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Effects of the forced ventilation on composting of a solid olive-mill by-product (“alperujo”) managed by mechanical turning

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Abstract

The evaluation of the most suitable aeration technology for olive-mill by-product “alperujo” (AL) composting was carried out by using two identical piles prepared by mixing AL with a bulking agent (fresh cow bedding) and a mature compost (as inoculant). Forced ventilation was employed in conjunction with mechanical turning in one of the piles, whereas only mechanical turning was used in the other pile. These two treatment methods were evaluated by assessing process efficiency and end-product quality.

The results show that the composting process was completed in less time when forced ventilation was coupled with mechanical turning. A slight delay in the evolution of pH, C/N ratio, and biodegradation of fats and organic matter was observed when only turning was employed. However, the recommended method for composting AL was mechanical turning without forced ventilation since the composition of the end-product in this case was comparable to the composted AL using forced ventilation coupled with mechanical turning. Furthermore, there were substantial economic savings by selecting mechanical turning alone, which included capital costs for equipment.

1. Introduction

The olive oil extraction industry has great economic and social importance in many Mediterranean countries such as Spain, Italy, Greece, Tunisia, Turkey and Morocco, but is often associated with the generation of wastes and by-products that provoke adverse environmental problems. Improving the appropriate management of these materials urgently needs more intensive research. At present, the most abundant olive-mill by-product in Spain (the yearly production of which may exceed 4 million tons) is “alperujo” (AL), a very wet material with a lack of consistency and low porosity (poor physical structure) obtained by the most recent technology employed for olive oil extraction (the continuous two-phase centrifugation system). AL has a unique pungent odour and shows a certain hydrophobic character due to its residual fat content. Its main agrochemical characteristics have been previously described (Alburquerque et al., 2004).

Composting has been used as a simple, suitable, and low cost technology for processing and adding value to the olive-mill wastes and by-products in order to obtain composts useful either as organic fertilisers or soil amendments (Tomati et al., 1995; Madejón et al., 1998; Paredes et al., 2001, 2002; Filippi et al., 2002; Ait Baddi et al., 2004; Baeta-Hall et al., 2005). Also, composting is known to require appropriate conditions of particle size, porosity, and free air space (all related with the substrate physical structure and correct air distribution in the mass); a balanced equilibrium of nutrients and C/N ratio; and accurate conditions of temperature, moisture and oxygen supply (De Bertoldi et al., 1985; Verdonck, 1988; McCartney and Chen, 2001), all of which influence optimal conditions for microbial development.

Moreover, the main problem that must be resolved in open composting systems is the even distribution of oxygen to the mass, which is especially important in substrates

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with poor physical structure such as AL. The addition of appropriate bulking agents, such as wheat straw, poplar sawdust and bark chips, grape stalk and cotton waste (Madejón et al., 1998; Filippi et al., 2002; Baeta-Hall et al., 2005; Alburquerque et al., 2005), has been shown to decisively influence AL composting by improving its scarce porosity.

Among the different composting systems, the use of static piles aerated by forced ventilation allows a sustained supply of oxygen and removes heat, decomposition gases and water vapour, so that effective control of the substrate temperature can be performed. However, preferential air channels and anaerobic pockets can also be formed, and the homogenisation of the mass (redistribution of microorganisms, nutrients and water) is not allowed. On the contrary, mechanical turning mainly homogenises the composting substrate and is the most simple and inexpensive composting method, but the oxygen supply can not be kept at a constant level and temperature control is more limited than in the forced ventilation system (Finstein and Hogan, 1993; Stentiford, 1996). Therefore, the combination of forced ventilation and turning can overcome the main disadvantages of both systems, but also involves a major cost (Stentiford, 1996).

The key to optimisation of AL composting is controlling the aeration conditions of the piles. Therefore, the aim of this work was to comparatively study the effectiveness of two aeration composting strategies: only mechanical turning, and forced ventilation coupled with mechanical turning.

2. Materials and methods

2.1. Composting performance

The mixture used for the composting experiments was made by mixing 90% of AL with 9% of a fresh cow bedding (FCB) and 1% of a mature AL compost (MC), based on fresh weight (87/11/2 on a dry weight basis). Later the mixture was separated into two equal sized piles (2 m wide, 3 m long and 1.5 m high) of about 4000 kg each.

The AL used was supplied by "Fábrica y Envasadora de Aceite de Oliva Vírgen OLIBAZA S.L." from Baza (Granada, Spain), the bulking agent FCB by "Grupo Cárnico Angelín" from Santomera (Murcia, Spain), while the compost added (MC) to inoculate the mixture was previously obtained in another composting experiment where AL was mixed with olive leaves. As shown in Table 1, AL exhibited a considerable moisture content, acidic pH and high organic matter content, mainly composed by hemicellulose and lignin; FCB, which was formed by liquid and solid livestock wastes including abundant cereal straw, had neutral pH, high electrical conductivity, considerable hemicellulose and nutrient contents, low C/N ratio and good water-retention characteristics, whereas MC had basic pH, high organic matter and lignin load and low nutrient content.

Table 1
Main characteristics of the "alperujo" (AL), fresh cow bedding (FCB) and mature compost (MC) employed to prepare the composting substrate (dry weight)

Parameters	AL	FCB	MC
Moisture (% f.w.)	55.6	46.1	15.2
pH[a]	5.08	7.47	8.99
EC[a] (dS m^{-1})	4.76	7.53	2.96
OM (g kg^{-1})	942.3	664.0	912.2
Lignin (g kg^{-1})	335.0	185.0	399.2
Cellulose (g kg^{-1})	205.0	122.1	208.0
Hemicellulose (g kg^{-1})	406.0	325.3	291.4
TOC (g kg^{-1})	523.3	369.1	484.9
TN (g kg^{-1})	13.2	19.4	23.1
C/N ratio	39.6	19.0	21.0
P (g kg^{-1})	0.8	2.5	1.5
K (g kg^{-1})	27.3	35.8	36.2
Ca (g kg^{-1})	6.6	63.7	9.4
Mg (g kg^{-1})	1.2	8.8	1.9
Fe (mg kg^{-1})	690	1442	525
Cu (mg kg^{-1})	14	23	33
Mn (mg kg^{-1})	9	191	44
Zn (mg kg^{-1})	18	159	50

[a] Water extract 1:10.

The composting experiment was developed in two chambers of a pilot plant. Each chamber was constructed with three sides made of concrete and the front was closed off by metal doors. A metal roof structure provided shade and also housed the irrigation system. The experiment was conducted inside this chamber to avoid the drying effect of the extreme heat, which can reach above 40 °C in this region. Pile 1 was only aerated by mechanical turning whereas the pile 2 was subjected to both mechanical turning and forced ventilation with temperature feedback control, based on the Rutgers strategy (Finstein et al., 1985). On/off cycles of 5/15 min for intermittent ventilation were employed by using a blower (1/6 HP) attached to an easily-removable air distribution system composed of seven flexible polyvinyl chloride tubes, 3 m in length and 3.5 cm in diameter, with aeration holes on the horizontal and vertical axis of the tubes. The tubes were placed approximately at one-third of the total pile height from the base of the pile. To avoid high temperatures that could limit the process, the ceiling temperature for continuous air blowing was fixed at 55 °C, the ventilation system was automatically connected when the temperature was higher and the ventilation demand measured as the time necessary to maintain temperature below 55 °C.

Both piles were turned over 14 times, once a week during the first 2 months and every 2 weeks afterwards, as shown in Fig. 1 using a tractor with a shovel. The active phase was considered finished when the temperature of the piles was close to ambient and re-heating did not occur (26 weeks). The air blowing and the mechanical turning were then stopped to allow the composts to mature over a period of approximately 3 months. The moisture was checked and controlled weekly so that the necessary amount of water was added by irrigation to maintain moisture within

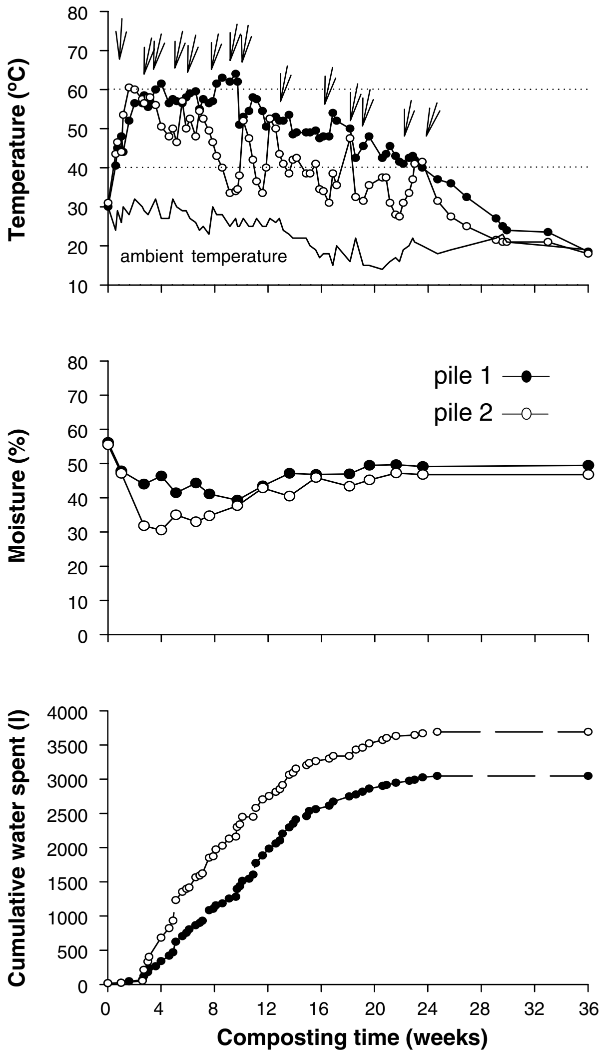

Fig. 1. Temperature profile (arrows indicate turnings), moisture content and water added during composting (pile 1: mechanical turning and pile 2: forced ventilation combined with mechanical turning).

the range of 40–55%; excess water leached from the piles was re-circulated.

Composting materials were sampled from randomised sites around the pile coinciding with each turning operation, and then after maturation. The representative samples were homogenised and subdivided into three sub-samples at the laboratory. One of them was frozen (−20 °C) and kept for the determination of NH_4^+–N and NO_3^-–N, the second was dried in an oven at 105 °C for 24 h to determine the moisture content, while the third sub-sample was freeze-dried and ground to less than 0.5 mm prior to analysis.

2.2. Analytical methods

The water-soluble organic carbon (WSC) was determined by using an automatic carbon analyser for liquid samples; NH_4^+–N was extracted with 2 M KCl from the frozen sub-samples and determined by a colorimetric method based on Berthelot's reaction (Sommer et al., 1992); NO_3^-–N was measured by using an ion-selective electrode on the water extract and phytotoxicity was determined from the germination index (GI) according to Zucconi et al. (1981). Other parameters, including electrical conductivity (EC) and pH, organic matter content (OM), total nitrogen (TN), total organic carbon (TOC), P, K, Na, Ca, Mg, Fe, Cu, Mn and Zn, total fat content, water-soluble phenols (WSPH), lignin, cellulose and hemicellulose were determined according to the methods previously described by Alburquerque et al. (2004). Losses of total organic matter and its main components, lignin, cellulose and hemicellulose, were calculated taking into account the apparent increase in the ash content resulting from the loss of dry matter weight in order to better reflect the overall changes (Stentiford and Pereira Neto, 1985; Nuntagij et al., 1989; Paredes et al., 2002).

2.3. Statistical analyses

The least significant difference was used to compare parameter values ($P < 0.05$).

3. Results and discussion

A rapid increase in temperature was recorded in both piles during the first days of composting (Fig. 1), which suggested a clear improvement of the physical structure of the composting substrate due to the addition of the bulking agent to AL. Moreover, FCB also provided an available nutrient source and had an inoculum effect similar to MC. Mechanical turning also favoured the increase of temperature by reducing compaction and homogenising and re-inoculating the substrates, since other AL composting experiments have demonstrated that forced ventilation alone is scarcely effective for the advance of the process (Baeta-Hall et al., 2005; Alburquerque et al., 2005, 2006). Temperatures in both piles clearly reached thermophilic range, and pile 1 showed higher, less variable thermophilic temperatures for a longer duration than in pile 2. This could be explained by the cooling effect from the forced ventilation that caused greater water evaporation in pile 2, particularly during the ventilation demand. At the end of the 24th week, the temperatures progressively fell in both piles to reach the mesophilic phase and continued to cool down until the end of maturation.

In the periods of maximum activity, the forced ventilation treatment was unable to maintain the temperature below 55 °C in the central zone of pile 2, probably due to the excessive pile size. In spite of the above fact, the average temperature in pile 2 was still lower than in pile 1 most of the composting time, thus forced ventilation most likely favoured more diverse microbial activity in pile 2, as it is known that temperature acts as a selective factor for microbial populations. Moreover, the heat dissipated by the ascending air currents could have generated large thermic variations in the vertical profile of pile 2, also favouring the existence of greater microbial diversity in the different layers of this pile which was subjected to both forced ventilation and turning. Also, it is to be noted that forced ventilation of pile 2 enhanced the process performance during the initial stages of composting, when the oxygen was more limited due to the intense microbial activity. On the contrary, pile 1 was submitted to a less constant oxygenation and higher temperatures; both are factors which contribute to the delay of OM decomposition (Sikora and Sowers, 1985; Darbyshire et al., 1989; Nakasaki et al., 1990; Vuorinen and Saharinen, 1997).

As mentioned by Li et al. (2004), an ideal aeration system must reach an optimal balance between the enhancement of airflow (oxygen supply) and other factors, including moisture, in order to achieve the maximum biodegradation. Thus, an undesirable consequence of using the forced ventilation technique was the difficulty in maintaining a suitable level of moisture in pile 2, which showed moisture values under 40% during most of the initial weeks of the process, coinciding with the long ventilation demand. Adding abundant quantities of water only raised the moisture content close to 40% at the beginning of the third month. The values of this parameter remained almost the same during the rest of the experiment in both piles (Fig. 1). The results show that the forced air pile needed approximately 21% more water during the whole process.

As shown in Fig. 2, the pH rose rapidly from 6 around 9 in pile 2 at the end of the second month. In pile 1 the pH rose more slowly, where it rose to pH 7 during the first week and only exceeded this value at the beginning of the third month, and continued to rise steadily thereafter until it reached similar values to those attained in the pile with forced ventilation. These results are directly related to the aeration system used, since the oxygen supply was more sustained in pile 2 than in pile 1. Periodic turning in pile 1 led to insufficient oxygen conditions to satisfy the intense demand of the bio-oxidative reactions during the initial composting period, when the greatest microbial activity occurred (Nakasaki et al., 1990; Michel and Reddy, 1998). During the rest of the process, from week 16 onwards, the pH remained practically stable in both piles until the maturation phase was reached, although it was slightly higher in the non-ventilated pile.

High losses of total OM (Fig. 2) were observed in both piles, the degradation was greater and faster in pile 2 due to its generally lower temperatures and more sustained and intense oxygen supply compared with pile 1. The greatest losses were associated to the thermophilic phase of the process, when total losses higher than 50% were reached. Also, the absolute lignin, cellulose and hemicellulose contents fell, and were more evident for the third component. Total losses for lignin were 30.2% (pile 1) and 41.4% (pile 2); for cellulose, 60.0% (pile 1) and 66.1% (pile 2) and for hemicellulose, 68.1% (pile 1) and 70.0% (pile 2). The greater resistance of lignin to the microbial metabolic activity compared to the susceptibility of cellulose and hemicellulose was observed by Whitney and Lynch (1996). Moreover, lignin biodegradation was enhanced by the forced ventilation conditions of pile 2 since according to Haider (1994), this process occurs much faster under well aerated conditions.

The C/N ratio decreased continuously from approximately 33 in the initial mixtures to 17 in the mature composts (Fig. 3). This behaviour, more rapid in pile 2, was caused by the decrease in the content of organic carbon and the increase in the total nitrogen due to the concentration effect provoked by the OM biodegradation (weight loss).

Also, a clear decrease in the NH_4^+–N content was observed from initial values of about 1200 mg kg^{-1} to

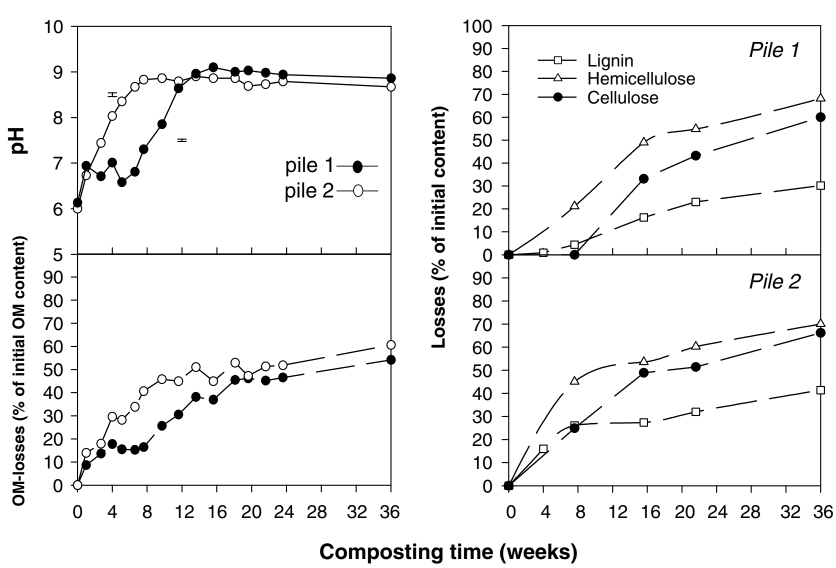

Fig. 2. Evolution of the pH (bars correspond to the least significant difference at $P < 0.05$), organic matter, lignin, cellulose and hemicellulose losses during composting (pile 1: mechanical turning and pile 2: forced ventilation combined with mechanical turning).

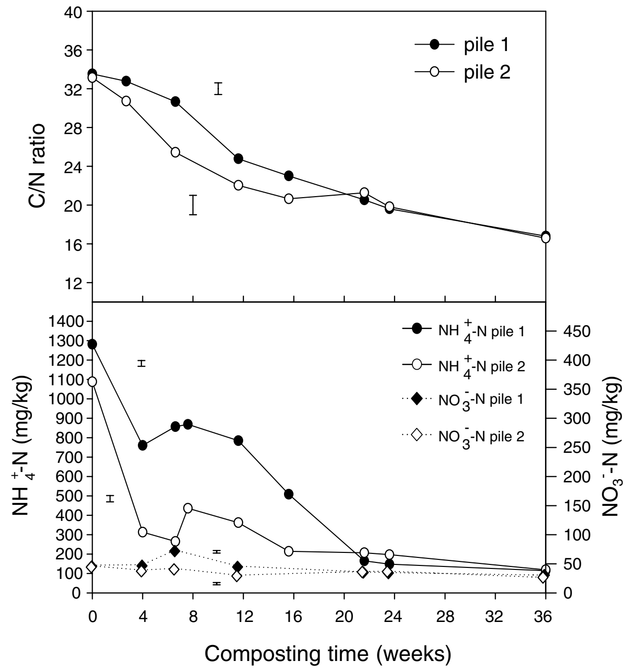

Fig. 3. Evolution of the C/N ratio and inorganic nitrogen (NH_4^+–N and NO_3^-–N) during composting (pile 1: mechanical turning and pile 2: forced ventilation combined with mechanical turning). The bars correspond to the least significant difference at $P < 0.05$.

114 and 119 mg kg^{-1} for mature composts 1 and 2, respectively (Fig. 3). This reduction proceeded faster in pile 2, probably due to the more rapid pH increase and the intense ventilation periods applied during the thermophilic phase. In agreement with our data, it is to be added that high pH, mixing and increased aeration have been revealed to enhance ammonia loss during composting (Sikora and Sowers, 1985; Jeong and Kim, 2001). Mineralisation of the organic nitrogen is a frequently observed phenomenon during composting. It is generally accepted that the ammonium form is first generated, then the nitrate towards the end of composting, hence the common belief that a good compost should contain substantial quantities of mineral nitrogen and a preferably higher concentrations of nitrate than ammonium. However, the formation of important NO_3^-–N quantities was not detected during our experiment (Fig. 3), which probably was due to the low NH_4^+–N concentration in the last phase of composting, unfavourable pH for nitrifiers or to the predominance of the nitrogen immobilisation.

Changes in the WSC content were monitored during composting because of its close relationship with the microbial activity and the fact that WSC constitutes the most immediate source of directly available organic compounds. This organic fraction is considered to be made up of peptides, amino-acids, sugars and other easily biodegradable compounds. Its initial value was near 8% in both piles and fell to about 3% in the mature composts (Fig. 4). However, the fall was much more pronounced during the first 12 weeks, coinciding with the higher temperatures of the thermophilic phase, after which the values gradually decreased until the mesophilic phase was reached. The evolution of the WSC content was approximately similar in both piles, although it might have been expected to fall more in pile 2 due to its presumed higher biological activity resulting from better ventilation and lower temperatures. The relative constancy of this parameter in the final stage of composting showed an equilibrium between the rates of depolymerisation of complex materials and the mineralisation of the resultant fractions (Canet and Pomares, 1995).

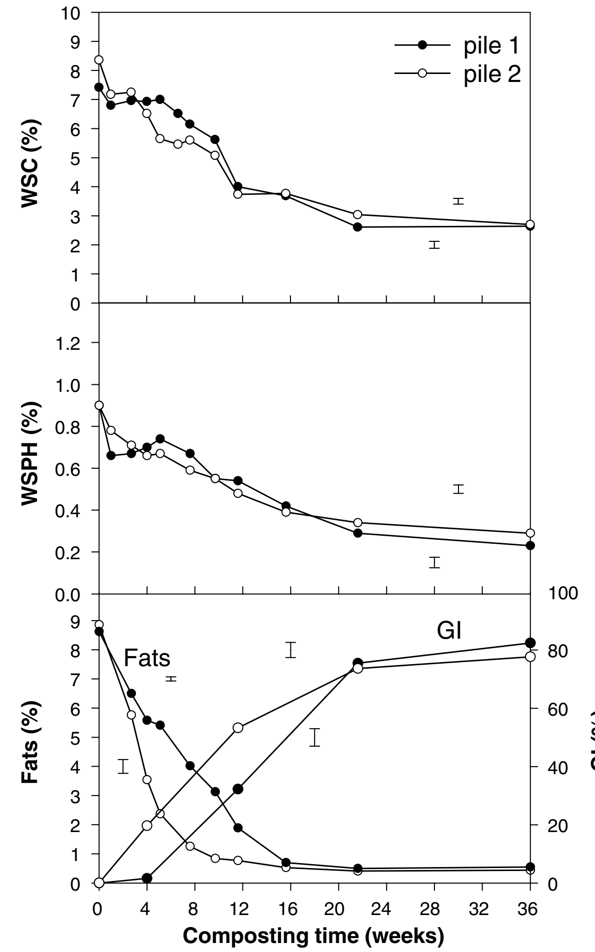

Fig. 4. Changes in water-soluble organic carbon (WSC), water-soluble phenols (WSPH), fat content and germination index (GI) during composting (pile 1: mechanical turning and pile 2: forced ventilation combined with mechanical turning). The bars correspond to the least significant difference at $P < 0.05$.

Studies carried out with olive-mill wastes and by-products have shown that phytotoxic effects currently ascribed to them are related mainly to lipids, phenolic compounds and organic acids (Estaún et al., 1985; Madejón et al., 1998; Filippi et al., 2002; Linares et al., 2003; Sampedro et al., 2005). The total fat content decreased from nearly 9.0% to 0.5% half-way through the fourth month, the decrease was even more rapid in pile 2 coinciding with its better aeration conditions compared with pile 1. Also, the WSPH content fell from an initial value of 0.9% to below 0.4% in both piles at the end of the process. The decreases

Table 2
Main characteristics of the mature composts (dry weight)

Parameters	Pile 1	Pile 2
pH[a]	8.86	8.67
EC[a] (dS m^{-1})	4.52	4.81
OM (g kg^{-1})	815.5	792.9
Lignin (g kg^{-1})	405.7	387.2
Cellulose (g kg^{-1})	166.1	156.7
Hemicellulose (g kg^{-1})	245.9	260.5
TOC (g kg^{-1})	442.3	434.8
TN (g kg^{-1})	26.3	26.2
NH_4^+–N (mg kg^{-1})	114	119
NO_3^-–N (mg kg^{-1})	33	31
C/N ratio	16.8	16.6
P (g kg^{-1})	1.9	1.9
K (g kg^{-1})	42.7	42.5
Ca (g kg^{-1})	24.0	29.7
Mg (g kg^{-1})	5.1	5.7
Na (g kg^{-1})	4.1	4.1
Fe (mg kg^{-1})	1365	1468
Cu (mg kg^{-1})	34	36
Mn (mg kg^{-1})	86	98
Zn (mg kg^{-1})	125	138

[a] Water extract 1:10.

in these potentially phytotoxic compounds coincided with a gradual increase in GI, which was more rapid in pile 2 (Fig. 4). Thus, the more aerobic conditions in this pile probably favoured the fat degradation, whereas the WSPH content seemed to be unaffected. Also, the persistence of phytotoxic effects in pile 1 coincided with low pH values; this fact could be related to the existence of phytotoxic compounds having an acid character, probably organic acids. Therefore, phytotoxicity during AL composting should not be related only to a particular group of compounds, but rather to several groups including phenols, lipids and organic acids, phytotoxin diminution being mainly dependent on oxygen availability.

As shown in Table 2, the agrochemical characteristics of both mature composts obtained were similar, their macro and micronutrient contents were practically identical. Thus, composting AL led to non-phytotoxic end-products, having considerable amounts of nitrogen (mostly organic), potassium and calcium, but rather low amounts of phosphorus and micronutrients.

4. Conclusions

In summary, the composting process of "alperujo" proceeded faster when forced ventilation was used in conjunction with mechanical turning, but similar end-product quality was achieved at maturity with (pile 2) or without (pile 1) forced ventilation, although it is true that a slight delay in the evolution of some parameters of pile 1 such as pH, C/N ratio and organic matter biodegradation was recorded, in comparison to pile 2. Therefore, improving the oxygen supply by forced ventilation proved to be unnecessary, thus greatly reducing production costs as forced ventilation equipment involves high capital investments and operating costs.

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