# Evaluation of two different aeration systems for composting two-phase olive mill wastes

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## Abstract

Composting of two-phase olive mill waste mixed with sheep litter and grape stalks was performed using two different aeration systems: forced aeration and windrow turning. The aim was to find out which of these technologies was the most appropriate for the composting of these materials. The efficiency of each aeration method was evaluated by monitoring the evolution of parameters such as temperature, biodegradation of organic matter fractions (carbohydrates, lipids, phenols, lignine, cellulose and hemicellulose) and nitrogen loss. Besides, the quality of the final composts was compared in terms of their main chemical characteristics (total N, N-$NH_4^+$, N-$NO_3^-$, $P_2O_5$, $K_2O$, pH, electrical conductivity, polymerisation degree, humification degree and germination index) and their hygienisation level (faecal streptococci) . The study revealed that forced aeration of static pile presents several drawbacks for the composting of two-phase olive mill waste (TPOMW) due to its physical properties. Several windrow turnings were required to avoid the formation of preferential air path-flows, the compaction and heterogeneous drying of the material. Piles elaborated by windrow turning showed a longer termophile phase which lead to a higher degradation of fibres and a greater loss of nitrogen. The quality of the end products obtained by both methods was quite similar, although the organic matter of composts prepared by windrow turning had a higher humification degree. Turnings of TPOMW composting piles are necessary for the normal development of the process and the high investment necessary to implement the forced aeration could be avoided. The benefits that forced aeration introduces by means of the control of temperature can be obtained by optimising pile size and turning frequency.

***Keywords:*** composting, olive mill wastes, sheep litter, grape stalks, forced aeration, windrow turning

## 1. Introduction

Management of olive mill wastes represent an important problem in Mediterranean countries. They are produced in large quantities in short periods of time and must be properly disposed of in order to avoid environmental risks. In last years a new low-water consuming technology has been implemented for the extraction of olive oil in Spain. This process generates a new semisolid by-product called two-phase olive mill waste (TPOMW), which contains a considerable amount of lipids, organic acids and phenols. Its peculiar composition, it is a phytotoxic material that can cause a great impact on land and water environments. The environmental problems arisen from the production of this residue have led to the study of a broad number of possible revalorisation methods which have been recently reviewed by Roig et al. [1].

Among the possible technologies for recycling the TPOMW, composting is one of the most promising options as it transforms this material into a valuable organic amendment. Composting is a biotechnological aerobic process where different microbial communities produce the mineralization of organic matter. The end product exhibits humic-like characteristics and can be safely applied as organic soil amendment. Some authors have demonstrated that composting may be a suitable low-cost strategy for the recycling of TPOMW with a complete detoxification of starting materials. However, the semisolid consistency of TPOMW makes necessary to mix it with another by-products (or wastes) in order to get the appropriate structure. Some of these materials, used as bulking agents, are straw [2], cotton waste [3], poplar sawdust and bark chips [4] and sheep litter [5]. In all cases the end product showed a high humification degree, no phytotoxic effects and considerable amounts of nutrients. Despite these advantages, the feasibility of industrial composting depends on the implementation of the best management practices in order to assure a high quality product at the lowest cost. Therefore, since aeration is required to supply oxygen to microorganisms and promote the degradation of organic matter, the aeration method obviously influences composting process efficiency and it is one of the most important parameters to be optimised. The best aeration method will depend on the nature of material to be composted. The most commonly used aeration systems are windrow turning and forced aeration.

Both aeration methods have shown to be suitable for a wide range of substrates. In general terms, the composting process with forced aeration is faster and results in higher quality composts [6]. Furthermore, it has been defined as a good method to reduce nitrogen loss by volatilisation [7]. However, it has the disadvantage, compared to pile turning, of the limited homogenisation of the pile and the formation of temperature gradients. Besides, there is a higher need of watering because of evaporation. The main disadvantages of the windrow turning system are the difficulty in controlling the temperature and the loss of nitrogen during the turnings.

The efficiency of composting under different aeration methods has been tested for some materials such as pig litter and sawdust [8], poultry litter [9], sheep manure and straw [10], vinasse and cotton gin waste [11]. However, the studies about the best aeration system when composting TPOMW are rather scarce [12].

The aim of this work was the comparison of two different aeration methods (forced aeration and mechanical turning) for the composting of TPOMW using sheep litter and grape stalks as bulking agents. The evolution of the composting process was evaluated in terms of organic matter decomposition rate (including the evolution of important fractions of organic matter characterised by different levels of biodegradability), nitrogen losses and quality of the end product.

## 2. Materials and methods

### *2.1. Composting piles elaboration*

All the by-products were supplied by an organic farm located in Murcia (Spain) which is currently developing farming (olive orchards, vineyards, livestock, etc.) and processing activities (mainly olive oil extraction).

Four composting piles were prepared by mixing two-phase olive mill waste (TPOMW), sheep litter (SL) and grape stalks (GS). The general characteristics of these residues are shown in Table 1. The TPOMW is a semi-solid waste obtained from the olive oil extraction process. It is constituted by olive pulp, mucilage, pectin, oil and vegetation waters. Sheep litter, a combination of sheep manure with straw from ovine bedding, was added to increase the concentration of nutrients, especially N, and, at the same time, to act as a bulking agent. Finally, grape stalks were added in two composting mixtures for contributing to the improvement of their structure. Two different aeration systems were tested: mechanical windrow turning and forced aeration.

The mixtures were prepared in the following proportions (dry weight basis):

a) Forced aeration

Mixture 1: TPOMW + SL (50:50)
Mixture 2: TPOMW + SL + GS (45:45:10)

b) Mechanical turning (windrow)

Mixture 3: TPOMW + SL (50:50)
Mixture 4: TPOMW + SL + GS (45:45:10)

Mixtures 1 and 2 (2000 kg) were composted in a pilot plant forming trapezoidal piles (1.0 m high with a 2×3m base) by the Rutgers composting system [13]. The air was blown from the base of the pile through the holes of three PVC tubes of 3m length and 12 cm diameter. During the first 30 days the timer was set for 1 min of ventilation every 15 min in order to activate the process and reduce the initial high moisture (65%). Afterwards, the timer was set for 1 min of ventilation every 30 min. However, it was seen that, even when high ventilation rates were applied, the process still needed mechanical turning to overcome the compaction and increase homogenisation so the process could develop properly. Therefore, several windrow turnings were performed. The ceiling temperature for continuous air blowing was 55ºC.

Mixtures 3 (40000 kg) and 4 (50000 kg) were composted in an industrial composting facility in trapezoidal piles (between 1.0 and 1.5 m high × 3.0 m base × 18 m length). The windrows were turned approximately once a fortnight (every two weeks) during the first two months and monthly afterwards with a front-end loader. During the thermophilic stage all the piles were watered regularly to maintain a moisture level between 35 and 50%.

Composts samples were obtained by mixing five sub-samples taken from different locations of the pile. Sampling was performed at four different stages of the composting process:

- I: From the initial non decomposed mixture: (first week of composting)
- T1: From the termophilic phase (12-14 weeks of composting).
- T2: From the termophilic phase (25 weeks of composting).
- F: From the final compost obtained (35-40 weeks of composting).

Each sample was divided into two parts, one of which was immediately analysed for faecal contamination, another was frozen for $NH_4^+$ analysis, while the other subsample was air-dried and ground to 0.5 mm for other analyses.

### *2.2. Analytical methods*

Temperature during composting was measured at five points in each pile with a temperature probe. The organic matter concentration (OM) was analysed by loss on ignition at 430ºC for 24 h [14]. Lignin and cellulose concentration were determined by the American National Standards Methods [15] and the hemicellulose concentration by substracting the cellulose concentration from the delignified sample (hollocelulose) obtained by Browning's method [16]. Phenolic substances were determined in 1:20 (w:v) water extracts by a modified version of the Folin method [17]. The total lipid content was determined using the traditional method of extraction in a Soxhlet with diethil-eter and later weighing and water-soluble carbohydrates by the anthrone method [18]. Total nitrogen ($N_T$) and organic carbon ($C_{org}$) were determined by automatic elemental microanalysis. Phytotoxicity, expressed as germination index (GI), was assayed by the *Lepidium sativum* test [19]. Extractable carbon ($C_{ext}$) was measured in a 0.1 M NaOH compost extract (20:1 w/v) and the fulvic acid carbon ($C_{FA}$) after precipitation of the humic acid at pH 2 in the supernatant solution. The humic acid carbon content ($C_{HA}$) was calculated by subtracting fulvic acid carbon to the extractable carbon. Cation exchange capacity (CEC) was determined with $BaCl_2$-triethamolamine [20]. Streptococcus counts were determined by the most probable number (MPN) method (APHA, 1985) in a suspension 1:4 (w/v).

Loss of nitrogen from the pile during composting was calculated according to the equation:

$$\text{N-loss (\%)} = 100 - 100\ [(X_1 N_2)/(X_2 N_1)]$$

where $X_1$ and $X_2$ are the initial and the final ash concentrations, and $N_1$ and $N_2$ are the initial and final total nitrogen concentration [7].

### *2.3. Statistical Analysis*

The mean and standard deviation of at least three replicates were reported for all the parameters measured. The Waller-Duncan test was used to compare chemical parameter values ($P<0.05$) using the SPSS 12.0 program for Windows.

## 3. Results and discussion

### *3.1. Temperature profiles*

As shown in figure 1, two different temperature profiles were found for both aeration systems. Piles 1 and 2, prepared by forced aeration, showed irregular temperature profiles (with sudden increases and drops) indicating that this method had several drawbacks for the composting of TPOMW that slowed down the process. Thus, owing to the oily consistency and lack of porosity of this residue, the injected-air formed preferential pathways trough the pile, drying the material heterogeneously and making up aggregates that paralysed the process (figure 2). Therefore, piles 1 and 2 needed to be turned in order to activate the process and improve homogeneity. This procedure is normally followed to overcome the major disadvantages of the Rutgers system, performing one or two turnings during the whole process [12, 21]. Nevertheless, in this study, once the thermophile phase was achieved, it was not possible to maintain temperatures above 40ºC, even at different operational regimes (high or low flow rate) and therefore pile-turnings were required to reactivate the process. Furthermore, an equally important hindrance was the compaction of piles in time due to the small particle size of TPOMW. Hence, subsequent turnings were required to increase the aeration of the mass. This disadvantage was less evident in pile 2, where grape stalks had been added to improve the structure of the material.

Air-blowing was stopped after 24 and 17 weeks of composting in piles 1 and 2 respectively and an immediate rise of temperature was observed in both piles. After that, another turning was made before allowing the composts to mature.

On the contrary, piles 3 and 4 showed an extended thermophilic phase, which is a characteristic of this organic matrix because of its high thermal inertia. A long duration of the composting process has been reported for olive mill wastes [5, 12, 22] and other ligno-cellulosic by-products [23, 24]. Nowadays there is a debate regarding the optimal and maximum temperatures for the decomposition of organic matter. Thus, different authors have found optimum values between 45ºC and 70ºC [25]. Nevertheless some composting materials are able to self-heat up to 80ºC and the Rutgers strategy is able to remove heat through ventilation.

The control of temperature is more difficult in windrows, where the size of the pile plays an important role. Thus, too small piles do not reach temperatures high enough to favour the development of a thermophilic micro-flora and too big piles reach temperatures too high that paralyse the process. In this study the selected pile-size and turning program gave temperature values between 45 and 55 in pile 3, which were considered adequate for the development of the composting process, and between 50 and 67 in pile 4, which in some points were above the recommended values. The higher temperatures reached in pile 4 could be due to the greater pile size and also to the enhancement of microbial activity produced by grape stalks.

### *3.2. Organic matter degradation*

The organic matter (OM) of the four mixtures studied was partially degraded during the composting process and the extent of the degradation was affected by the aeration method used (figure 2). Mixtures 1 and 2 (forced aeration) underwent lower OM degradation (around 40% of their initial content), whereas the OM concentration in mixtures 3 and 4 (windrow), where higher temperatures were achieved, was reduced by more than 60% of the initial values. The longer process and higher temperatures achieved by windrowing caused a greater degradation of the organic matter.

The evolution of the different OM fractions was also monitored during composting. From all the fractions lignin is the most abundant for this kind of material (Figure 2). The starting mixtures showed a high concentration of lignin of around 30%, which was more intensely degraded in piles performed by the windrow system (more than 50% of the initial value) than in forced aerated piles, where the biodegradation barely reached 30%.

Lignin is very resistant to microbial degradation but, at the same time, has been defined as one of the main precursors of humic substances and therefore it can play an important role in humification processes. Some authors have reported little or no degradation of lignin during the composting of TPOMW [2, 12]. However, it is known that some microorganisms, mainly fungi, have developed the enzymes necessary to degrade lignin. According to a broad review recently published by Tuomela et al. [26], thermophilic microfungi are the most important lignin degraders in a composting environment and have their optimal temperature around 50ºC. The effect of temperature on lignine degradation has been studied by several authors, showing that the duration of the thermophilic phase is crucial for the degradation of lignin during the composting of diverse organic materials [27, 28, 29]. Therefore, in the present study, the short thermophilic periods in piles elaborated by forced aeration (1 and 2) did not allow optimum temperature conditions for the growth of thermophilic fungi. Hence, the degradation of fibres was lower than in piles performed by the windrow system (3 and

4) where high temperatures were kept for long. Similar results were found by Solano et al. [10], who observed a faster degradation of lignin and cellulose in a mixture of sheep manure and straw when using pile turning as aeration system, which led to a longer thermophilic phase compared to the forced aeration system.

Cellulose and hemicellulose were also abundant (between 15 and 25%) and were reduced in most cases to more than 50% of the initial value. Similarly to the lignin fraction, the degradation of these polymers was more intense in piles 3 and 4, reflecting the effect of the aeration method on its degradation. Although these fibres are less resistant to biodegradation, the presence of lignin can reduce their available area to microbial attack [30]. In pile 4 the degradation rate was lower than in pile 3 probably because this pile held grape stalks which showed higher particle size and therefore less available surface for microbial attack.

The aeration system used to compost TPOMW had different effects on the degradation patterns of the more easily degradable fraction of the organic matter (Table 2). Regarding water-soluble carbohydrates, their concentration varied greatly among the initial composting mixtures (between 0.98 and 5.96%). The reason of this variability is that carbohydrates concentration in TPOMW depends on many factors such as olive variety and the ripeness of the fruit which are subjected to temporal changes. In all piles the concentration of carbohydrates fell sharply during the first stage of composting by more than 60% of the initial values although there was little variation during the rest of the composting process (pile 3 was an exception due to the low initial concentration). Results indicate that this fraction of water-soluble organic carbon, the most labile and sensitive in reflecting the biochemical transformations, was used immediately by microorganisms and no differences were observed with respect to the aeration method used.

A great decrease was also observed for the lipid fraction with a reduction of about 90% of the initial values in all piles. The initial values, which depend on the extraction yield obtained in the olive mill, ranged between 2.1 and 7.2% but in the final stage they were lower than 0.5% (Table 2). The degradation pattern of the lipid fraction was unaffected by the aeration system used in the composting piles and in both cases the final composts achieved a satisfactory reduction of lipids. The quick and intense degradation of the lipid fraction has been previously reported by other authors when composting TPOMW with different bulking agents [2, 4] such as cotton waste, poplar sawdust and bark chips.

Water soluble phenols are important components of organic matter during composting since they are involved in degradation and humification processes. A reduction of 34% and 44% was observed in piles 1 and 2 prepared by mechanical turning (Table 2). However, piles 3 and 4 underwent a different pattern with increases and falls during the composting process, showing no clear degradation trend for this fraction. The behaviour shown by the piles prepared by windrowing was probably due to the release of these compounds to the medium as a consequence of lignin degradation which was much more intense in these piles. Other authors have reported greater reductions for phenols during the composting of TPOMW [2, 12], but it is important to indicate that they did not find such an intense lignin degradation.

### *3.3. Nitrogen losses*

Different patterns were evident for both aeration methods, showing that nitrogen losses were always lower in the piles equipped with forced aeration. Thus, while in piles 1 and 2 the variations (increases or decreases) in nitrogen losses where within 10% of the initial values, in piles 3 and 4, total nitrogen losses at the end of the composting process were 45 and 32% respectively (Figure 3).

During composting, nitrogen is mainly lost trough volatilisation of $NH_3$ at high pH and temperatures. These N-losses are associated to stages of maximum degradation of organic matter, where higher amounts of $NH_4^+$ are released to the medium. Since the pH of all the piles studied followed a similar pattern, from initial values of 7 to final values of 9, the main differences between the piles studied were the higher temperatures, number of pile turnings and degradation rate of the piles prepared by mechanical turning (piles 3 and 4). In these piles there was a greater release of $NH_4^+$ to the medium as consequence of the higher OM mineralization, and higher temperatures were responsible for the largest N-losses through ammonia volatilisation.

A different behaviour was also observed in piles containing grape stalks as bulking agent (piles 2 and 4) which suffered less nitrogen losses than the correspondent pile elaborated without the bulking agent, regardless of the aeration method. This fact confirms the importance of adding bulking agents for avoiding N losses [7, 21].

A suitable strategy for preventing N-losses during the composting process could be the control of pH. Thus, in a recent study, Roig et al [31] proposed the use of elemental sulphur to control pH during composting of olive mill wastes.

### *3.4. Characteristics of the final composts*

Table 3 shows some of the main chemical characteristics of the composts obtained. Overall, the four end composts obtained showed similar characteristics with regard to their agronomic value. All of them exhibited an adequate agronomic quality, with high concentration in potassium, moderate conductivity and alkaline pH. The OM concentration ranged between 35 and 55%, depending on the initial OM concentration in the mixture and the degree of mineralisation achieved. The total N was lower in piles 3 and 4, which is due to higher N losses trough volatilisation of ammonia produced by greater ammonia concentration as a result of OM degradation and higher temperatures. Low concentrations of inorganic nitrogen ($NH_4^+$, $NO_3^-$) were generally detected in all cases, which indicate that N is mainly associated to organic fractions. None of the composts obtained showed phytotoxic effect, with germination indices between 72 and 104%, higher than those obtained by other authors for TPOMW composts [3, 12].

In order to asses the compost maturity two humification parameters were determined by means of both polymerisation ($C_{HA}/C_{FA}$) and humification ($CEC/C_{org}$) degrees. Both indices showed higher values in composts obtained by windrow turning, where the highest biodegradation had been produced and the lignin was more intensely degraded.

When manures are used as conditioning agents the level of pathogens are important criteria that must be evaluated. In the present study, the faecal contamination of the final composts was evaluated by analysing total faecal streptococcus, that are important markers of faecal contamination and have been broadly used by many authors. The low levels found, showed the high level of sanitisation of the piles.

## 4. Conclusions

The main conclusions of this work can be summarized as follows:

- The forced aeration of static pile showed several drawbacks for the composting of TPOMW due to its physical properties. Thus, successive turnings of the pile were required to reactivate the process.

- Composting piles performed by mechanical turning developed higher temperatures, what allowed the degradation of lignin and enhanced the humification processes but, on the other hand increased the losses of nitrogen.

- The quality of the end product obtained by both aeration methods was similar from an agricultural point of view, although the organic matter of the composts obtained by mechanical turning had a higher humification degree and a lower N concentration.

- The control of temperature may be done by selecting an appropriate pile size and turning program. A successful composting process was achieved by adding bulking agents (sheep litter and grape stalks) to the TPOMW and performing a turning every two weeks during the first two months and monthly afterwards.

As general conclusion, the aeration method based on windrow turning is recommended for the successful composting of TPOMW in terms of the OM degradation and humification degree of the end products.

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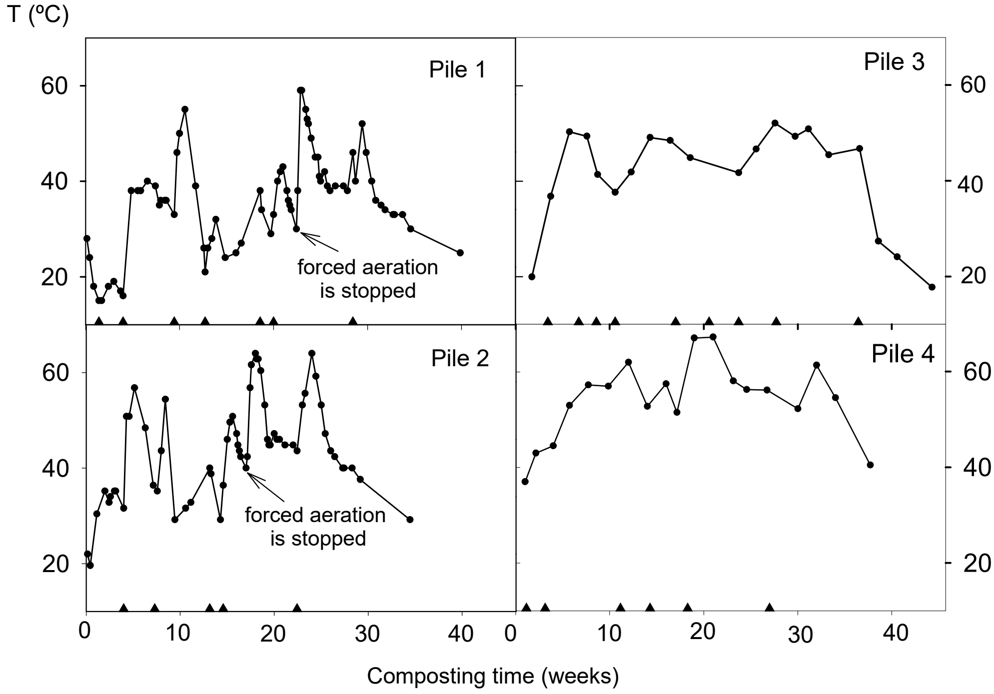

Figure 1. Temperature evolution of the piles during composting. Triangles in the x-axis indicate the turning time of the piles.

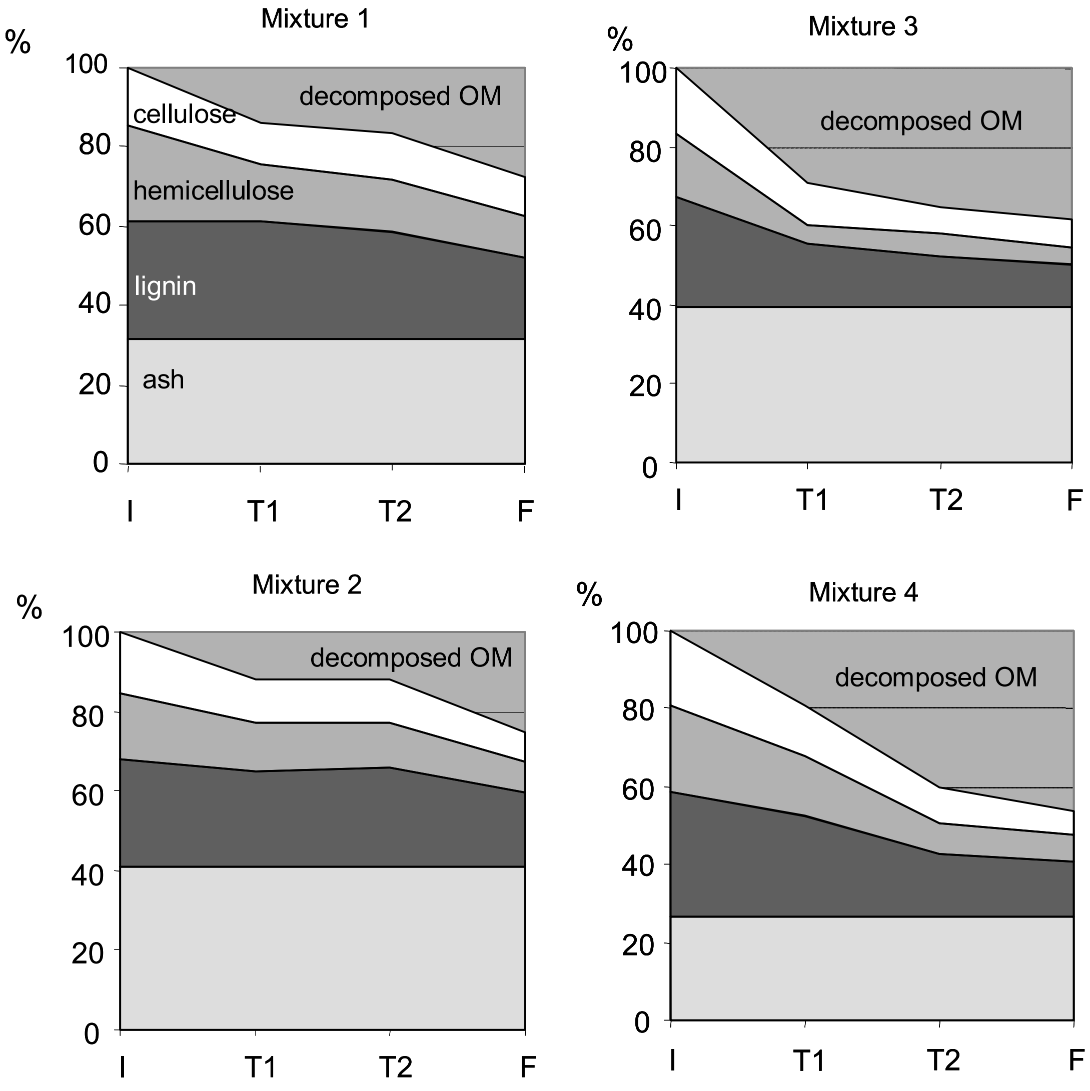

Figure 2. Absolute levels of the main constituents (cumulative areas) of the organic matter in the composting mixtures at different stages of the composting process (I: initial, T1 and T2: termophile, F: final). Coefficient of variation was in all cases inferior to 5%.

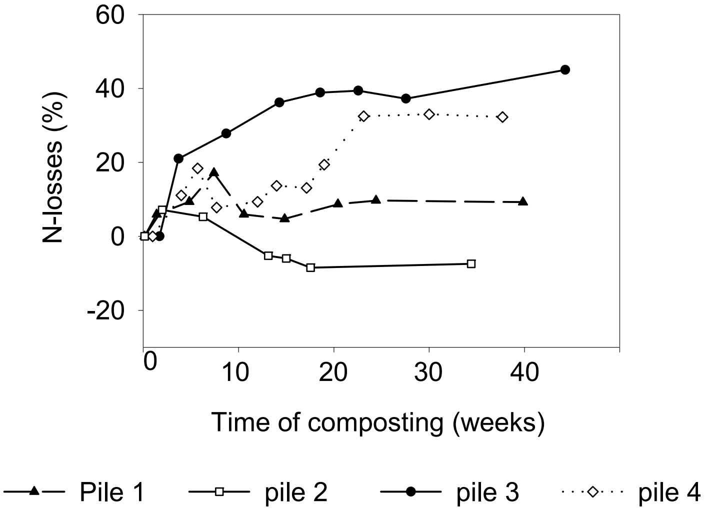

Figure 3. Time course of the N-losses of the four composting mixtures.

Table 1. Main chemical characteristics of the by-products used for composting.

| | Two-phase olive mill waste | | Sheep litter | | Grape stalks | |
|---|---|---|---|---|---|---|
| Parameter | Mean | sd | Mean | sd | Mean | sd |
| Moisture(%) | 64.5 | 3.6 | 28.1 | 10.7 | 53.2 | 11.4 |
| OM (%) | 94.3 | 1.5 | 40.6 | 6.6 | 75.3 | 9.4 |
| TOC (%) | 55.1 | 3.0 | 23.1 | 6.0 | 41.8 | 1.3 |
| TN ($g\cdot kg^{-1}$) | 11.3 | 1.2 | 17.0 | 4.0 | 13.8 | 5.4 |
| P ($g\cdot kg^{-1}$) | 0.9 | 0.3 | 2.5 | 0.5 | 1.3 | 0.8 |
| K ($g\cdot kg^{-1}$) | 2.4 | 0.4 | 2.7 | 0.8 | 2.8 | 0.9 |
| Lignin (%) | 47.5 | 5.8 | 21.6 | 4.5 | 42.5 | 0.9 |
| Cellulose (%) | 16.5 | 1.8 | 12.5 | 5.3 | 30.8 | 11.6 |
| Hemicellulose (%) | 38.7 | 6.0 | 9.3 | 4.5 | 19.0 | 0.9 |
| Carbohydrates ($g\cdot kg^{-1}$) | 96.0 | 50.0 | 6.9 | 0.9 | 8.0 | 1.4 |
| Lipids ($g\cdot kg^{-1}$) | 202 | 60 | 6.3 | 3.2 | 5.5 | 2.1 |
| Phenols ($g\cdot kg^{-1}$) | 12.2 | 1.6 | 1.9 | 0.6 | 2.1 | 0.4 |
| pH | 5.2 | 0.2 | 8.6 | 0.4 | 8.1 | 0.1 |
| EC($dS\cdot m^{-1}$) | 5.2 | 0.6 | 6.9 | 3.1 | 2.5 | 1.2 |

For the characterisation of the by-products used, seven samples of TPOMW, five of SL and two of GS were taken.
sd: standard deviation

Table 2. Some important constituents of organic matter at different stages of composting.I : initial, T1 and T2: termophile, F: final.

| | Phase | Carbohydrates | Lipids | Phenols |
|---|---|---|---|---|
| Forced aeration | | | (%) | |
| Pile 1 | I | $5.96^{a}$ | $4.43^{a}$ | $0.65^{a}$ |
| | T1 | $2.01^{b}$ | $1.41^{b}$ | $0.56^{b}$ |
| | T2 | $1.90^{bc}$ | $0.63^{c}$ | $0.52^{c}$ |
| | F | $1.64^{c}$ | $0.23^{d}$ | $0.43^{d}$ |
| Pile 2 | I | $3.62^{a}$ | $3.31^{a}$ | $0.57^{a}$ |
| | T1 | $1.19^{c}$ | $0.66^{b}$ | $0.51^{b}$ |
| | T2 | $1.50^{b}$ | $0.56^{b}$ | $0.48^{c}$ |
| | F | $1.29^{c}$ | $0.22^{c}$ | $0.32^{d}$ |
| Mechanical turning | | | | |
| Pile 3 | I | $0.98^{a}$ | $2.09^{a}$ | $0.43^{b}$ |
| | T1 | $0.61^{b}$ | $0.57^{b}$ | $0.45^{a}$ |
| | T2 | $0.51^{b}$ | $0.25^{c}$ | $0.24^{c}$ |
| | F | $0.51^{b}$ | $0.25^{c}$ | $0.44^{ab}$ |
| Pile 4 | I | $3.66^{a}$ | $7.24^{a}$ | $0.54^{a}$ |
| | T1 | $1.42^{b}$ | $4.51_{b}$ | $0.27^{c}$ |
| | T2 | $0.95^{d}$ | $0.52^{c}$ | $0.38^{b}$ |
| | F | $1.06^{c}$ | $0.48^{c}$ | $0.29^{c}$ |

Values followed by the same letter are not statistically significant at $P<0.05$ according to the Waller-Duncan test.

Table 3. Main chemical characteristics of the final composts (dry weight basis).

| | **Forced aeration** | | | | **Mechanical turning** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Compost 1** | | **Compost 2** | | **Compost 3** | | **Compost 4** | |
| | **Mean** | **sd** | **Mean** | **sd** | **Mean** | **sd** | **Mean** | **sd** |
| OM (%) | 54.6 | 0.3 | 43.7 | 0.3 | 34.9 | 0.3 | 48.6 | 0.6 |
| TOC/TN | | | | | | | | |
| TN (%) | 1.94 | 0.05 | 1.89 | 0.04 | 1.38 | 0.00 | 1.56 | 0.01 |
| N-NH$_4^+$ (mg·kg$^{-1}$) | 106 | 3 | 130 | 6 | -- | -- | 124 | 2 |
| N-NO$_3^-$ (mg·kg$^{-1}$) | <10 | -- | 387 | 13 | 296 | 7 | 414 | 11 |
| $P_2O_5$ (g·kg$^{-1}$) | 4.7 | 0.1 | 4.2 | 0.1 | 6.9 | 0.6 | 6.0 | 0.02 |
| $K_2O$ (%) | 4.7 | 0.3 | 3.8 | 0.03 | 2.5 | 0.07 | 3.3 | 0.12 |
| pH | 9.50 | 0.02 | 9.44 | 0.01 | 9.27 | 0.03 | 9.13 | 0.02 |
| EC (dS·m$^{-1}$) | 7.31 | 0.12 | 4.98 | 0.06 | 3.10 | 0.01 | 3.09 | 0.05 |
| $C_{HA}/C_{FA}$ | 2.7 | 0.3 | 3.3 | 0.1 | 6.2 | 0.5 | 5.0 | 0.1 |
| CEC/$C_{OT}$ (mE·g$^{-1}$) | 2.4 | 0.1 | 3.6 | 0.1 | 3.5 | 0.3 | 4.0 | 0.2 |
| GI (%) | 74.2 | -- | 87.8 | -- | 72.4 | -- | 104.2 | -- |
| Faecal streptococcus (MPN/g) | | | | | | | | |