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

Ahmed Ismail Khalil¹,²*, Fahad Nasser Alkoaik¹, MajdiAli Al-Mahasneh¹, Ronnel Blanqueza Fulleros¹ and Ahmed Mohamed El-Waziry³

¹Department of Agricultural Engineering, College of Food and Agriculture Sciences, King Saud University, Saudi Arabia.
²Department of Environmental Studies, Institute of Graduate Studies and Research, University of Alexandria, Alexandria, Egypt.
³Department of Animal Production, College of Food and Agriculture Sciences, King Saud University, Saudi Arabia.

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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 m³. 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
organic waste treatment technology having the
capacity to transform organic wastes into well-
stabilized product that can benefit 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 m³. 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 cyclotoc 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 Selimbaşi, 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):

\[
\text{OM- loss} (%) = 100 - 100 \left[ \frac{(X_1 \times \text{OM}_1)}{(X_2 \times \text{OM}_2)} \right]
\]

Where:

- \(X_1\) and \(X_2\) are the initial and final ash concentrations, and \(\text{OM}_1\) and \(\text{OM}_2\) 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).

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°C) (approx. 15 hrs), (ii) a thermophilic phase (T > 40°C) (approx. 25 hrs), (iii) cooling down (7 days) and (iii) maturation phase (6 days). It is noticed that the temperature remained in the range of 40-54°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°C causes 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°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. 1. Schematic diagram of composting system

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

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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
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 García (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 (Gómez-Brandín 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

![Image](image-url)
the 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 a chemical indicator of the composting status (Pan and Sen, 2013). EC is the measure of a solution’s 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 Selimbašić, 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 Gmez-Brandn et al. (2008). Generally, the obtained results are in agreement with those reported by many investigators (Gmez-Brandn et al., 2008; Petric and Selimbašić, 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 Selimbašić, 2008); 3.8-8.4 mS/cm (Khan et al., 2009; 2.4-7.7 mS/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.

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*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 Inbaret et al. (1990) who mentioned that about 50% of OM is metabolized to CO₂ and H₂O 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 (Goyalet 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 García, 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 Goyalet et al. (2005).

Microbial Changes

Composting 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°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°C) and then gradually decreased with time (Figure 5a). The decrease in thermophilic 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, mesophilic 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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