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Physical, Chemical and Microbial Changes during the Composting of *Conocarpus erectus* Residues

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Changes in physical, chemical and microbial parameters were monitored during the composting of *Conocarpus erectus* residues using a bioreactor. The residues (leaves and small stems) were collected, cut into small pieces and mixed. The C/N ratio of the mixture was 25.22. The moisture content was adjusted to 65% at the start of the experiment.The total volume of the bioreactor was 0.03 m^3. Airflow was supplied at a rate of 10 L/min. The results showed that the temperature increased and reached its maximum (54°C) after 36 hrs and then decreased to 26°C. The final compost was odourless and black. The pH decreased from 6.50 to 6.35 after 3 days and then increased to 6.83. The electrical conductivity increased with time from 1.77 to 2.09 mS/cm. The organic matter decreased from 83.93 to 75.85% and the loss reached to 39.86% and followed the first-order kinetic equation. The C/N ratio decreased from 25.22 to 18.48. The mesophilic bacteria and fungi decreased after 3 days and then increased, whereas the thermophilic ones increased after 3 days and then decreased. It can be concluded that composting can be a suitable method for converting *Conocarpus erectus*residues into compost if the optimum conditions are performed.

Key words: Composting; *Conocarpus erectus* residues; Evaluation parameters.

Production of organic wastes is increasing while soils are progressively losing organic matter due to intensive cultivation and climatic conditions (Massiani and Domeizel, 1996). 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 (Hassen *et al*., 1998). Many alternatives for the disposal of organic wastes have been proposed, composting being one of the most attractive on account of its low environmental impact and cost (Bustamante *et al.*, 2008; Canet *et al.*, 2008; Lu *et al.*, 2008), as well as its capacity for generating a valuable product used for increasing soil fertility (Weber *et al.*, 2007) or as a growing medium in horticulture (Pérez-Murcia *et al.*, 2005).

Composting is an aerobic process by which organic materials are degraded through the activities of successive groups of microorganisms; it is an environmentally sound way to reduce organic wastes and produce organic fertilizer or soil conditioner (Gajdos, 1992). Composting is an

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organic waste treatment technology having the capacity to transform organic wastes into well-stabilized product that can beneficial to agriculture (Jindo *et al.*, 2012a). During composting, organic matter is transformed into a humus-rich product by the action of microorganisms and their enzymes (Vargas-Garcia *et al.*, 2010). Microbes and their secreted enzymes play a key role in biological and biochemical transformations of compost matrixes in the composting process (Guo *et al.*, 2012).

Composting as a successful strategy for the sustainable recycling of organic wastes relies mainly on the quality of the end products (Mondini *et al.*, 2004). Generally, most studies in composting have focused on physico-chemical parameters to evaluate both process evolution and compost quality (Said-Pullicino *et al.*, 2007; Albrecht *et al.*, 2008). Microbiological and biochemical parameters have also recently arisen as good indicators for the characterization of the composting process (Raut *et al.*, 2008; Vargas-Garcia *et al.*, 2010; Liu *et al.*, 2011).

Conocarpus erectus L. tree is widely spread in Taif governorate and other parts of the Kingdom of Saudi Arabia (Abdel-Hameed *et al.*, 2012). Generally, *C. erectus* residues as agricultural wastes are very rarely utilized and consider as a source of environmental pollution. The utilization of these wastes in the production of compost is very important from the environmental and agricultural point of view. Therefore, the aim of this study was to monitor of physical, chemical and microbial changes during the composting of *C. erectus* L. trees residues using a static system.

MATERIALS AND METHODS

Materials

Conocarpus erectus L. trees residues (leaves and small stems) were collected from the streets of Riyadh City, Saudi Arabia) and cut into small pieces.

Composting System

A static composting system was designed at the Educational Farm, Agricultural Engineering Department, College of Food and Agriculture Sciences, King Saud University, Riyadh City, Saudi Arabia. As shown in Figure 1, the system consisted of two bioreactors, ventilation unit 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 0.03 m^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. The airflow was supplied (12 hrs a day) at a rate of 10 L/min to the bottom of each bioreactor (0.2 L/min/kg) for 5 min period intervals. Three thermocouples (type T) were placed near the center of the bioreactor for temperature measurements. The thermocouples were connected to the data acquisition unit (Multiscan 1200) and then to computer.

Composting Method

Moisture content of the mixture was adjusted to 65% at the start of the experiment and was not controlled during the reaction. After adjusting the moisture content, the mixture was transferred to the bioreactors. Two bioreactors were used for composting. The reactors were filled up to 80% of total volume. Thermocouples were connected inside the mixture to measure the temperature and the air was interred the bioreactor as mentioned above for 9 days. Afterwards, the compost from the two bioreactors was pooled and transferred to a container for maturation (6 days) and the aerobic conditions were maintained by opening a small part in the door of container. During the composting process, some physical, chemical and microbial parameters were monitored.

Sampling

Three samples (10.0 g each) were taken at random from different locations of the bioreactor. Composite samples were transferred aseptically in closed bags under cooling to the laboratory for analyses. Sampling was done every 3 days.

Analytical Methods

Physical analysis

Temperature was monitored by insert three thermocouples (type T) inside the compost mixture in each bioreactor at different locations (near the center) and connected to the data acquisition unit (Multiscan 1200) and then to the computer. It was recorded every 12 hrs for 9 days during the composting process, whereas during the maturation period, it was recorded every 3 days. The ambient temperature was monitored also during the period of experiment.The colour was assessed by visual observation, while the odour was through olfactory judgement (Khalil, 1996; Pan and Sen, 2013).

Chemical analysis

Fresh samples were used to determine moisture content, pH and electrical conductivity (EC), whereas, for the other chemical analyses, samples were oven-dried at 65°C for 24 hrs and then ground using the cyclotec mill. The ground samples were stored in dry, airtight containers until use. Moisture content was determined after drying the samples at 105°C for 24 hrs (Cabañas-Vargas *et al.*, 2005; Huang *et al.*, 2010; Madan *et al.*, 2012). The pH was determined by shaking 5.0 g sample in 50.0 ml distilled water (1:10, w/v) for 30 min, then the pH was measured in the suspension using pH meter (Taiwo and Oso, 2004; Cabañas-Vargas *et al.*, 2005; Moldes *et al.*, 2007). EC was determined by shaking 5.0 g sample in 50.0 ml distilled water (1:10, w/v) for 30 min. Filtrate of the mixture after passing through Whatman filter paper 42 was used to measure the EC using a conductivity meter (Petric and Selimbaši, 2008; Madan*et al.*, 2012). The ash content (X) was determined after drying the sample at 105°C for 24 hrs and ashing at 550°C in a muffle furnace for 5 hrs (WHO, 1978; Wu *et al.*, 2000; Cabañas-Vargas *et al.*, 2005; Jindo *et al.*, 2012a). Organic matter (OM) and organic carbon (OC) were estimated as follows: OM (%) = 100- X (%), OC (%) = OM (%)/1.8 as mentioned by several investigators (WHO, 1978; Faure and Deschamps, 1990; Abdullah and Chin, 2010). Total nitrogen (N) was determined by an automatic C/N/S elemental analyzer (Jindo *et al.*, 2012a,b; Tian *et al.*, 2012), while the C/N ratio was calculated using values of the organic carbon and the total nitrogen (WHO, 1978). The loss of organic matter (OM) was calculated according to the following equation (Paredes *et al.*, 2000):

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

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.

Microbiological analysis

Quantitative estimation of different culturable aerobic microorganisms was conducted during the composting process by inoculating the appropriate media with 0.1 ml volumes of different tenfold serial dilutions. Bacteria and fungi, both mesophilic and thermophilic, were isolated from the compost samples as described by Nakasaki *et al.* (1992). Nutrient agar (NA) and potato dextrose agar (PDA) media were used for bacteria and fungi, respectively. Incubation temperature was 30°C for isolation of mesophiles and 50°C for thermophiles. The incubation time was 3 days for mesophilic and thermophilic and 5 days for mesophilic and thermophilic fungi. All microbial counts were calculated on the wet weight basis. The average number of microorganisms isolated on three plates was expressed as colony-forming units (CFU) per wet weight of compost.

Statistical analysis

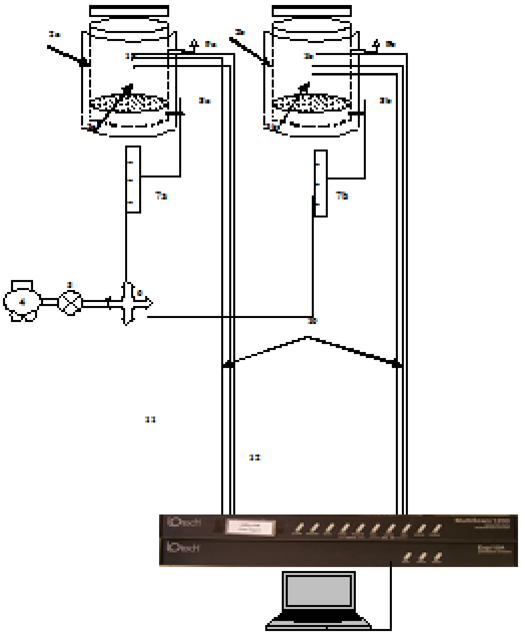
One-way analysis of variance (ANOVA) was used to compare mean values from different samples. Where significant differences were obtained, individual means were tested using the Least Significance Difference test ($P< 0.05$).

RESULTS AND DISCUSSION

Physical Changes

Temperature

The temperature is one of the main parameters to evaluate the composting process, since its value determines the rate at which many of biological reactions take place as well as the sanitation capacity of the process (Bustamante *et al.*, 2008). In the present study, the changes in temperature are shown in Fig 2. The temperature began to rise soon after the establishment of composting conditions and reached its maximum (54°C) after 36 hrs and then decreased gradually and reached to 26°C by the end of composting. Generally, the increase in temperature may be attributed to the abundant and active indigenous microorganisms in the raw composting materials and to the suitability of composting conditions (aeration, C/N ratio, particle size and moisture content) for microbial and enzymatic activities. On the other hand, the decrease in temperature after that may be attributed to the decrease of microbial and enzymatic activities due to most of the easily degradable organic matter had been metabolized. 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 (Nogueira *et al.*, 1999). The changes in temperature followed a pattern similar for many composting processes as described by several authors (Poincelot, 1974; Inbar *et al.*, 1993; Khalil *et al.*, 2001, Alkoaik *et al.*, 2011).



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

Fig. 1. Schematic diagram of composting system

Generally, the composting process has four overlapped stages. These are mesophilic, thermophilic, cooling down and maturation (Gray *et al.*, 1971a; Poincelot, 1974; Fogarty and Tuovinen, 1991). The four typical phases of composting were observed during the process: (i) a short initial mesophilic phase (T <40^{o}C) (approx. 15 hrs), (ii) a thermophilic phase (T > 40^{o}C) (approx. 25 hrs), (iii) cooling down (7 days) and (iiii) maturation phase (6 days). It is noticed that the temperature remained in the range of 40-54^{o}C (for about 80 hrs) which is suitable with the other parameters such as aeration and moisture content for microbial and enzymatic activities and therefore the increase of organic matter degradation. It is mentioned that reaching the peak temperature is very important because the peak temperature of 50-60^{o}Ccauses further degradation of organic matter and destruction of all pathogens (Ko *et al.*, 2008). It is generally agreed that the temperature of the composting process should not exceed 60^{o}C to avoid thermal inactivation of the desired microbial community necessary for the efficient degradation of organic wastes (Fogarty and Tuovinen, 1991). Thus, precise temperature control is necessary to provide pathogenic reduction while maintaining a healthy community of composting microbes (Mckinley *et al.*, 1985). The further expansion will depend on control of the composting process, assuring compost quality and minimizing

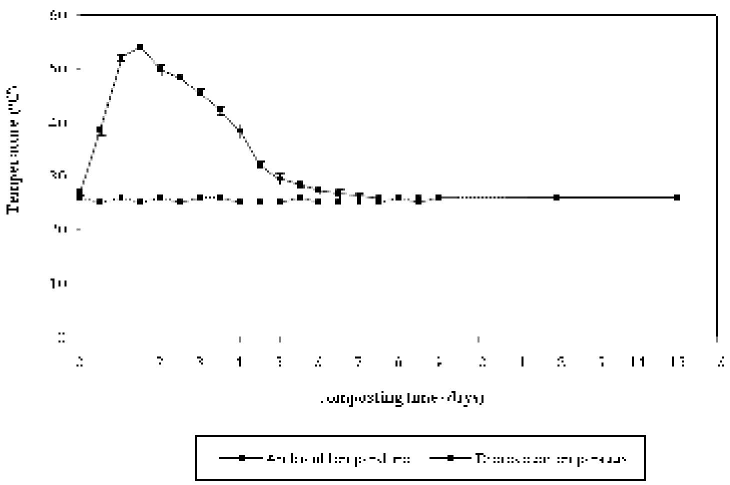


Fig. 2. Changes in temperature (^{o}C) during the composting of *Conocarpus erectus* residues. Values are means of 6 replicates ± standard deviations

environmental impact. The control of the composting process relates especially to regulating aeration to meet oxygen requirements (de Guardia *et al.*, 2008). Aeration in composting is important for providing the oxygen needed to support aerobic microorganisms, for controlling the temperature, and for removing water vapour, CO_2 and other gases (Gray *et al.*, 1971b; Poincelot, 1974; Haug, 1986). The overall goal of the aeration is to maintain temperature of compost in the range of 50-55°C to obtain efficient thermophilic decomposition of organic wastes and destruction of pathogens (Jeris and Regan, 1973; Mckinley and Vestal, 1984; Raut *et al.*, 2008). Temperature of the end product was very low (as the ambient temperature) and this could be attributed to the completion of compost maturity. Compost is mature enough when the temperature remains more or less constant and does not vary with the turning of the material (Gotaas, 1956; Harada *et al.*, 1981). Consequently, as mentioned by Jiménez and Garcia (1989), temperature may be considered a good indicator of the end of the biooxidative phase in which the compost achieves some degree of maturity.

Odour

Odour of the compost is often used as a measure of maturity and stability by experienced composting operator. Generally, the presence of unpleasant odour suggests further potential degradability of the composting materials (Zhiyi, 2004). The odour was observed during the composting process. The unpleasant odour decreased with time. By the end of composting, the compost was nearly odourless or earthy odour. The obtained observations are in agreement with those reported by Gotass (1956) and Alexander (1990) who stated that the final compost should be odourless or have a slightly earthy odour or the musty odour of moulds and fungi.

Colour

Colour has been described as another physical parameter to assess the compost maturity and stability (Inbar *et al.*, 1990; Jiménez and Garcia, 1989). Colour is a quick measurement and requires little skill and no sophisticated equipment (Zhiyi, 2004). It is generally suggested that as the compost stabilizes it darkens to a dark brown or black colour (Haug, 1993). During the composting process, a gradual darkening of the material took place and this gave indication of the maturity progress. The final compost was dark-brown or greyish-black. The obtained results are in agreement with those

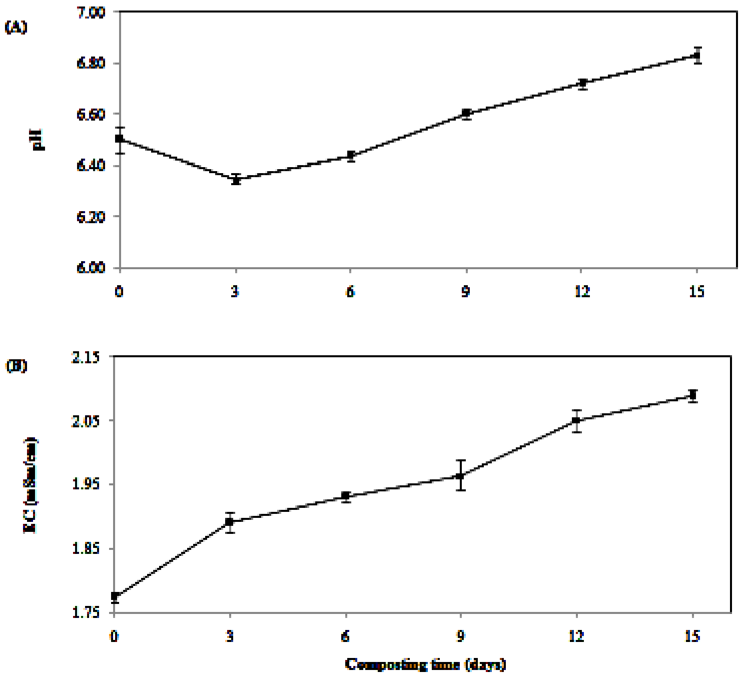


Fig. 3. Changes in pH (**A**) and EC (**B**) during the composting of *Conocarpus erectus* residues. Values are means of 3 replicates ± standard deviations

reported by Gotaas (1956) and Diaz *et al*. (1993) who mentioned that the matured compost should be greyish-black or brownish-black in colour. Jiménez and Garcia (1989) stated also that the final compost should have a dark brown or almost black colour.

Chemical Changes

pH

The pH value of compost is looked as an indicator of decomposition and stabilization (Zhiyi, 2004).The changes in pH value during the composting process are shown in Figure 3a. The starting pH value was 6.50. After 3 days of composting, the pH decreased to 6.35 and then gradually increased and reached the maximum value (6.83) by the end of composting. It is noticed that the pH was near the neutrality during the composting process. Generally, the pattern of pH during the composting process was similar to that described by several authors (Chang and Hudson, 1967; Poincelot, 1974; Inbar*et al.*, 1993). It was reported that the decrease in pH during the first period is expected because of the acids formed during the metabolism of readily available carbohydrates. After that, the pH is expected to rise, with evolution of free ammonia and to stabilize or drop slightly again to near neutral as a result of humus formation with its pH-buffering capacity at the end of composting (Poincelot, 1974; Fogarty and Tuovinen, 1991). Moreover, acceptable pH ranges should be within tolerable levels to microorganisms (GÌmez-BrandÌn*et al.*, 2008).It was also mentioned that the optimal pH values for composting range from pH 5.5 to 8.0. Bacteria favour a near-neutral pH, whereas fungi favour an acidic range. The effects of extreme pH on the

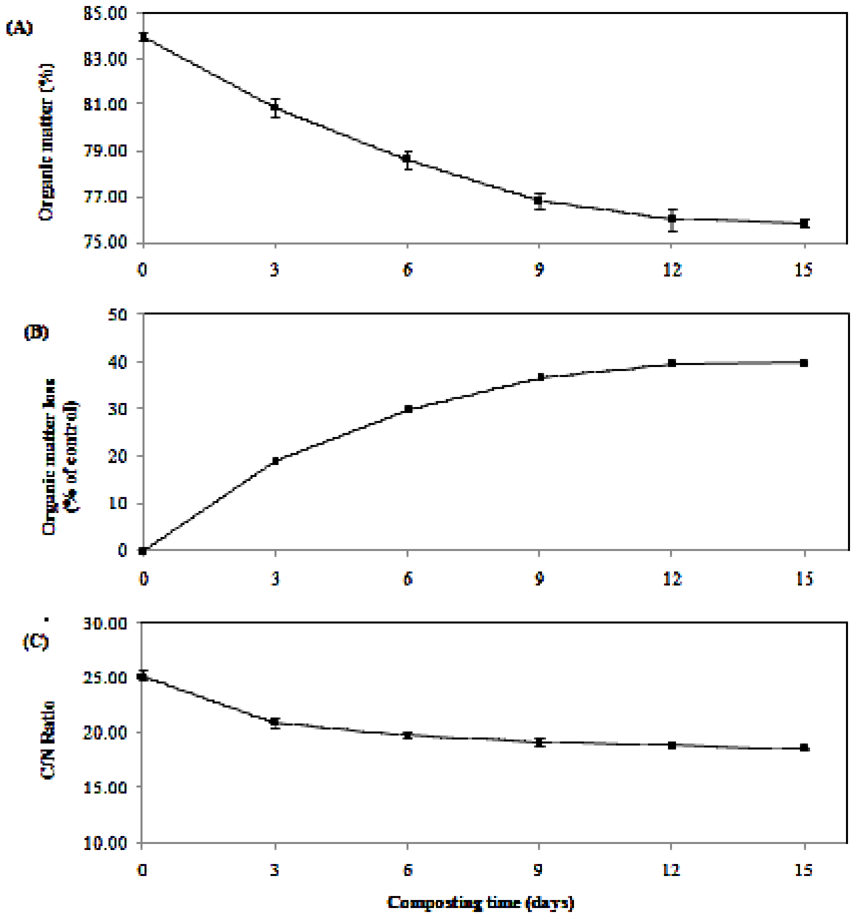


Fig. 4. Changes in organic matter (%)* **(A)**, organic matter loss (%) **(B)** and C/N ratio* **(C)** during the composting of *Conocarpus erectus* residues. *Values are means of 3 replicates ± standard deviations

composting process are directly related to the effect of pH on microbial activity or, more specifically, on microbial enzymes (Fogarty and Tuovinen, 1991)

Electric conductivity (EC)

Electric conductivity (EC), an indirect measurement of the soluble salts of a sample, is used as chemical indicator of the composting status (Pan and Sen, 2013). EC is the measure of a solutions ability to carry electrical charge, that is, a measure of the soluble salt content of compost. The salt content of compost is due to the presence of sodium, chloride, potassium, nitrate, sulphate and ammonia salts (Brinton, 2003). The EC value reflected the degree of salinity in the compost, indicating its possible phytotoxic/phyto-inhibitory effects on the growth of plant if applied to soil (Petric and Selimbaši, 2008). Salinity in composts can vary with the sources of compost and can reach electrical conductivities of about 10 mS/cm (Barker, 1997).The changes in EC value during the composting process are shown in Figure 3b. It increased with time from 1.77 to 2.09 mS/cm. Such an increase may be due to the increase in salt concentration and to the mineralization of organic matter as mentioned by Michel and Reddy (1998) and GÌmez-BrandÌn*et al.* (2008). Generally, the obtained results are in agreement with those reported by many investigators (GÌmez-Brando *et al.*, 2008; Petric and Selimbašic, 2008; Khan *et al.*, 2009;Shyamala and Belagali, 2012; Pan and Sen, 2013). It is noticed that the obtained values were lower than those found in the other studies (3.5-4.31 mS/cm (Petric and Selimbašic, 2008); 3.8-8.4 mS/cm (Khan *et al.*, 2009; 2.4-7.7mS/cm (Shyamala and Belagali, 2012)). This finding gives a benefit to the obtained compost for growth of plant if applied to soil.

Organic matter (OM)

Organic matter is mineralized after composting, mostly due to degradation of easily degradable compounds, which are utilized by microorganisms as carbon and nitrogen sources.

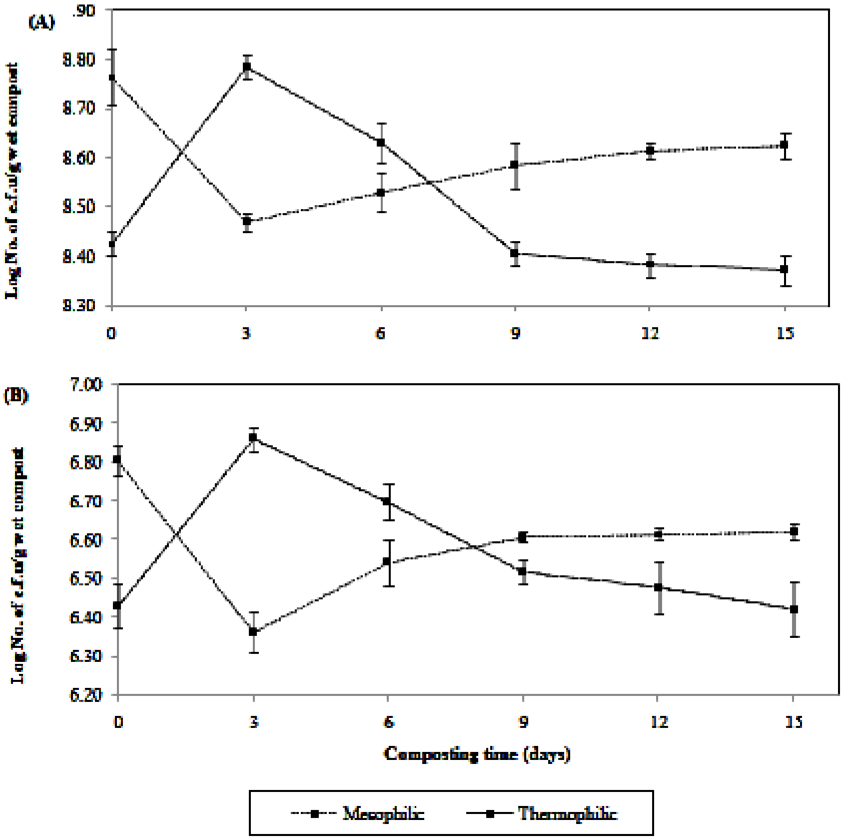


Fig. 5. Changes in counts of mesophilic and thermophilic bacteria (**A**) and fungi (**B**) during the composting of *Conocarpus erectus* residues. Values are means of 3 replicates ± standard deviations. c.f.u.: colony-forming units

Rate of organic matter loss is an indicator of the overall composting rate (Petric*et al.*, 2009). The results showed that OM decreased with time. It decreased from 83.93% to 75.85% (Figure 4a). By the end of composting, the loss in OM reached to 39.86% from the starting value (Figure 4b). The OM degradation was revealed by the OM loss, which is directly related to microbial respiration as mentioned by Paredes*et al.* (2002). Generally, the loss in OM was less than that found by Inbar*et al.* (1990) who mentioned that about 50% of OM is metabolized to CO_2 and H_2O during the composting of separated cattle manure. On the other hand, the low OM-loss was in agreement with that reported in another study(Alburquerque*et al.*, 2009) and reflects the resistance of this material to degradation. 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 (Chang and Hudson, 1967; Poincelot, 1974).

From an engineering point of view, kinetics is one of the important factors for scaling up reactor to a larger unit (Levenspiel, 1999). The composting of most substrates is characterized by an initial period of rapid degradation followed by a longer period of slow degradation (Diaz *et al.*, 2002). The OM degradation profile during composting, as determined by OM loss, follows a first-order kinetic equation (Figure 4b) and this is in agreement with that found by Paredes*et al.* (2002) and Serramiá*et al.* (2010).

C/N Ratio

C/N ratio is a traditional parameter, which has been used to evaluate the compost maturity and stability as it defines the agronomic quality (Zhiyi, 2004). The initial carbon to nitrogen (C/N) ratio is one of the most important factors influencing compost quality (Michel *et al.*, 1996). The optimal C/N ratios for the microbiological decomposition of organic material in composting processes have been reported to be in the range of 26 to 35 (Poincelot, 1972). In general, initial C/N ratios of 25-30 are considered ideal for composting (Kumar *et al.*, 2010). The changes in C/N ratio are shown in Figure 4c. The results indicated that the C/N ratio decreased with time from 25.22 to 18.48 and this could be attributed to the suitability of moisture content, aeration and temperature for composting process. 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 (Goyal*et al.*, 2005). 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 (Mathur, 1991). It was reported that a C/ N ratio below 20 is indicative of an acceptable maturity (Poincelot, 1974), a ratio of 15 or even less being preferable (Jiménez and Garcia, 1989). However, Hirari*et al.* (1983) stated that the C/N ratio cannot be used as an absolute indicator of compost maturity, since the values for well composted materials present great maturity variability, due to characteristics of the waste used. Generally, 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.* (2005).

Microbial Changes

Composing is a biological and biochemical process involving microbes and their secreted enzymes (Zeng *et al.*, 2007, 2010). In the process of composting, the succession of various microbial groups plays a crucial role, and the appearance of nutritionally specialized microbial groups reflects the maturity of composts (Goyal *et al.*, 2005).Monitoring of the microbial succession may provide important information for the effective management of the composting process and the appearance of certain groups of microorganisms is believed to reflect the degree of stabilization of the organic matter (Ryckeboer *et al.*, 2003). Therefore, changes in the numbers of mesophilic and thermophilic bacteria and fungi during the composting process were determined. The changes in the numbers of these microbes are illustrated in Figure 5. The figure shows the logarithm of the number present. As shown in Figure 5a, the mesophilic bacteria decreased with time and this could be attributed to the maintained high temperature and then slightly increased again after 6 days (when the temperature decreased to below 30^{o}C).Close results were found by several investigators (Chang and Hudson, 1967; Khalil *et al.*, 1999; Hassen *et al.*, 2001).The thermophilic bacteria increased and reached the maximum after 3 days (when the temperature was at the maximum value, 54^{o}C) and then gradually decreased with time (Figure 5a). The decrease inthermophilic bacteria could be attributed to the lower temperature.Close results were found by some investigators (Chang and Hudson, 1967; Khalil *et al.*, 2001). Chang and Hudson (1967) stated that the thermophilic bacteria increased during the first 2 days of composting and continued to increase during the maximum temperature phase and then gradually decreased. The same trend of decrease and increase was found in case of mesophilic and thermophilic fungi(Figure 5b).

Generally, as mentioned by Fogarty and Tuovinen (1991), mesophilic microorganisms are responsible for the initial decomposition of organic materials and the generation of heat responsible for the increase in compost temperature. As the temperature begins to rise, thermophilic microorganisms begin to dominate, while during the cooling phase of composting, mesophilc microorganisms reappear again (Poincelot, 1974; Fogarty and Tuovinen, 1991). The microbial biomass of some groups of microorganisms, especially thermophilic bacteria, decreases in the last phases of composting as the product reaches maturity, so that a total count of microorganisms (principally bacteria) throughout the process can be indicative to the state of compost maturity (Jiménez and Garcia, 1989).

CONCLUSION

It can be concluded from the obtained results that adjustment of the composting conditions such as aeration, moisture content and temperature is very important to increase of microbial populations and their enzymatic activities and therefore the increase of organic matter decomposition. The decrease in temperature and C/N ratio at the end of composting is a good indicator of the compost maturity. The changes in odour, colour, pH, electrical conductivity and microbial populations could be used also indicators for the progress of composting and compost maturity. Thus, composting can be a suitable method for converting *Conocarpus erectus* residues into compost that can be used as a fertilizer and soil conditioner by using the static composting system.

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REFERENCES

1. Abdel-Hameed, E. S., Bazaid, S.A., Shohayeb, M. M., El-Sayed,M. M., El-Wakil,E.A. Phytochemical studies and evaluation of antioxidant, anticancer and antimicrobial properties of *Conocarpus erectus* L. growing in Taif, Saudi Arabia. *Eur. J. Med. Plants*, 2012; **2**(2): 93-112.
2. Abdullah, N., Chin, N. L. Simplex-centroid mixture formulation for optimized composting of kitchen waste. *Bioresour. Technol.*,2010; **101**(21): 8205-8210.
3. Albrecht, R., Joffre, R., Gros, R., Le Petit, J., Terrom,G.,Périssol, C. Efficiency of near-infrared reflectance spectroscopy to asses and predict the stage of transformation of organic matter in the composting process. *Bioresour. Technol.*, 2008; **99**: 448-455.
4. Alburquerque, J.A., Gonzálvez, J., Tortosa, G., AitBaddi,G. Cegarra, J. Evaluation of ‘‘alperujo” composting based on organic matter degradation, humification and compost quality. *Biodegradation*,2009; **20**: 257-270.
5. Alexander, R. Expanding compost markets.*Biocycle*,1990; **31**(8): 54-59.
6. Alkoaik, F. N., Khalil,A. I., Alqumajan, T. Performance evaluation of a static composting system using date palm residues. *Middle- East J. Sci. Res.*,2011; **7**(6): 972-983.
7. Barker, A.V. Composition and uses of compost. In: *Agricultural Uses of By-products and Wastes*.Rechcigl, J.E. and MacKinnon, H. C. (eds.). American Chemical Society, Washington, DC,1997; pp 140-162.
8. Brinton, W.F. Interpretation of waste and compost tests. *J. Woods End Res. Lab.*,2003; **1**(4): 1-6.
9. Bustamante, M.A., Moral, R., Paredes, C., Vargas-Garcßa, M.C., Suárez-Estrella,F., Moreno,J. Evolution of the pathogen content during co-composting of winery and distillery wastes.*Bioresour. Technol.*, 2008; **99**(15): 7299-7306.
10. Cabañas-Vargas, D.D., Sánchez-Monedero, M.A., Urpilainen, S.T., Kamillaki, A., Stentiford,E.I. Assessing the stability and maturity of compost at large-scale

plants.*Ingeniería*,2005; **9**(2): 25-30.

11. Canet, R., Pomares, F., Cabot, B., Chaves, C., Ferrer, E., Ribó,M., Albiach, M.R. Composting olive mill pomace and other residues from rural southeastern Spain.*Waste Manage.*,2008; **28**: 2585-2592.
12. Chang, Y., Hudson, H.J.The fungi of wheat straw compost. I. Ecological studies. *T. Brit. Mycol. Soc.*,1967; **50**: 649-666.
13. de Guardia, A., Petiot,C., Rogeau, D. Influence of aeration rate and biodegradability fractionation on composting kinetics. *Waste Manage.*,2008; **28**: 73-84.
14. Diaz, L.F., Savage, G.M., Eggerth,L.L., Golueke, C.G. Composting and Recycling Municipal Solid Waste. Lewis Publishers, Cal Recovery Inc, Hercules, California, USA, 1993.
15. Diaz, M.J., Madejon, E., Lopez, F., Lopez,R., Cabrera, F. Optimization of the rate vinasse/ grape marc for co-composting process.*Process Biochem.*,2002; **37**: 1143-1150.
16. Faure, D.,Deschamps, A.M.Physico-chemical and microbiological aspects in composting of grape pulps.*Biol. Waste.*,1990; **34**: 251-258.
17. Fogarty, A.M.,Tuovinen, O.H. Microbiological degradation of pesticides in yard waste composting. *Microbiol. Rev.*,1991; **55**(2): 225-233.
18. Gajdos, R. The use of organic waste materials as organic fertilisers-recycling of plant nutrients.*ActaHorticul.*,1992; **302**: 325-331.
19. Gotaas, H.B. Composting: Sanitary Disposal and Reclamation of Organic Wastes. WHO. Monograph Series, No. 31, Geneva, 1956.
20. Goyal, S., Dhull,S.K., Kapoor, K.K. Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bioresour. Technol.*,2005; **96**: 1584-1591.
21. Gray, K.R, Sherman,K., Biddlestone, A.J.A review of composting.Part 1.Microbiology and biochemistry.*Process Biochem.*,1971a; **6**: 32-36.
22. Gray, K.R., Sherman,K., Biddlestone, A.J. Review of composting. Part 2.The practical process.*Process Biochem.*,1971b; **10**: 22-28.
23. Guo, X., Gu, J., Gao, H., Qin, Q., Chen, Z., Shao, L., Chen, L., Li, H., Zhang, W., Chen,S. Liu,J. Effects of Cu on metabolisms and enzyme activities of microbial communities in the process of composting. *Bioresour. Technol.*,2012; **108**: 140-148.
24. Gümez-Brandün, M., Lazcano,C.,Domínguez, J.The evaluation of stability and maturity during the composting of cattle manure.*Chemosphere*,2008; **70**: 436-444.
25. Harada, Y., Inoko, A., Tadaki,M., Izawa, T. Maturity processes of city refuse compost during piling. *Soil Sci. Plant Nutr.*,1981; **27**: 357-364.
26. Hassen, A., Belguith, K., Jedidi, N., Cherif, A., Cherif, M., Boudabous, A. Microbial characterization during composting of municipal solid waste.*Bioresour. Technol.*,2001; **80**: 217-225.
27. Hassen, A., Jedidi, N., Cherif, M., M'hiri, A., Boudabous,A., Van Cleemput, O. Mineralization of nitrogen in a clayey loamy soil amended with organic waste residues enriched with Zn, Cu and Cd. *Bioresour. Technol.*,1998; **64**: 39-45.
28. Haug, R.T. The Practical Handbook of Compost Engineering.Lewis Publishers, London and New York, 1993.
29. Haug, R.T. Composting process design criteria. Part III. Aeration.*Biocycle*,1986; **27**(9): 53-57.
30. Hirari, M., Chanyasak,V., Kubota, H.A standard measurement for compost maturity.*Biocycle*,1983; **4**: 54-56.
31. Huang, D.-L., Zing, G.-M., Feng, C.-L., Hu, S., Lai, C., Zhao, M.-H., Su, F.-F., Tang,L., Liu, H.-L. Changes of microbial population structure related to lignin degradation during lignocellulosic waste composting. *Bioresour. Technol.*,2010; **101**: 4062-4067.
32. Inbar, Y., Chen, Y., Hadar,Y., Hoitink,H.A.J. New approaches to compost maturity.*Biocycle*,1990; **31** (12): 64-69.
33. Inbar, Y., Hadar,Y., Chen, Y. Recycling of cattle manure: the composting process and characterization of maturity. *J. Environ. Qual.*,1993; **22**: 857-863.
34. Jeris, J.S., Regan, R.W. Controlling environmental parameters for optimum composting. Part 1: Experimental procedures and temperature. *Compost Sci.*,1973; **14**(1): 10-15.
35. Jiménez, E.I., Garcia, V.P. Evaluation of city refuse compost maturity: a review. *Biol.Waste.*,1989; **27**: 115-142.
36. Jindo, K., Suto, K., Matsumoto, K., García, C., Sonoki, T., Sánchez-Monedero, M.A. Chemical and biochemical characterisation of biochar-blended composts prepared from poultry manure.*Bioresour.Technol.*,2012a; **110**: 396-404.
37. Jindo, K., Sánchez-Monedero, M.A., Hernández, T., García, C., Furukawa, T., Matsumoto, K., Sonoki, T., Bastida,F. Biochar influences the microbial community structure during manure composting with agricultural wastes. *Sci. Total Environ.*,2012b; **416**: 476-481.
38. Khalil, A.I. Composting and the utilization of organic wastes: an environmental study. PhD. Thesis.University of Alexandria, Alexandria,

Egypt,1996.

39. Khalil, A.I., Beheary,M.S., Salem,E.M. Changes in microbial populations and their enzymatic activities during the composting of municipal solid wastes: a comparative study. International Conference on Environmental Management, Health and Sustainable Development, Alexandria, Egypt,1999.
40. Khalil, A.I., Beheary,M.S., Salem, E.M. Monitoring of microbial populations and their cellulolytic activities during the composting of municipal solid wastes. *World J.Microbiol.Biotechnol.*,2001; **17**: 155-161.
41. Khan, M.A.I., Ueno, K., Horimoto, S., Komai, F., Tanaka,K., Ono, Y. Physicochemical, including spectroscopic, and biological analyses during composting of green tea waste and rice bran. *Biol.Fert. Soils*,2009; **45**:305-313.
42. Ko, H.J., Kim, K.Y., Kim, H.T., Kim,C.N., Umeda,M.Evaluation of maturity parameters and heavy metal contents in composts made from animal manure. *Waste Manage.*,2008; **28**(5):813-820.
43. Kumar, M., Ou Yan,L., Lin, J.G. Co-composting of green waste and food waste at low C/N ratio.*Waste Manage.*,2010; **30**:602-609.
44. Levenspiel, O. Chemical Reaction Engineering.John Wiley and Sons, New York, 1999.
45. Liu, D., Zhang, R., Wu, H., Xu, D., Tang, Z., Yu, G., Xu,Z., Shen,Q. Changes in biochemical and microbiological parameters during the period of rapid composting of dairy manure with rice chaff. *Bioresour. Technol.*,2011; **102**:9040-9049.
46. Lu, A.L., Kumar, M., Tsai,J.C., Lin, J.G. High-rate composting of barley dregs with sewage sludge in a pilot scale bioreactor.*Bioresour. Technol.*,2008; **99**:2210-2217.
47. Madan, S., Bhatia, A., Rajpal,A., Kazmi, A.A. Maturity assessment of rotary drum and windrow composts in terms of germination index and enzymatic activities. *Int. J. Appl. Sci. Eng. Res.*,2012; **1**(3):415-426.
48. Massiani, C.,Domeizel, M. Quality of compost organic matter stabilization and trace metal contamination. In:*The Sciences of Composting*.De Bertoldi, M., Sequi, P., Lemmes, B. and Papi,T. (eds.). Blackie Academic and Profissional, Glasgow, UK, 1996; pp 185-194.
49. Mathur, S. P. Composting processes. In: *Bioconversion of Waste Materials to Industrial Products*.Martin, A.M. (ed.). Elsevier Applied Science Publishers, London and New York, 1991; pp 147-183.
50. Mckinley, V.L., Vestal, J.R.Biokinetic analyses of adaptation and succession: Microbial activity in composting municipal sewage sludge. *Appl. Environ.Microbiol.*,1984; **47**(5): 933-941.
51. Mckinley, V.L., Vestal,J.R., Eralp, A.E. Microbial activity in composting. Part II. *Biocycle*,1985; **26**(7): 47-50.
52. Michel, F.C. Jr, Reddy,C.A. Effect of oxygenation level on yard trimming composting rate, odor production, and compost quality in bench-scale reactors.*Compost Sci.Util.*,1998; **6**(4): 6-14.
53. Michel, F.C. Jr, Forney, L.J., Huang, A.J.F., Drew, S., Czuprendski, M., LindebergJ.D., Reddy, C.A. Effects of turning frequency, leaves to grass mix ratio and windrow vs. pile configuration on the composting of yard trimmings. *Compost Sci.Util.*,1996; **4**: 126-143.
54. Moldes, A.B., Vàzquez, M., Domínguez, J.M., Díaz-Fierros,F., Barral, M.T. Evaluation of mesophilic biodegraded grape marc as soil fertilizer.*Appl. Biochem.Biotechnol.*,2007; **141**: 27-36.
55. Mondini, C., Fornasier,F., Sinicco, T.Enzymatic activity as a parameter for the characterization of the composting process. *Soil Biol.Biochem.*,2004; **36**: 1587-1594.
56. Nakasaki, K., Watanabe, A., Kitano,M., Kubota, H. Effect of seedling on thermophilic composting of refuse.*J. Environ. Qual.*,1992; **21**: 715-719.
57. Nogueira, W.A., Nogueira,F.N., Devens, D.C. Temperature and pH control in composting of coffee and agricultural wastes. *Water Sci. Technol.*,1999; **40**(1): 113-119.
58. Pan, I.,Sen, S.K. Microbial and physic-chemical analysis of composting process of wheat straw.*Indian J.Biotechnol.*, 2013; **12**: 120-128.
59. Paredes, C., Roig, A., Bernal, M.P., Sánchez-Monedero,M.A., Cegarra, J. Evolution of organic matter and nitrogen during co-composting of olive mill wastewater with solid organic wastes. *Biol.Fert. Soils*,2000; **3**: 222-227.
60. Paredes, C., Bernal, M.P., Cegarra,J., Roig,A. Bio-degradation of olive mill wastewater sludge by its co-composting with agricultural wastes.*Bioresour. Technol.*,2002; **85**: 1-8.
61. Pérez-Murcia, M.D., Moreno-Caselles, J., Moral, R., Pérez-Espinosa, A., Paredes,C., Rufete,B. Use of composted sewage sludge as horticultural growth media: effects on germination and trace element extraction. *Commun. Soil Sci. Pl. An.*,2005; **36**: 571-582.
62. Petric, I., Sestanb,A., Sestan, I. Influence of initial moisture content on the composting of poultry manure with wheat straw.*Biosyst. Eng.*,2009; **104**: 125-134.
63. Petric, I.,Selimbašiæ, V. Composting of poultry

manure and wheat straw in a closed reactor: optimum mixture ratio and evolution of parameters. *Biodegradation*,2008; **19**: 53-63.
64. Poincelot, R.P. A scientific examination of the principles and practice of composting.*Compost Sci.*,1974; **15**: 24-31.
65. Poincelot, R.P. The Biochemistry and Methodology of Composting. Connecticut Agricultural Experimental Station bulletin 127. Connecticut Agricultural Experimental Station, New Haven, USA, 1972.
66. Raut, M.P., Prince William, S.P.M., Bhattacharyya, J.K., Chakrabarti,T., Devotta, S. Microbial dynamics and enzyme activities during rapid composting of municipal solid waste - a compost maturity analysis perspective.*Bioresour. Technol.*,2008; **99**(14): 6512-6519.
67. Ryckeboer, J., Mergaert, J., Coosemans, J., Deprins,K., Swings, J. Microbiological aspects of biowaste during composting in a monitored compost bin.*J. Appl.Microbiol.*,2003; **94**: 127-137.
68. Said-Pullicino, D., Erriquens,F.G., Gicliotti, G. Changes in the chemical characteristics of water-extractable organic matter during composting and their influence on compost stability and maturity. *Bioresour. Technol.*,2007; **98**: 1822-1831.
69. Serramiá, N., Sánchez-Monedero, M.A., Fernández-Hernández, A., Garc¯a-Ortiz Civantos,C., Roig,A. Contribution of the lignocellulosic fraction of two-phase olive-mill wastes to the degradation and humification of the organic matter during composting. *Waste Manage.*,2010; **30**: 1939-1947.
70. Shyamala, D.C.,Belagali, S.L. Studies on variations in physico-chemical and biological characteristics at different maturity stages of municipal solid waste compost.*Int. J. Environ. Sci.*, 2012; **2**(4): 1984-1997.
71. Taiwo, L. B.,Oso,B. A. Influence of composting techniques on microbial succession, temperature and pH in a composting municipal solid waste. *Afr. J.Biotechnol.*,2004; **3**(4): 239-243.
72. Tian, W., Li, L., Liu, F., Zhang, Z., Yu, G., Shen,Q., Shen,B. Assessment of the maturity and biological parameters of compost produced from dairy manure and rice chaff by excitation–emission matrix fluorescence spectroscopy. *Bioresour. Technol.*,2012; **110**: 330-337.
73. Vargas-Garcßa, M.C., Suárez-Estrella, F., López,M.J., Moreno, J. Microbial population dynamics and enzyme activities in composting processes with different starting materials. *Waste Manage.*,2010; **30**(5): 771-778.
74. Weber, J., Karczewska, A., Drozd, J., Licznar, M., Licznar, S., Jamroz,E., Kocowicz, A. Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. *Soil Biol.Biochem.*,2007; **39**: 1294-1302.
75. WHO.Methods of Analysis of Sewage Solid Wastes and Compost.International Reference Centre for Wastes Disposal.CH-8600, Dübendorf, Switzerland,1978.
76. Wu, L., Ma,L.Q., Martinez, G.A. Comparison methods for evaluating stability and maturity of biosolids compost. *J. Environ. Qual.*,2000; **29**(2): 424-429.
77. Zeng, G.M., Huang, D.L., Huang, G.H., Hu, T.J., Jiang, X.Y., Feng, C.L., Chen, Y.N., Tang,L., Liu, H.L. Composting of lead-contaminated solid waste with inocula of white-rot fungus. *Bioresour. Technol.*,2007; **98**: 320-326.
78. Zeng, G.M., Yu, M., Chen, Y.N., Huang, D.L., Zhang, J.C., Huang, H.L., Jiang,R.Q., Yu,Z. Effects of inoculation with *Phanerochaetechrysosporium* at various time points on enzyme activities during agricultural waste composting. *Bioresour.Technol.*,2010; **101**: 222-227.
79. Zhiyi, F. A Fuzzy inference system for synthetic evaluation of compost maturity and stability.MSc. Thesis.University of Engineering, Regina,2004.