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# EVALUATION OF FORCED AERATED AND TURNED PILE COMPOSTING OF ROSE OIL PROCESSING WASTES

Composting of rose oil processing solid wastes was experimented by two different aeration methods: forced aeration and mechanical turning. The objective of this study was to assess which aeration methods were the most convenient for the composting process. Assessment of aeration methods was performed based on the parameters such as temperature, $O_2$, $CO_2$, $CH_4$ concentration profiles, and physical and chemical properties of the finished composts. The two aeration methods were also compared based on the energy consumed by aeration per unit organic matter loss (OML) of composting, which is a major proportion of operating costs. Although composting performance parameters of temperature and $O_2$/$CO_2$ in the function of time showed some differences, similar end-product quality in terms of moisture, pH, electrical conductivity, $NH_4^+$–N and $NO_3^-$–N and contents was obtained. These results suggested that both methods (forced aeration and mechanical turning) may be utilized for composting operation of rose oil processing solid wastes. However, in this study, energy consumed by aeration provided by mechanical turning per unit OML of composting was 1.24 times higher than that of forced aeration. Furthermore, mechanical turning created anaerobic conditions for the formation of $CH_4$ concentration in the pile, which was higher than that of the forced aeration.

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## 1. INTRODUCTION

The management of rose oil processing solid waste (ROPSW) resulting from the production of rose oil, bioconcrete, absolute, bioabsolute, and rose water from the petals of Rosa damascena Mill requires proper disposal to avoid environmental risks in a short time. ROPSW is burned for both cooking and heating purposes in rural areas. In addition, it is used to increase the organic matter of the soil. Inappropriate storage of these wastes leads to soil and groundwater pollution and thereby affecting human health problems [1].

Composting process that treats organic waste with a suitable low-cost strategy can be used to produce useful and salable products. Stentiford [2] and Cayuela et al. [3] highlighted that the selection of aeration methods is a critical issue to supply the necessary amount of air. The aeration methods, which are one of the most crucial components of the composting systems to be optimized, directly affect the efficiency of the composting process. Mechanical turning and forced aeration are widely accepted composting aeration methods. Although both aeration methods have been proven to be convenient for a broad range of organic solid wastes, it was reported that generally forced aeration method produces faster and better compost. Furthermore, optimizing the airflow rate in forced aeration is a very important criterion for the successful completion of the process. When physical ventilation, passive ventilation, and continuous ventilation systems are compared, continuous ventilation stands out as the system that produces the lowest greenhouse gas emission due to its sufficient $O_2$ source [4]. Öztürk [5] stated that if the airflow rate is not optimized, composting temperature and oxygen level may not be controlled properly in forced aeration systems. Cayuela et al. [3] reported that the partial homogenization and temperature differences occurred for the aerated static pile composting method. In addition, more water is needed because of the evaporation that occurs during composting. The main disadvantage of the turned windrow composting method is that it causes problems with temperature control and nitrogen loss.

The objective of this study was to evaluate forced aeration and mechanical turning for the composting of ROPSW using separated dairy manure (SDM), poultry manure (PM), and straw as bulking agents in terms of process parameters such as temperature and gas concentrations, the main characteristics of the final compost (C/N ratios, $NH_4^+$–N and $NO_3^-$–N contents, etc.), and energy consumed by aeration per unit organic matter loss.

## 2. MATERIALS AND METHODS

This study involved ROPSW, SDM, PM, and straw. Initial characteristics of feedstocks and the composting mix used in the experiment (dry weight basis) are given in

Table 1. The mixture used for the composting experiment was made by mixing 20% of ROPSW with 61.83% of SDM, 8.17% of PM, and 10% of straw based on the dry weight.

Table 1

Physical and chemical properties of feedstocks and composting mix used in the experiment (dry weight basis)

| Parameter | ROPSW | SDM | PM | Straw | Mixture |
|---|---|---|---|---|---|
| Moisture[a], % | 71.58±0.08 | 73.62±0.50 | 18.53±0.37 | 3.48±0.02 | 71.39±0.94 |
| Organic matter, % | 91.74±0.08 | 80.69±0.99 | 87.36±0.26 | 94.46±0.61 | 85.86±0.97 |
| *EC*, dS/m | 0.82±0.03 | 2.95±0.05 | 7.37±0.08 | 1.09±0.03 | 3.23±0.00 |
| pH | 4.75±0.2 | 8.81±0.33 | 8.77±0.12 | 6.4±0.4 | 9.01±0.00 |
| Total C, % | 29.25±0.53 | 40.51±0.10 | 41.88±0.04 | 44.405±1.75 | 40.55±0.33 |
| Total N, % | 1.9±0.13 | 1.22±0.03 | 5.07±0.45 | 0.49±0.06 | 1.42±0.21 |
| C/N | 15.39 | 33.20 | 8.26 | 90.62 | 28.56 |
| $NH_4^+$–N, mg/kg | 72.82±23.73 | 174.2±10.74 | 236.5±14.17 | 33.54±0.46 | 201.7±1.00 |
| $NO_3^-$–N, mg/kg | 179.75±5.30 | 182.81±12.03 | 870.9±79.91 | 256.97±32.45 | 267.15±22.2 |
| TP,% | 0.17±0.00 | 0.17±0.00 | 0.97±0.01 | 0.04±0.00 | 0.21±0.01 |
| Pb, mg/kg | 0.53±0.20 | 0.4±0.06 | 0.18±0.00 | 0.23±0.05 | 0.23±0.00 |
| Cd, mg/kg | <LOD[b] | <LOD | <LOD | <LOD | <LOD |
| Cr, mg/kg | 2.08±1.52 | 3.69±0.72 | 0.9±0.04 | 2.27±0.66 | 2.95±0.26 |
| Cu, mg/kg | 46.28±7.79 | 16.75±1.47 | 39.87±0.56 | <LOD | 23.26±0.39 |
| Ni, mg/kg | 5.42±0.67 | 11.11±0.37 | 6.14±0.23 | 2.67±0.09 | 9.1±0.28 |
| Zn, mg/kg | <LOD | 47.23±6.96 | 171.87±2.83 | <LOD | 52.4±5.05 |

[a]Value on a wet weight basis.
[b]LOD – level of detection.

Two trapezoidal piles, ca. 4600 kg each, were set up with the same size (6.20×2.10 ×1.03 m) for the forced aerated pile (Pile-1) and mechanically turned pile (Pile-2). Pile-1 was subjected to forced ventilation with temperature feedback control, which was described in the study of Ekinci et al. [6]. Pile-1 was centered over two aeration lines consisting of perforated pipes installed in a concrete floor. The pipes were covered with unchopped straw at the height of 10 cm and packed with shade net to equally distribute air in the pipes. The outer part of the piles was not covered. Pile-2 was aerated by mechanical turning (seven times) with a front-end loader.

Temperature readings were made in every one minutes for both piles. Three thermocouples per pile were positioned along the length of each pile: at the beginning (P1), middle (P2) and end (P3) of compost piles (0.5 m down from the top of the pile). Measurement of $O_2$ and $CO_2$ concentrations was performed with Quantek Model 902P. $CH_4$ concentrations were measured using a sensor (PIR 7200 Draeger). Gasses were manually measured twice a day using an internal pump through the desiccant from 3 points (P1, P2, and P3) from the piles (0.5 m below the top). Three 500 cm$^3$ volumes were created at the tip of the gas sampling point. For Pile-1, the fan was stopped to measure gas concentrations. The same points as thermocouples were used for gas measurements for both piles. Energy consumed by aeration fan for the forced aerated pile was measured by single-phase electricity meters (VEM-T580DB2 Viko Turkey) and measurements were recorded once a day. While the readings of Pile-1 were recorded by a PC system, that of Pile-2 were measured and recorded with a separate PLC unit.

The process was also monitored for moisture, organic matter, electrical conductivity (*EC*), pH, C, N, $NH_4^+$–N and $NO_3^-$–N contents, total phosphorus, heavy metals (Cd, Cr, Cu, Zn, Ni, and Pb) as described elsewhere [7]. Compost samples were gathered from the randomized sites around the piles. The composting experiment lasted for 62.7 days. Organic matter loss (OML) was determined from the ash contents at the beginning and the end of composting based on the study of Paredes et al. [8].

The values of free air space (FAS) was calculated based on density of materials and particles [9]

$$\mathrm{FAS} = \left(1 - \frac{BD}{PD}\right) \times 100\% \tag{1}$$

where *BD* is bulk density, kg/dm$^3$, and *PD* is the wet particle density determined using kerosene, kg/dm$^3$.

Statistical analyses were carried out using Minitab (version 16.2.4). All the parameters presented were average of three replicates with standard deviations. Data concerning compost samples at 62.7 days were analyzed by ANOVA. The Tukey test was used to compare the differences between the two aeration systems. The significance level was selected as $p < 0.01$.

## 3. RESULTS AND DISCUSSION

Compost temperature in the function of time measured at three locations is given for Pile-1 (Fig. 1a) and Pile-2 (Fig. 1b). In Pile-1, where forced aeration was applied, the initial mean temperature was 41.5 °C. A sharp temperature increase was verified and the temperature rose rapidly to the set temperature of 65 °C. The average maximum temperature was measured at 72.5 °C at day 0.84 indicating that the forced aeration was not able to keep the temperature below 65 °C in the periods of maximum activity. The highest temperature difference between P1 and P2 measured horizontally was 31 °C due to aeration. The thermophilic temperatures continued until the 51.4 days and it then decreased continuously. At the end of the experiment, the temperature approached that of the ambient air (32 °C). Data (temperature, $O_2$/$CO_2$ concentrations, volumetric air flow rates, energy consumption by fans) was not recorded due to a problem with data acquisition at the 21th days of composting. This problem lasted for almost 4 days and ventilation fans kept working at this period.

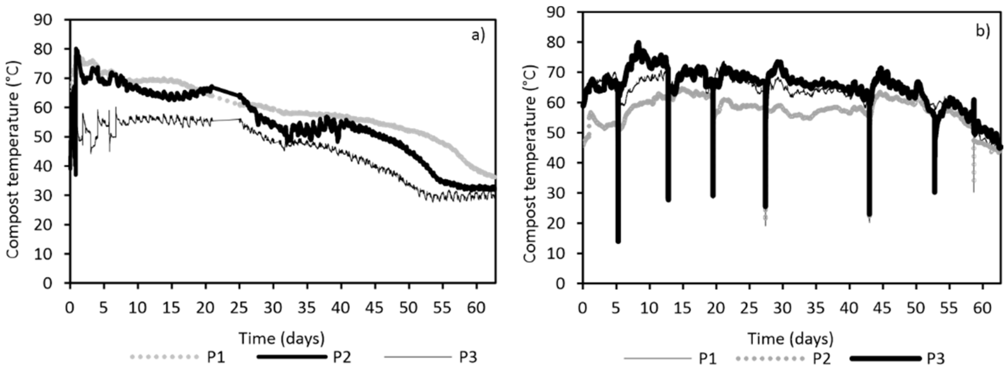


Fig. 1. Temperature patterns for Pile-1 (a) and Pile-2 (b)

In Pile-2, where aeration was maintained by mechanical turning, when preparing the pile by a front loader, the initial mean temperature of the pile already increased to 54.8 °C and reached the maximum of 69.7 °C at day 11.72, averagely. The highest temperature difference horizontally between P1 and P2 was 20.7°C on day 8.31.

Temperatures in Pile-2 were usually higher and less variant than in Pile-1 for a longer time [10]. Sánchez-Monedero et al. [11] observed a similar extended thermophilic phase for two-phase olive mill waste composting due to its high thermal inertia. Mechanical turning occurred at 5.27, 12.8, 19.51, 27.38, 42.98, 52.77, and 58.65 days of composting. Golueke [12] suggested that the windrow is required to be turned for a total of seven turns maximum during the thermophilic phase. Each turning led to spikes in temperature. It was reported a marked temperature increase immediately after mechanical turning due to probably mixing of the exterior material into the pile, providing a degradable substrate for the microbial biomass [8]. Mechanical turning also favored the increase of temperature by reducing compaction and homogenizing and re-inoculating the substrates [10]. Compared to the two piles, it can be said that the mechanical turning piles was more effective than the forced aeration method since the thermophilic phase of the turned pile was longer than that of the aerated static pile and mechanical turning led to more uniform temperature distribution horizontally.

The level of $O_2$ concentration during composting should be maintained above 10% [13]. The changes of oxygen concentration with time for two piles measured at three locations are given in Fif. 2. The mean $O_2$ concentration at three locations in Pile-1 never decreased below 10% (average of three readings) during the composting process. In this pile, $O_2$ concentration measured at P1 and P3 was between 8.5–9.3% between day 31 and 35. These results implied that Pile-1 was well aerated. $O_2$ concentration in Pile-1 increased at the surrounding level at the end of 62.7 days.

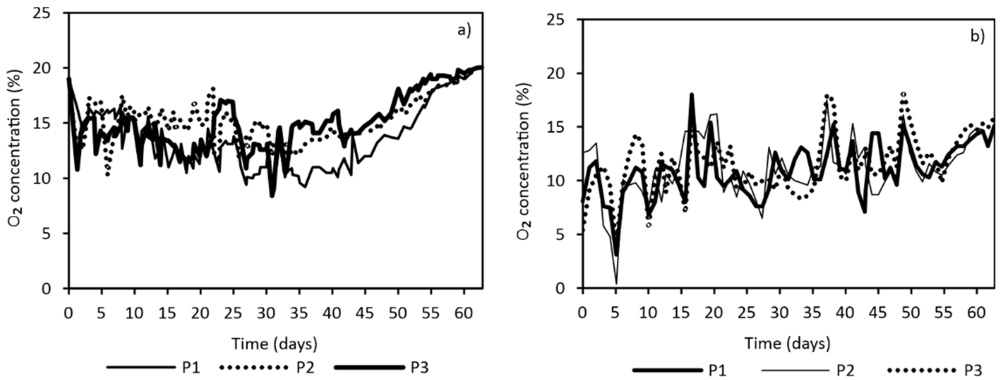


Fig. 2. Time dependences of oxygen concentrations in Pile-1 (a) and Pile-2 (b)

For mechanically turned pile, the oxygen concentration was measured as 0.4% for P1 at 5.1 days of composting showing scarcity of $O_2$ levels in the compost matrix, which was below 5% [14]. Then, it was between 5 and 10% until day 48. It increased to the level of 15–16% at the end of 62.7 days. This results showed that mechanical turning supplied a limited amount of $O_2$ in the first days while forced aerated pile was well aerated during the process.

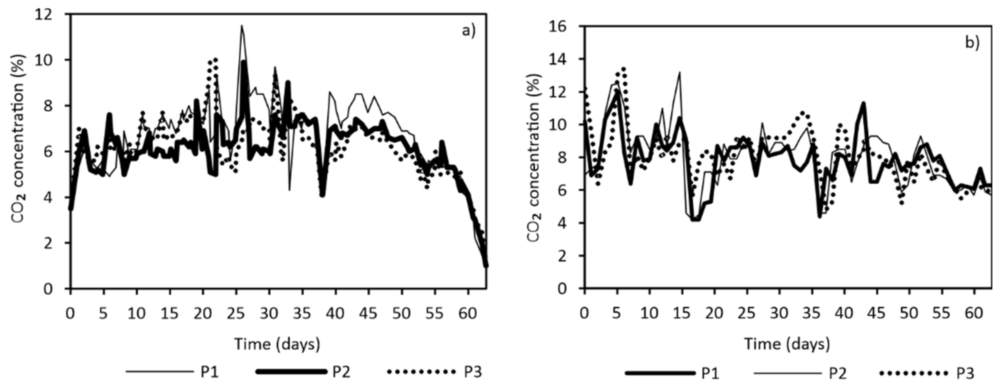


Fig. 3. Time dependences of $CO_2$ concentrations in Pile-1 (a) and Pile-2 (b)

At the onset of the process, $CO_2$ emission from two piles at three locations showed the similarity with the temperature histories (Fig. 3). Furthermore, as the temperature elevation started at around 50–60 °C, the corresponding $CO_2$ concentration was also measured high. The increase in $CO_2$ concentrations in the piles may be due to the decomposition of easily decomposable organics such as carbohydrates and proteins. The course of the $CO_2$ and $O_2$ concentration had an inverse relationship. The $CO_2$ concentrations measured in Pile-2 was usually higher than that in Pile-1. In the piles, $CO_2$ stayed above 5% more than 55 days for both piles.

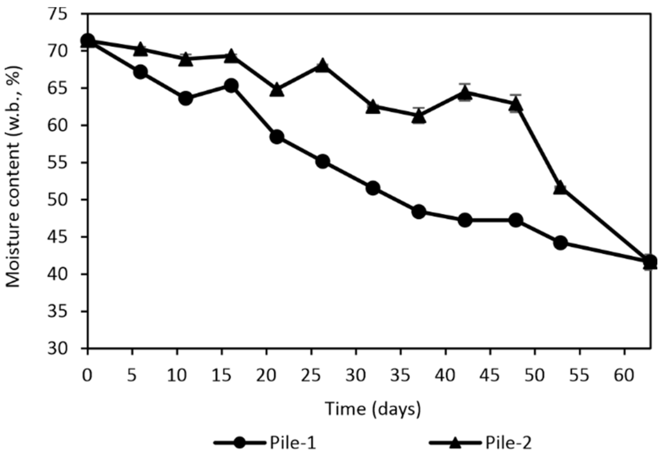


Fig. 4. Time dependences of moisture content for two piles with standard deviations

The initial moisture content of the mixture was 71.39%, which was higher than reasonable limits [14] because of the moisture contents of SDM and ROPSW. Addition of water to piles was not performed during the process (Fig. 4). The main difference of both aeration methods was the trajectory, which each pile followed. This could be due to the greater evaporation from forced aeration in Pile-1 (especially in the temperature feedback aeration period) [10]. The resultant moisture contents were around 41.66 and 41.61%, respectively, for both piles. No significant differences in the final moisture contents between the two piles were detected.

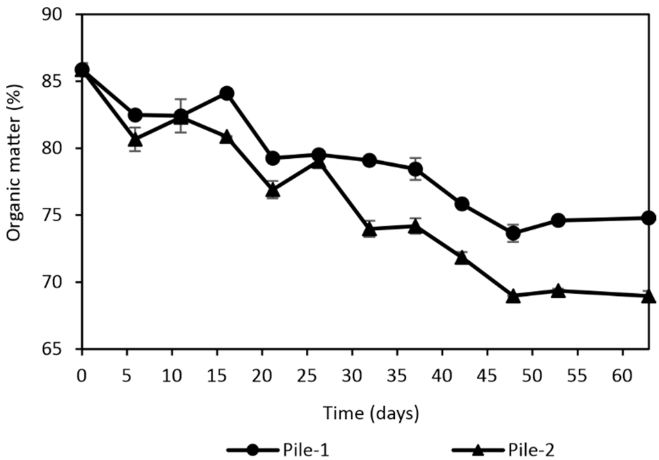


Fig. 5. Time dependences of organic matter for two piles with standard deviations

The initial organic matter content of the piles decreases from 85.86% to 74.79% and 68.97% for Pile-1 and Pile-2, respectively (Fig. 5). The maximum decomposition existed at the thermophilic phase because of high microbial activity. This may be due mainly to the mineralization of the unstable organic compounds which occur in the thermophilic phase. Aeration methods significantly affected the final organic matter contents of piles ($p < 0.01$). Pile-1 and Pile-2 exhibited OML of 51.1 and 62.32%, respectively. Differences between aeration methods in terms of OML were not statistically significant. Similarly, Sánchez-Monedero et al. [11] found OML of 40% for forced aerated piles and OML of 60% for mechanically turned piles, where the temperatures were constantly high. Then, they added that long-term high temperatures caused high OML. Cayuela et al. [3] reported that the mechanical turning produced longer-term thermophilic temperatures in the composting environment than the forced aeration, resulting in more lignin decomposition and nitrogen loss. On the other hand, Cegarra et al. [10] stated that forced aeration performed the composting operation in a shorter time than mechanically turned piles.

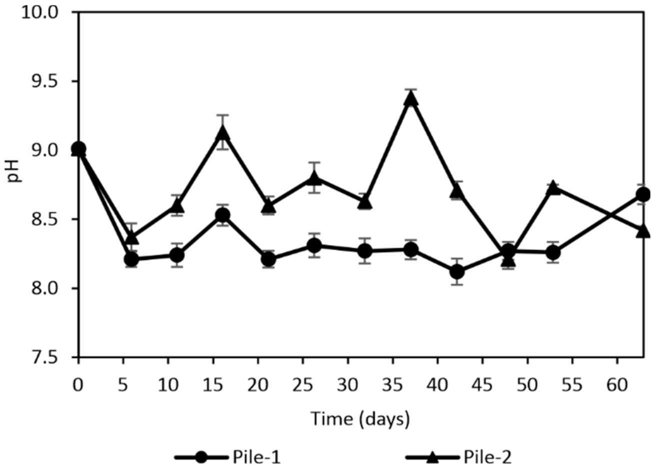


Fig. 6. Time dependences of pH for two piles with standard deviations

The trends of pH of the forced aerated and turned piles were similar during composting (Fig. 6). pH of the two piles decreased from an initial 9.01 to 8.68 and 8.42, respectively by day 62.7. A larger fluctuation occurred for Pile-2 due to the turning process than in Pile-1. The pH values at the end of the experiment were slightly higher due to possible ammonium evolution and nitrogen losses. Lasaridi et al. [15] reported that pH of the finished compost should be within the range of 6.0–8.5 in terms of compost applications in plant cultivation.

Regarding the *EC*, it decreased from the beginning of the process to day 15 for the two piles (Fig. 7). At the advance of the process, *EC* of the piles fluctuated till the end of the process. The final EC of forced aerated and turned piles was 3.48 and 3.10 dS/m Even with different absolute EC values of piles, the final EC values of piles were less than 4 dS/m and classified as non-saline soil [16]. Aeration methods showed no significant differences on the final pH and EC of final composts.

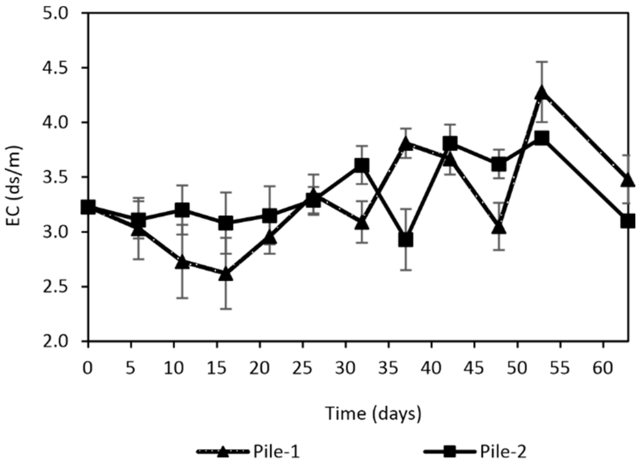


Fig. 7. Time dependences of EC for two piles with standard deviations

As a result of the C and N variations, the C/N ratio decreased continuously from approximately 28.66 to 15.52 and 12.36, for Pile-1 and Pile-2, respectively (Fig. 8) in the final composts. This process, which was faster in Pile-2, may be due to a decrease in the total carbon content and an increase in total nitrogen (concentration effects) resulting from the organic matter decomposition [10]. C/N ratio was nearly constant at the end of the experiment in all piles. Final C/N ratios of composts in this study indicated that the finished composts can be utilized in agriculture. Aeration methods significantly affected the final C/N ratios of piles ($p < 0.01$).

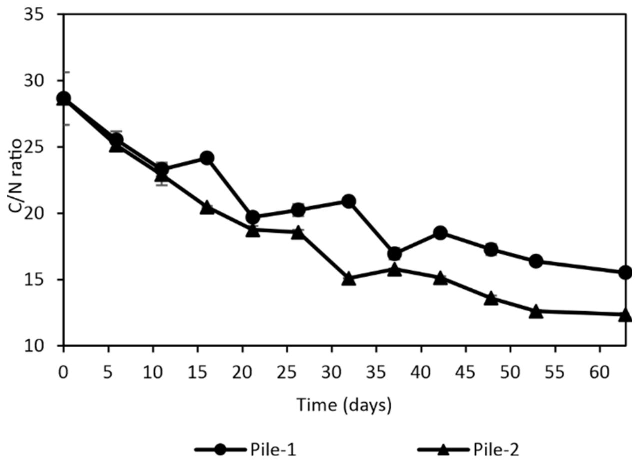


Fig. 8. Time dependences of C/N ratio for two piles with standard deviations

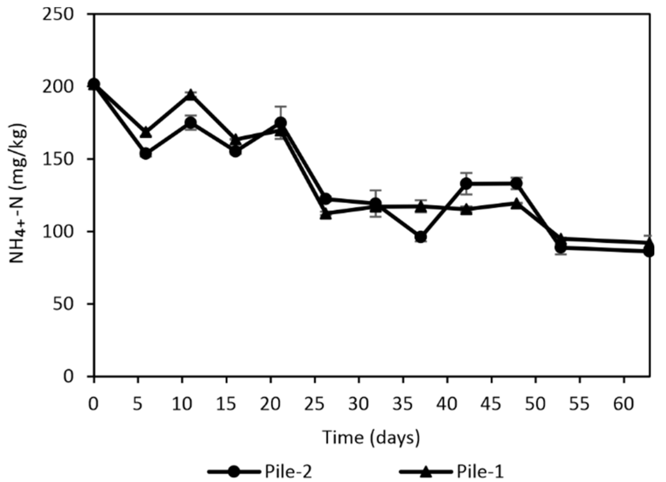


Fig. 9. Time dependences of $NH_4^+$–N contents for two piles with standard deviations

The decrease in the $NH_4^+-N$ content was observed from the initial value of 201.7 to 92.05 and 86.3 mg/kg for Pile-1 and 2, respectively at the end of composting (Fig. 9). The decrease was more pronounced for Pile-2 since it had higher pH during the process. Riffaldi et al. [17] stated that the absence of $NH_4^+-N$ or its reduction during composting is a good indicator of both good composting and compost maturation. Zucconi and de Bertoldi [18] suggested that the highest $NH_4^+-N$ content in mature compost is 400 mg/kg. It can be said that $NH_4^+-N$ content of composts from both piles satisfies the recommended value for agricultural application.

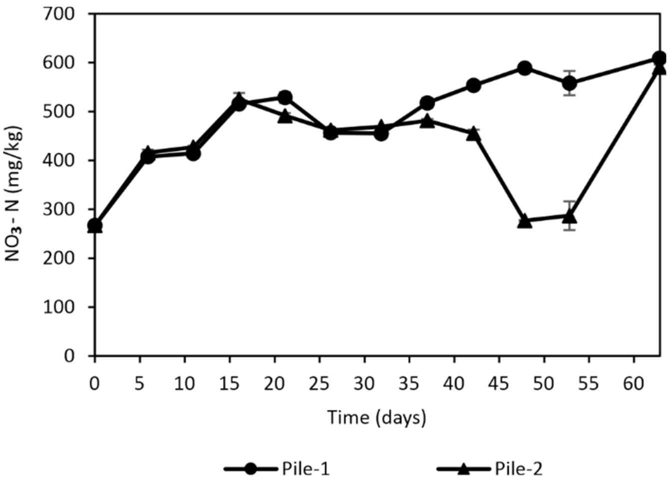


Fig. 10. Time dependences of $NO_3^-$–N contents for two piles with standard deviations

The $NO_3^- - N$ content in the two piles continually increased during the composting process (Fig. 10). A dramatic increase in the $NO_3^- - N$ content for both piles was measured in the first fifteen days for both piles. The change was higher in Pile-2 than Pile-1. Aeration methods showed no significant differences in the final $NH_4^+ - N$ and $NO_3^- - N$ contents of composts.

Figure 11 presents the time dependence of the total phosphorus content for the two piles. It increased from 0.21% to 0.51% and 0.73%, respectively (Fig. 11). Alfano et al. [19] found that the content of total phosphorus increased from 0.3–0.4% to 0.4–0.6% for composting of two-phase olive mill waste. Similarly, Rasapoor et al. [20] reported that the initial content of total phosphorus of 0.3–0.32% resulted in 0.35–0.5% at the end of the composting of municipal solid wastes. Results showed that aeration methods had a significant effect on the final total phosphorus contents of composts ($p < 0.01$).

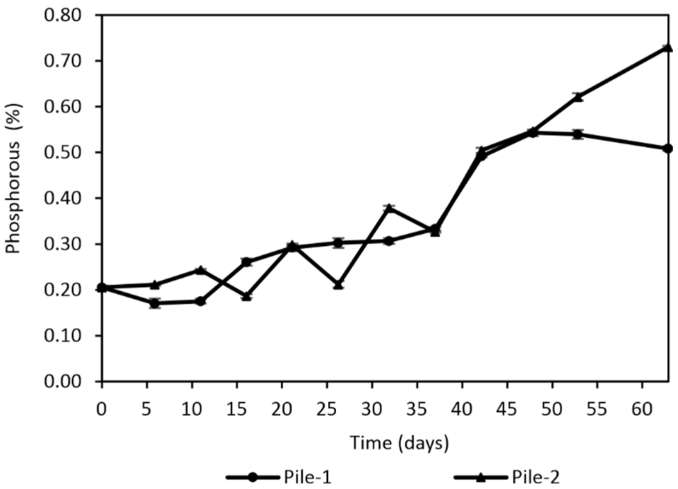


Fig. 11. Time dependences of total phosphorus percentage with a standard deviation

The changes of FAS of Pile-1 and Pile-2 during the composting are presented in Fig. 12. FAS was suggested by Haug [21] between 30% and 35%. Although the initial FAS (31%) of Pile-1 and Pile-2 were similar, the ending FAS (17% and 26%, respectively) differed due to the forced aerated and mechanically turned composting method. Breitenbeck and Schellinger [22] stated that the volume losses in the composting process were not only due to the loss of mass but also to the formation of smaller particles with the degradation of organic compounds.

Heavy metal concentrations in the final composts are given in Table 2. It can be said that the heavy metal concentration of composts increased compared to the initial value of the heavy metal concentration of the mixture. A similar increment was reported by research [23]. This increase may be due to weight loss caused by organic matter decomposition. All heavy metals examined in this study met the criteria required by both Turkish regulation on organic farming [24] and Eco-label limits [25].

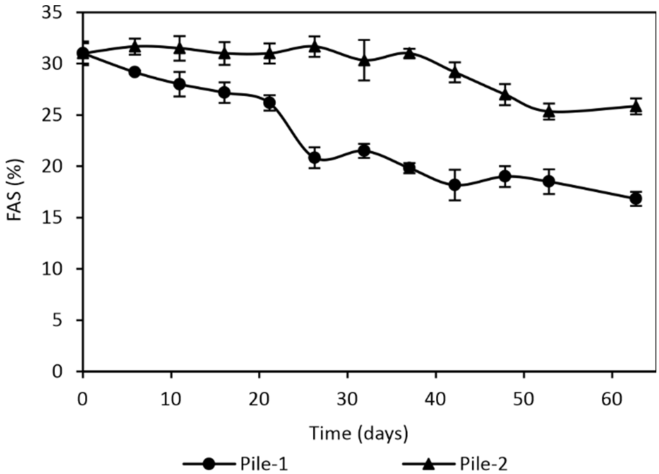


Fig. 12. Time dependences of FAS with a standard deviation

Table 2

Heavy metal concentrations in the examined composts with Turkish regulation on organic farming [24] and Eco-label limits [25] based on a dry weight basis

| Heavy metal concentration (mg/kg) | Initial | Final | | Turkish regulation limits | Eco-label limits |
|---|---|---|---|---|---|
| | | Pile-1 | Pile-2 | | |
| Pb | 0.55±0.49 | 1.61±0.48 | 1.56±0.45 | 45 | 100 |
| Cd | <LOD[a] | <LOD | <LOD | 0.7 | 1 |
| Cr | 8.05±1.32 | 18.98±0.69 | 17.58±2.09 | 70 | 50 |
| Cu | 16.56±0.05 | 30.49±4.26 | 34.05±0.72 | 70 | 100 |
| Ni | 9.01±1.06 | 21.01±1.62 | 23.21±0.64 | 25 | 50 |
| Zn | 39.22±4.24 | 83.59±5.63 | 80.28±2.2 | 200 | 300 |

[a]LOD – limit of detection.

The presence of $CH_4$ indicates anaerobic conditions in the composting process. The time dependences of $CH_4$ concentrations with the time for two piles measured at three locations are given in Fig. 13. The $CH_4$ concentrations of forced aerated pile fluctuated from 0 to 0.2% on average. This result implied that forced aeration oxygenated the pile well thereby yielding fewer $CH_4$ concentrations. The high amount of $CH_4$ present in the Pile-2 indicated that the anaerobic conditions in this pile were more dominant. It was observed that once the turning operation of the pile was performed, the $O_2$ concentration was immediately depleted. In Pile-2, the highest $CH_4$ concentration was recorded as 5.60% at day 16.8 days. This result is following the findings reported by Manios et al. [26] as 6% for windrow composting of two-phase olive oil mill sludge composting. The time-averaged $CH_4$ concentration of Pile-2 (1.25%) was higher than that of Pile-1 (0.06%). Similarly, Hao et al. [4] assessed the impact of composting methods on $CO_2$ and $CH_4$ emissions. Mechanically turned windrow had higher emission than that of the passively aerated pile.

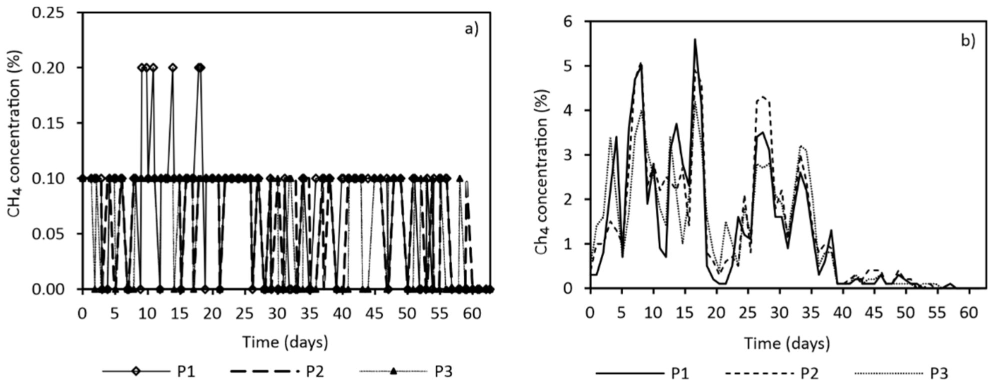


Fig. 13. Time dependences of $CH_4$ concentrations in Pile-1 (a) and Pile-2 (b) at three locations

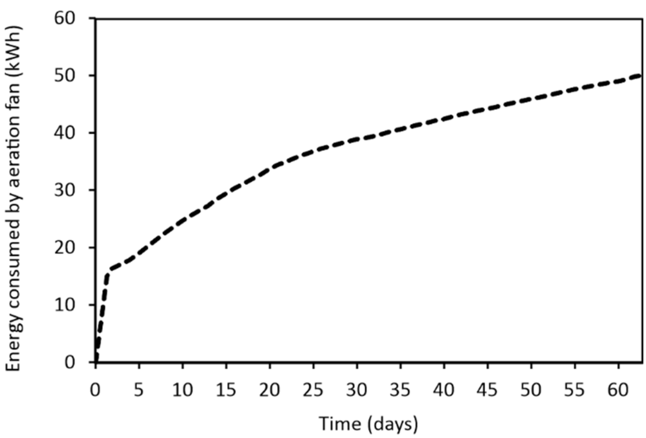


Fig. 14. Energy consumed by aeration fans during composting for Pile-1

The electrical energy consumed by the aeration fan was measured by electric meters during composting for Pile-1 and presented as changing with time in Fig. 14. The highest incline occurred within the first day of composting due to required airflow rates. End of composting, energy consumed by fans for Pile-1 was measured as 49.99 kWh. On the other side, the OML of Pile-1 was calculated as 51.1%. Based on these parameters, a useful number was defined as the energy consumed by aeration per unit OML of composting (*Ec*). *Ec* was calculated for Pile-1 as 0.98 kWh/OML corresponding on/off cycle of 10/30. This number is a normalization of energy consumed by fans considering OML of composting and could be used for intra-comparison of different treatments at the same composting experiment.

Seven turning operations were executed for Pile-2 and the full operation took 10 min. Diesel consumption by turning was estimated as 6.5 $dm^3/h$. The net calorific value of diesel fuel was 35.9 $MJ/dm^3$ and the conversion coefficient of 1 kJ = 0.00028 kWh. The corresponding total energy consumption by aeration for mechanical turning was 75.62 kWh. *Ec* was calculated for Pile-2 as 1.21 kWh/OML based on OML of 62.32% for Pile-2. This result showed that energy consumed by aeration per unit OML of composting for Pile-2 was 1.24 times greater than that of Pile-1. In this analysis, energy expenditure based on labor for installation of aeration pipes and tractor driver for mechanical turning was not included. On the other hand, Tiquia and Tam [27] reported that the energy requirement of the forced aeration was higher than that of a mechanically turned system for aeration. This clearly shows that the energy efficiency of the aeration system strictly rely on the selection of the aeration types, how they are operated, and the desired compost quality and OML level. Appropriate assessment of the management of composting aeration method is, therefore, needed if a composting system is run within an acceptable range and it should be optimized based on operating parameters.

## 4. CONCLUSION

Co-composting of rose oil processing solid waste, separated dairy manure, poultry manure, and straw (straw was used as bulking agents at the same time) was conducted to compare forced aeration and mechanical turning to evaluate their performances in terms of process parameters such as temperature and gas concentrations, the main characteristics of the final compost, energy requirement of the aeration systems. The results revealed that the efficiency of composting performed by two different aerations was quite identical. Differences that occurred in the temperature profiles indicated that the thermophilic phase lasted longer in a mechanically turned pile and mechanical turning led to more uniform temperature distribution horizontally. $O_2$ concentrations in the forced aerated pile never declined below 10% (average of three readings) while in the turned pile it dropped below a reasonable level and was usually lower than the forced aerated pile. This result implied that the forced aeration method supplied enough air for oxygen requirement. The magnitude of $CO_2$ concentrations measured in the mechanically turned pile was usually higher than that of the forced aerated pile. The time average of the $CH_4$ concentration of turned pile (1.25%) was higher than that of the forced aerated pile (0.06%). The results showed that maintaining the oxygen by forced aeration led to aerobic conditions to lessen the production of $CH_4$.

As regards the moisture content of piles, although the initial and final values of piles were similar, the pathways they followed were different due to evaporative cooling by forced aeration leading to higher water evaporation, especially in the temperature feedback period.

The composts obtained from both systems showed similar agronomic characteristics, which were of sufficient agronomic quality with high phosphorus, moderate electrical conductivity, and alkaline reaction. The pile with forced aerated underwent lower organic matter degradation (OML of 51.1%) whereas the organic matter concentration in the piles with mechanically turned was reduced by 62.32% of the initial values. There were significant differences in the final organic matter contents, C/N ratios, and total phosphorus between the two piles during the composting process. Aeration methods showed no significant differences in the final composts moisture, pH, *EC*, $NH_4^+$–N and $NO_3^-$–N contents.

The results suggested that forced aeration and mechanically turning can be used for composting of rose oil processing solid waste. When determining which of these systems should be used, the current state of the local economy should be considered. However, mechanical turning created anaerobic conditions for the formation of $CH_4$ concentration in the pile, which was higher than the forced-aerated pile. Secondly, energy consumed by aeration for 62.7 days composting was 49.99 kWh for the forced aerated pile and 75.62 kWh for the turned pile. Furthermore, energy consumed by aeration per unit OML of composting was 0.98 and 1.21 kWh/OML for forced aeration and mechanical turning, respectively. Further work should be carried out on greenhouse gas emissions and cost analysis of both methods for composting of rose oil processing solid wastes.

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