. Some physical and chemical parameters were monitored. The results showed that the temperature increased and reached to the maximum (56.96, 58.15, 56.38 and 54.96°C after 15, 10, 15 and 12 hrs and then decreased to 36.30, 34.45, 35.96 and 36.92°C by the end of composting in case of mixture 1, 2, 3 and 4, respectively. The final compost was nearly odourless and black. Moisture content decreased but not less than 40% in all mixtures. The general trend indicates a decrease in organic matter (OM), organic carbon (OC) and C/N ratio, whereas ash content increased. The loss in OM reached to 24.44, 24.85, 23.53 and 21.48% in case of mixture 1, 2, 3 and 4, respectively and followed the first- order kinetic equation with a maximum OM loss of 24.85% (mixture 2). Generally, the results found in case of mixture 2 was better than that fod in the other mixtures and therefore this mixture is considered to be the best for composting the date palm residues.

Key words: Date palm residues · Composting · Performance evaluation

INTRODUCTION

Vast quantities of agricultural and agro-industrial residues that are generated as a result of diverse agricultural practices represent one of the most important energy-rich resources [1]. Production of organic waste is increasing, while soils are progressively losing organic matter due to intensive cultivation and climatic conditions. This makes the recycling of organic waste as soil amendments a useful alternative to incineration, landfill or rubbish dumps [2]. Recycling of organic wastes in agriculture after appropriate biological treatment can produce valuable organic matter and be of great interest in countries where soils are depleted [3]. Many alternatives for the disposal of these organic wastes have been proposed, composting being one of the most attractive on account of its low environmental impact and cost [4-6], as well as its capacity for generating a valuable product used for increasing soil fertility [7] or as a growing medium in horticulture [8].

Palms are believed to be among the oldest flowering plants in the world [9]. Date palm (*Phoenix dactylifera*) is one of the most cultivated palms in the arid and semi-arid regions of the world [10]. Saudi Arabia is considered as one of the world's major producer of dates. In 2005, Saudi Arabia had more than 22 million date palm trees and this number is increasing gradually [11]. Date trees produce large quantity of agricultural waste. For example, each date tree produces about 20 kg of dry leaves yearly. Other wastes such as date pits represent an average of 10% of the date fruits [11,12]. Although these agricultural wastes consist of cellulose, hemicelluloses, lignin and other compounds which could be used in many biological processes, they were burned in farms causing serious threat to environment [13].

Composting is a biological process in which biodegradable organic wastes are stabilized and converted by the action of some microorganisms under controlled conditions (aeration, moisture,

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temperature, etc.) into a hygienic, humus-rich product (compost) for use as a soil conditioner and an organic fertilizer [14-16].

During composting, organic matter is transformed into a humus- rich product by the action of microorganisms and their enzymes. Most of the modifications that organic matter undergoes are mediated by microbial enzymes [17]. Nevertheless and in spite of this major role, most studies in composting have focused on physico-chemical parameters to evaluate both process evolution and compost quality [18-22].

The composting process requires adequate conditions of pH, temperature, moisture, oxygenation and nutrients, to allow the adequate development of the microbial population [23]. Therefore, changes in these conditions during the process will affect the proliferation of certain microflora, having different enzymatic activities, which control the organic matter degradation [24].

Generally, date palm residues as agricultural wastes are very rarely utilized in Saudi Arabia and consider as a source of environmental pollution. The utilization of these wastes in the production of compost is very important from the environmental, agricultural and industrial point of view. Therefore, the aim of this study was to evaluate the performance of a static composting system using the mixture of date palm residues and broiler chicken manure.

MATERIALS AND METHODS

Materials: Date palm residues (DPR) were collected from a large commercial farm in Al Kharj area (90 km south of Riyadh City, Saudi Arabia) and grinded into fine particles using a horizontal grinder. These residues consisted of midrib, leaflets and stems. Broiler chicken manure (BCM) as a nitrogen source was collected also from a commercial farm in Al Kharj. All materials were kept in a refrigerator at 4°C until use. The characteristics of the organic materials used in the composting process are shown in Table 1.

Table 1: Characteristics of the organic materials

Organic material	Moisture content (%)	Density (kg/m^3)	C/N ratio
Date palm residues (DPR)	20.00	68	79.25:1
Broiler chicken manure (BCM)	36.66	410	22.46:1

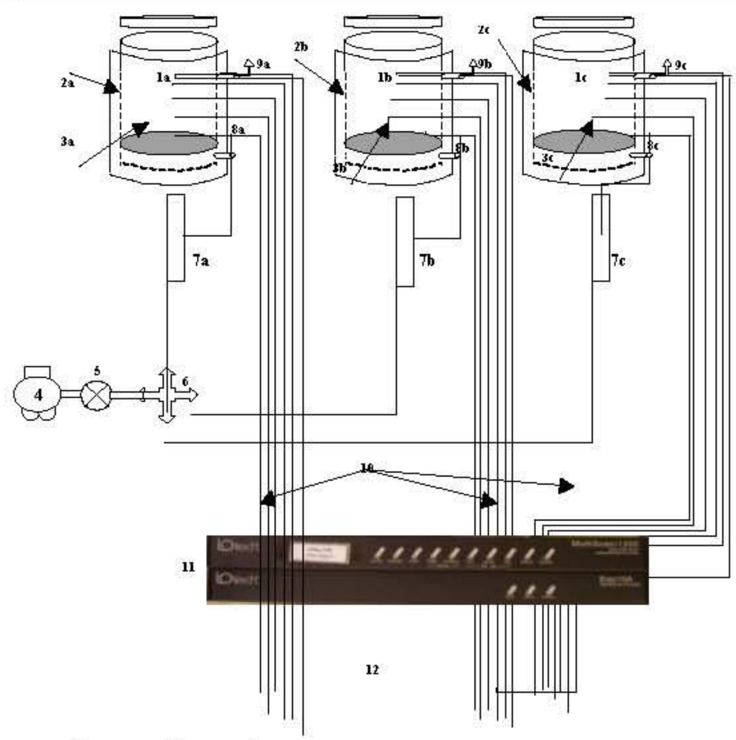

Fig. 1: Schematic diagram of composting system

1a-c. Bioreactor	4. Compressor	7a-c. Air flow meters	10. Thermocouples
2a-c. Insulator	5. Air pressure regulator	8a-c. Input air	11. Multiscan 1200
3a-c. Perforated plate	6. Air distributor	9a-c.Exhaust air	12. Computer

Laboratory Composting System: A static composting system was designed at the Educational Farm, Agricultural Engineering Department, College of Food and Agriculture Sciences, King Saud Uiversity, Riyadh City, Saudi Arabia. As shown in Fig. 1, the system consisted of three bioreactors, ventilation it and a temperature measurement unit. The bioreactor used is cylindrical (55-L) and made of thermoresistant material (galvanized iron) with a perforated plate at the bottom to distribute the air supplied from the outside. The total volume of the bioreactor is 0.03m^3. The bioreactor was surrounded with insulator (rock wool) (2cm) to maintain minimum heat loss from the wall of the reactor. Air from a compressor was used for aeration. A constant airflow was continuously supplied at a rate of 10 L/min to the bottom of each bioreactor. Six thermocouples (type T) were placed at the bottom, center and upper parts of the bioreactor for temperature measurements. The thermocouples were connected to the data acquisition unit (Multiscan 1200) and then to computer.

Composting Method: Four mixtures were prepared by using 4 ratios (v/v) of 2:3, 1:1, 3:2 and 7:3 (DPR:BCM). The C/N ratios were 25.0, 26.0, 27.5 and 30.0 for mixture 1, 2, 3 and 4, respectively. The moisture content of the mixture was adjusted to 60% at the start of the experiment and was not controlled during the reaction. After adjusting the moisture content, the mixture was transferred to the bioreactor. Three replicates were used for each mixture. Thermocouples were connected inside the mixture to measure the temperature and the air was interred the bioreactor as mentioned above. During the composting process, some physical and chemical parameters were monitored such as the changes in temperature, odour, colour, moisture content, ash content, organic matter, organic carbon, total nitrogen and C/N ratio.

Sampling: Three samples (10 gram each) were taken at random from different locations of the bioreactor. Sampling was done every 24 hrs.

Physical Analysis: Temperature was monitored by insert six thermocouples (type T) inside the compost mixture in each bioreactor at different locations and connected to the data acquisition unit (Multiscan 1200) and then to the computer. It was recorded every 1 hr during the composting process. The ambient temperature was monitored also during the period of experiment. The colour was assessed visually, while the odour was sensed by smelling [25].

Chemical Analysis: Moisture content was determined after drying the compost samples at 105°C for 24 hrs. Ash (X) was determined in the dried samples after ashing at 550°C in a muffle furnace for about 3hrs [26]. Organic matter (OM) and organic carbon (OC) were estimated as follows: OM (%) = 100- X (%), OC (%) = OM (%)/1.8 as mentioned by several investigators [26-29]. Total nitrogen was determined by the Kjeldahl method, while the C/N ratio was calculated using values of the organic carbon and the Kjeldahl total nitrogen [26]. The loss of organic matter (OM) was calculated according to the following equations [30]:

$$\text{OM- loss } (\%) = 100\text{-}100\ [(X_1 OM_2)/\ (X_2 OM_1)]$$

Where:
X_1 and X_2 are the initial and final ash concentrations and OM_1 and OM_2 are the initial and final OM concentrations. The loss of moisture content (MC) was calculated according to the following equation [31]:

$$\text{MC-loss } (\%)=100\ [1\text{-}\ \{100\text{-}OM_{\%}^{0}/100\text{-}OM_{\%}^{t}\} \times \{MC_{\%}^{t}/MC_{\%}^{0}\} \times \{100\text{-}MC_{\%}^{0}/100\text{-}MC_{\%}^{t}\}$$

Where:
$OM_{\%}^{0}$ and $OM_{\%}^{t}$ are the initial and final OM concentrations and $MC_{\%}^{0}$ and $MC_{\%}^{t}$ are the initial and final MC concentrations.

Statistical Analysis: One-way analysis of variance (ANOVA) was used to compare mean values from different samples. Where significant differences were obtained, individual means were tested using the Least Significance Difference test ($P < 0.05$). The relationship between the measured parameter with time was evaluated by using Pearson correlation analysis providing a correlation coefficient (‘‘*r*’’), where positive and negative *r* values denoted positive and negative correlations, respectively.

RESULTS AND DISCUSSION

Changes in Temperature: Temperature is an important factor in composting efficiency, due to its influence on the activity and diversity of microorganisms [32].

Changes in temperature that occurred during the composting process are shown in Fig. 2. The outside temperature was about 30 ± 3°C in the day and 20 ± 3°C in the night. At the beginning, the temperature was 27.70, 31.34, 28.87 and 27.23°C in case of mixture 1, 2, 3 and 4, respectively. The temperature increased and reached to

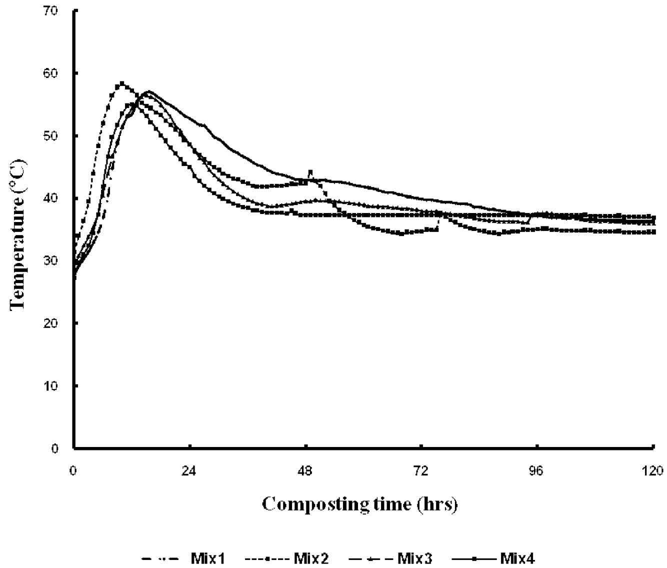

Fig. 2: Changes in temperature (°C) during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

40°C (the end of mesophilic stage) after 7, 4, 6 and 6 hrs and to 50°C after 11, 6, 10 and 9 hrs in case of mixture 1, 2, 3 and 4, respectively. The maximum values (56.96, 58.15, 56.38 and 54.96°C) were found after 15, 10, 15 and 12 hrs in case of mixture 1, 2, 3 and 4, respectively. Then, the temperature gradually decreased and reached to 36.30, 34.45, 35.96 and 36.92°C by the end of the composting period (120 hrs) in case of mixture 1, 2, 3 and 4, respectively. The obtained results revealed that a negative correlation was fod between temperature and composting time. This type of correlation indicated that the temperature moderately was decreased by the end of composting. Generally, the increase in temperature may be attributed to the suitability of composting conditions (C/N ratio, moisture content, aeration, particle size) for microbial and enzymatic activities and therefore, the increase in decomposition of wastes. On the other hand, the decrease in temperature after that may be attributed to the decrease of microbial and enzymatic activities because of the decrease of organic matter and this is indication for the maturity of compost. It was mentioned that, once the more easily degradable materials have decomposed the compost temperature fails to that of the environment temperature and the process is stabilized [33]. Generally, it is noticed that the temperature remained above 40°C for several hrs, which is suitable with the other parameters for microbial populations and enzymatic activities and therefore the increase of organic matter decomposition.

However, the further expansion of composting will depend on better control of the process, assuring compost quality and minimizing environmental impact. The control of the process relates especially to regulating aeration to meet oxygen requirements (which are closely linked to organic matter biodegradability and biodegradation kinetics) [34]. Aeration is important in composting for providing the oxygen needed to support aerobic microorganisms, for controlling the temperature and for removing water vapour, CO_2 and other gases [35-37]. The overall goal of the aeration is to maintain compost temperature in the range of 50-55°C to obtain efficient thermophilic decomposition of organic wastes [38-39].

It is generally agreed that the temperature of the composting process should not exceed 60°C to avoid thermal inactivation of the desired microbial community necessary for the efficient degradation of organic wastes [40]. Thus, precise temperature control is necessary to provide pathogenic reduction,while maintaining a healthy commity of composting microbes [41]. It was inferred that the course of temperature in a compost plant is indicative of the progress of the composting process from the beginning to its completion [42]. Compost is mature enough when the temperature remains more or less constant and does not vary with the turning of the material [43-44]. Therefore, this parameter is considered as a good indicator for the end of the biooxidative phase in which the compost achieves some degree of maturity [45].

By evaluating the performance of composting system through the method of quantitative assessment for the curve of temperature with time as mentioned by Mason and Milke [46], it is noticed that: a- the temperature reached to 40°C (lower thermophilic limit) in case of

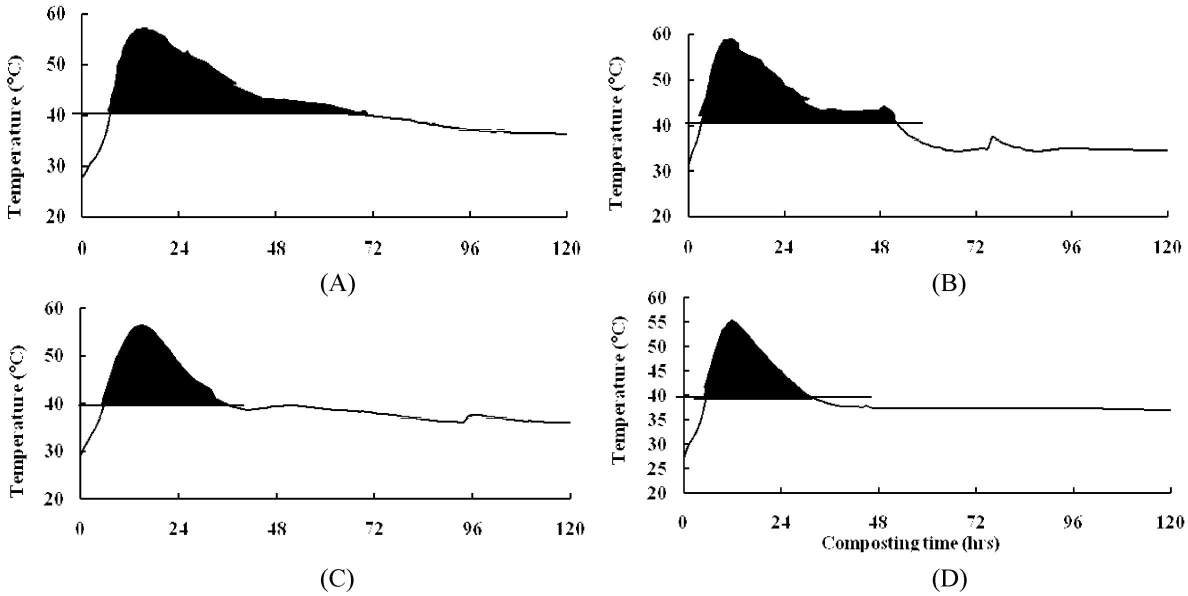

Fig. 3: The area of thermophilic stage under the temperature curve during the composting of date palm residues (DPR) with broiler chicken manure (BCM) different mixtures. A: Mixture 1, B: Mixture 2, C: Mixture 3, D: Mixture 4

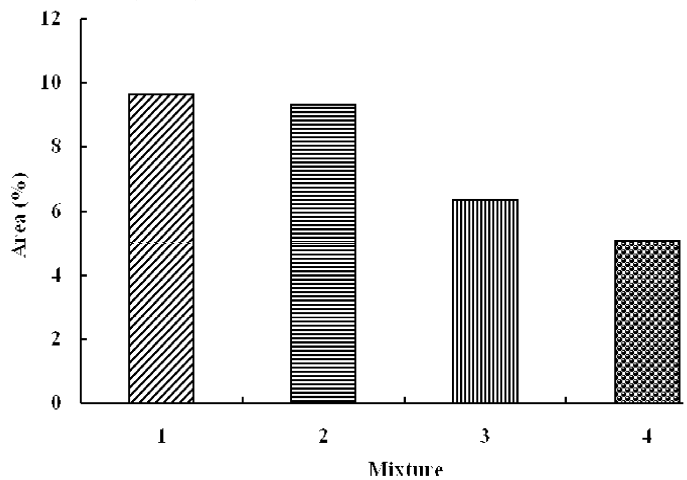

Fig. 4: The area (%) under of thermophilic stage curve during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

mixture 2 faster than in case of the other mixtures, b- the temperature reached to 55°C (typical lower disinfection limit) also in case of mixture 2 faster than the other mixtures, where it was after 10 hrs (mixure 2), 12 hrs (mixture 4) and 15 hrs (mixture 1 and 3), c- the highest temperature (58.15°C) was found also in mixture 2 and after time lower than that found for the other mixtures, d- the area of thermophilic stage under the curve of temperature (which was calculated by using "ArchiCAD 11" program) was the bigger in case of mixture 1 and followed by mixture 2,3 and 4, respectively (Figs. 3 and 4). In spite of the area of thermophilic stage in case of mixture 1 was bigger than that foundd with mixture 2, no significant difference was found. In addition to that, mixture 2 contained date wastes (50%) more than mixture 1 and this is the main objective in this study to treat it. Therefore, the mixture 2 is considered to be the best mixture for composting of date palm residues and this could be attributed to the suitability of C/N ratio (26:1) for decomposition.

Changes in Odour: Odour was recorded during the composting processes. It was found that the pleasant odour of composting materials decreased with time.

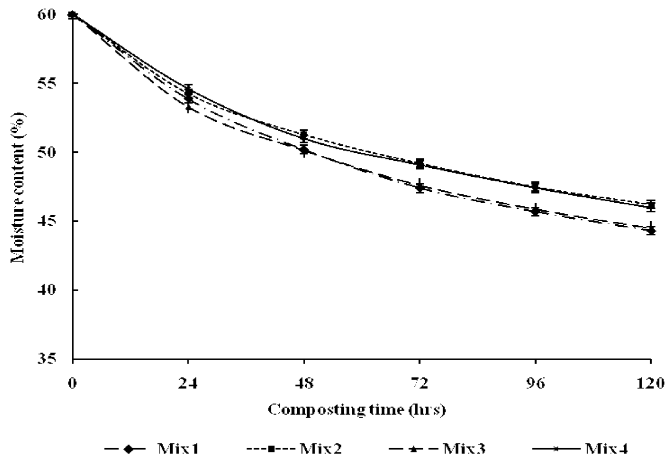

Fig. 5: Changes in moisture content (%) during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

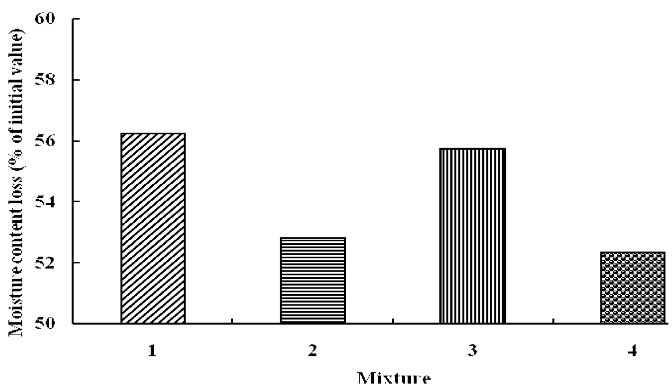

Fig. 6: Moisture content loss (%) during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

The obtained observations are in agreement with those reported by Haug [47] who mentioned that the odour emission rate dropped significantly during the first stage and then fluctuated somewhat during the remaining of the composting period. It was stated that the final material of composting should be odourless or have a slightly earthy odour or the musty odour of moulds and fungi [43,48]. The disappearing of the smell coincided with the onset of dark colour of the waste and the levelling off the temperature [49].

Changes in Colour: During the composting process, a gradual change in colour from black to brownish black took place and this gave indication of the maturity progress. The obtained results are in agreement with other studies which mentioned that the matured compost should be greyish-black or brownish-black in colour, depending on whether tannins, melanin or other materials containing brown pigments were originally present [43,50].

Changes in Moisture Content: Moisture content is a critical parameter in the composting process. It influences the microbial activity, free air space, oxygen transfer and temperature of the process [14,51,52]. Biological activity can be greatly reduced at a moisture content of less than 30% [35]. Below moisture contents of 40%, organic matter will not decompose rapidly. On the other hand, above 60%, the compost tends to become anaerobic, causing it to emit foul odours [36]. Numerous investigators mentioned that, the optimal moisture levels are usually between 40 and 60% [53-55]. For these reasons, moisture content of all mixtures was adjusted to 60% at the beginning of the experiment.

During the composting period, a gradual decrease in moisture content was found (Fig. 5). It decreased from 60% to 44.3, 46.2, 44.5 and 46.0% at the end of composting in case of mixture 1, 2, 3 and 4, respectively. The results revealed that a negative correlation was fod between moisture content and composting time as indication of the loss of moisture. The moisture content loss was 56.24,

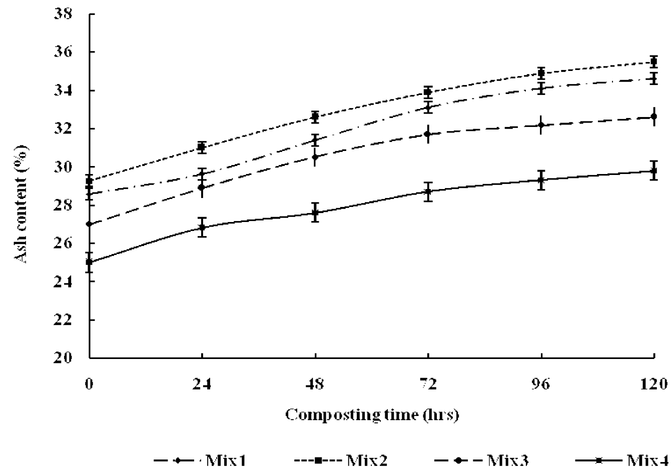

Fig. 7: Changes in ash content (%) during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

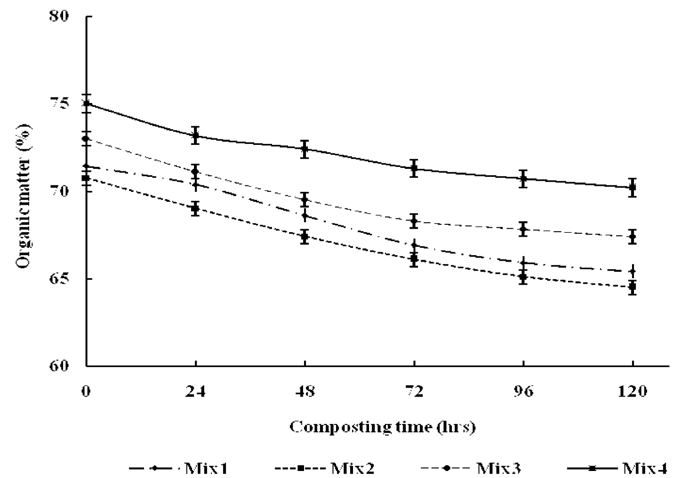

Fig. 8: Changes in organic matter (%) during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

52.81, 55.73 and 52.34% in case of mixture 1, 2, 3 and 4, respectively (Fig. 6). As mentioned by Polprasert [56], by increasing the temperature, the microbial populations and their enzymatic activities increase and then the loss in moisture occurs. Generally, the decrease in moisture content was less than 40% in all mixtures. Therefore, the moisture content was between 40- 60% during the composting period and this range is suitable for microbial populations and their enzymatic activities as mentioned above.

Changes in Ash Content: Changes in ash content are shown in Fig.7. The results showed that ash content was increased gradually by time. It increased from 28.56, 29.26, 27.00 and 25.00% to 34.60, 35.50, 32.60 and 29.80% by the end of composting in case of mixture 1, 2, 3 and 4, respectively. It is noticed that the increase in ash content was higher in case of mixture 2 than the others. The increase in ash content is mainly attributed to the decrease in organic matter (OM) content as expected. Several reports pointed that useful indices of rate and extent of decomposition include the concomitant increase in ash as the OM content decreases. Since the original ash content of a material remains changed even though mass is lost through oxidation of some organic constituents of the material, increase in ash content is thus proportional to extent of decomposition [41,42,57].

Changes in Organic Matter: Changes in organic matter (OM) are shown in Fig. 8. The obtained results showed that OM was decreased gradually by time. It decreased from 71.44, 70.74, 73.00 and 75.00% to 65.40, 64.50, 67.40 and 70.20% by the end of composting in case of mixture 1, 2, 3 and 4, respectively. It is noticed that the decrease

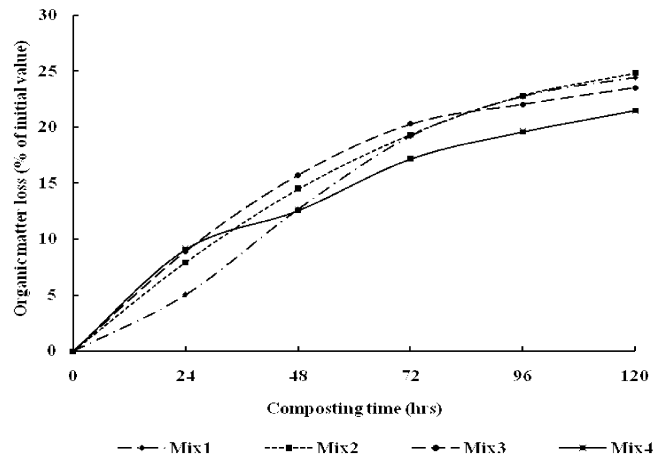

Fig. 9: Organic matter loss (%) during the composting of date palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

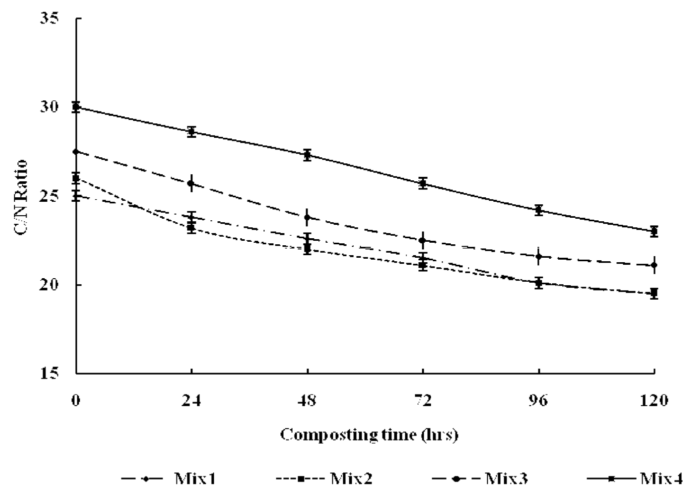

Fig. 10: Changes in C/N ratio during the composting of palm residues (DPR) with broiler chicken manure (BCM) for different mixtures

in OM was higher in case of mixture 2 than the other mixtures and this could be attributed to the content of this mixture, especially C/N ratio (26:1) is suitable for microbial populations and their enzymatic activities. The results revealed that at the beginning of composting, there is no significant difference between the mixtures 1 and 2 and between the mixtures 1 and 3, while there is significant difference between the mixtures 2 and 3 and between the mixture 4 and the other mixtures. At the end of composting, there is no significant difference between the mixtures 1 and 2, while there is significant difference between the mixture 4 and the other mixtures. The results revealed also that a negative correlation was found between OM and composting time. This type of correlation indicates that the OM decreased with time as the compost reached to the maturity.

OM loss (%) is shown in Fig. 9. By the end of composting, this loss reached to 24.44, 24.85, 23.53 and 21.48% from the starting value in case of mixture 1, 2, 3 and 4, respectively. The obtained results showed that the loss in OM was higher in case of mixture 2 than the others. The OM degradation was revealed by the OM loss, which is directly related to microbial respiration as mentioned by Paredes *et al*. [58]. Generally, the loss in OM was less than that found by Inbar *et al*. [59] who mentioned that about 50% of OM is metabolized to CO_2 and H_2O during the composting process of separated cattle manure. On the other hand, the low OM-loss was in agreement with those reported in other composting processes [60] and reflects the resistance of this material to degradation. It was reported that decomposition of OM to usable compost depends on the abilities of the microflora to produce and excrete specific degradative enzymes. Obviously, some substrates in natural materials such as sugar, starch, protein and lipids are more easily degraded and utilized than materials such as cellulose, lignin and other long chain polysaccharides [36,61].

From an engineering point of view, kinetics is one of the important factors for scaling up reactor to a larger unit [62]. The composting of most substrates is characterized by an initial period of rapid degradation followed by a longer period of slow degradation [63]. From Fig. 9, it can be seen that organic matter is found to be lost in the compost. The OM degradation profile during composting, as determined by OM loss, follows a first-order kinetic equation and this is in agreement with that found with García-Gómez *et al.* [24], Paredes *et al.* [58], Zahrim *et al.* [64] and Serramiá *et al.* [65].

Changes in C/N Ratio: The C/N ratio is often used as an index of compost maturity, despite many pitfalls associated with this approach [59], but it seems to be a reliable parameter for following the development of the composting process [59,66]. Raw materials blended to provide a C/N ratio of 25:1 to 30:1 are ideal for active composting [67,68].

Changes in C/N ratio during the composting process are shown in Fig.10. The obtained results showed that C/N ratio was decreased gradually by time. It decreased from 25.0, 26.0, 27.5 and 30.0 to 19.8, 19.5, 21.1 and 23.0 by the end of composting in case of mixture 1, 2, 3 and 4, respectively. The results revealed also that a negative correlation was found between C/N ratios and composting time. This type of correlation indicated that the C/N ratio was decreased with time as the compost turns to the maturity. The results also revealed that at the beginning of composting, there is no significant difference between the mixtures 1 and 2, while there is significant difference between the mixtures 3 and 4 and between these mixtures and the mixtures 1 and 2. At the end of composting, there is no significant difference between the mixtures 1, 2 and 3, while there is significant difference between the mixture 4 and the other mixtures, where the lower decrease in C/N ratio was found in mixture 4.

As the decomposition progressed due to losses of carbon mainly as carbon dioxide, the carbon content of the compostable material decreased with time and N content per unit material increased, which resulted in the decrease of C/N ratio. It was mentioned that the loss in carbon as carbon dioxide during the composting process is more than the loss in nitrogen [69]. Generally, the decrease in C/N ratio with time indicated that the conditions such as moisture content, aeration and temperature are suitable for microbial populations and their enzymatic activities and therefore the increase of organic matter decomposition.

It has been stated that the C/N ratio of mature compost should ideally be about 10 but this is hardly ever achievable, due to the presence of recalcitrant organic compounds, or materials which resist decomposition due to their physical or chemical properties [70]. Other studies reported that a C/N ratio below 20 is indicative of an acceptable maturity [36,71], a ratio of 15 or even less being preferable [45]. The decrease in C/N ratio can be taken as a reliable index of compost maturity when combined with other parameters as mentioned by Goyal *et al.* [72]. Generally, the obtained compost during this study was good according to the decrease in C/N ratio and the decrease in temperature at the end of composting, especially in case of mixture 2.

CONCLUSION

It can be concluded that the adjustment of composting conditions such as aeration, moisture content and temperature is very important. This would allow for microbial populations and their enzymatic activities to increase and therefore the increase of organic matter decomposition as a reduction in C/N ratio and then the composting time can be reduced. The OM degradation profile as determined by the OM loss followed a first-order kinetic equation. Thus, composting can be a suitable method for converting date palm residues into compost that can be used as a fertilizer and soil conditioner.

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