Agronomy Research **18**(1), 5–17, 2020
https://doi.org/10.15159/AR.20.004

Composting olive pomace: evolution of organic matter and compost quality

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Abstract. Morocco is one of the major olive-producing countries with an annual production of 1.56 million tonnes, part of which is dedicated to olive oil production. This important production generates, in addition to oil as the main product, a significant amount of waste (pomace and olive mill wastewater). The latter, when released in large quantities into the natural environment, cause fatal pollution. A suitable valuation of this waste will allow a clean and sustainable production for the sector. This work consists of composting olive pomace from the traditional system with two structural agents (poultry droppings and cattle manure) and comparing the two composts in terms of composting process parameters (pH, electrical conductivity, organic matter temperature, etc.), organic matter dynamics and compost quality, with manual aeration of the compost. Despite the high humidity level of the used pomace (80%), the adopted composting conditions have been effective in reducing high levels of organic matter and therefore organic carbon, as well as reducing the extreme phytotoxicity of the pomace. The experiment showed that the stabilization process in all the four treatments studied is comparable, and the final quality of the composts was adequate for agricultural use.

Key words: compost phytotoxicity, compost quality, degradation of organic matter, olive pomace.

INTRODUCTION

The imbalance between population growth in the Mediterranean Basin countries, particularly in the south and east of the Mediterranean, and the capacity of ecosystems to meet human needs, has led to over exploitation of agricultural soils and therefore to the depletion of soils in fertilizing elements, including carbon, which represents a large part of the organic matter. Therefore and in order to combat famine caused by this imbalance, Man has turned to the use of chemical fertilizers to increase productivity. But the irrational use of these fertilizers caused their accumulation, which affected the productivity and quality of the obtained fruit. In order to restore this soil degradation, Man has turned to organic farming, based on fertilizing the soil with organic matter, which present a reservoir of nutrients, and plays a major role in the physical fertility of soil, its aeration and its resistance to degradation and erosion (Girard et al., 2005).

For these reasons, organic matter is essential for fertilization and the base of the production method using biological, sustainable and environmentally friendly techniques. In Morocco, where the practice of organic farming is quite recent (the 1980s), the use of organic matter is becoming increasingly important, especially following the rapid expansion of the areas converted to organic production.

On the other hand, Morocco is one of the major olive oil producing countries with an annual production of 300,000 T (Ministry of Agriculture and Maritime Fisheries, 2013), this production generates a significant quantity of waste (Pomace and olive mill wastewater) which, when released into the natural environment, causes fatal pollution of the latter. The valuation of olive waste is a potential source of additional income that can contribute to improving the profitability of olive farms (Messineo et al., 2019). Olive pomace can be used as fuel, livestock feed, fertilizer and thermal insulation in some construction materials (Chouchene, 2010).

The use of olive pomace as an organic amendment has shown some problems in plant growth, due to their high organic content, the mineral salts, the low pH and the presence of phytotoxic compounds (Del Buono et al., 2011; Gigliotti et al., 2012; Proietti et al., 2015). Therefore, composting is necessary to stabilize the high organic content and benefit from the pomace fertilizing power (Gómez-Muñoz et al., 2012). However, no negative effects were observed when raw pomace was used as an amendment on soil fertility parameters (Ameziane et al., 2019). Similar studies have shown that olive pomace compost improves the physical and chemical characteristics of the soil, and provides the necessary nutrients for plant growth (especially nitrogen, potassium and phosphorus) (Sellami et al., 2008; Del Buono et al., 2011).

Consequently, and within the framework of the sustainable development aimed by the Moroccan kingdom, to guarantee proper agriculture, our work consists in valorizing olive pomace by composting with two structural agents (poultry droppings and cattle manure) and evaluating the quality of the obtained composts, while making a comparison between the studied treatments. This comparative study will determine the performance of each composting pile from the viewpoints matter evolution and different composting parameters (pH, electrical conductivity, temperature, humidity) in order to make the necessary adjustments for a good composting of these substances at the end of the process.

MATERIALS AND METHODS

Experimental design

The experiment consists of composting olive pomace with two structural agents: poultry droppings and cattle manure. The olive pomace compost subjects are from the traditional system and are used under two textures:

- Raw as sampled after trituration.
- Modified: dried at 60 °C to facilitate grinding and then ground.

While poultry droppings and cattle manure are used raw.

Composting is carried out in 30-litre drums, perforated to ensure an aerated environment and placed in a sunny place. This is a comparative study of four composting piles composed of:

- 57% poultry droppings and 43% raw pomace (C1).
- 57% poultry droppings and 43% ground pomace (C2).
- 57% cow manure and 43% raw pomace (C3).
- 57% cow manure and 43% ground pomace (C4).

The composting test lasted about 5 months (from 17/01/2019 to 04/06/2019), the follow-up parameters (pH, electrical conductivity, temperature, humidity, organic matter) were measured once a week. During composting, aeration was done manually using a pitchfork. At the end of the composting process (after maturation) a representative sample was analyzed to characterize the final compost.

Sampling of the raw material

Olive pomace is a by-product of the olive oil extraction process consisting of skins, pulp residues and stone fragments. These olive pomace were collected from an oil mill in the city of Tahla (Tahla, Morocco, latitude 34°02'58" North, longitude 4°25'17" West, altitude above sea level: 606 m). This oil mill crushes the olives traditionally and the paste is pressed manually using the pressing mats (scourtins).

Poultry droppings are all the elements released by the digestive and urinary tract through the poultry cloaca. This waste was collected from a poultry farm located in Tiflet (Tiflet, Morocco, latitude: 33°53′40″ North, longitude: 6°18′23″ West, altitude above sea level: 340 m).

Cattle manure is a mixture of cow dung and straw. It is the most commonly composted manure. Cattle manure is also collected from a cow stable in the city of Tiflet.

Physico-chemical characterization of the raw material and compost

To carry out the physico-chemical characterisation of the raw material and compost, a representative sample of the waste is dried in an oven at 60 °C and then ground and sifted to 2 mm to determine the pH and electrical conductivity (EC), then calcined in the oven at 500 °C for 4 hours. The obtained ashes are dissolved to determine the other mineral elements contained in the organic matter (OM), total organic carbon (TOC), total Kjeldhal nitrogen (TKN), potassium (K) and phosphorus (P).

Moisture is determined by drying the sample at 105 °C until constant weight (Rodier et al., 2009). For organic matter, a dried sample is burned in an oven at 525 °C for 3 hours (Rodier et al., 2009). pH and EC are measured in the aqueous extract using the ratio 2:5 (w/v) for pH (Rodier et al., 2009), and the ratio 1:5 (w/v) for EC (ISO 11265, 1994).

Total nitrogen is measured by the Kjeldahl method (Bremner & Mulvaney, 1982), while potassium and phosphorus are determined by atomic absorption spectrometry (Pinta, 1976). All analyses, which were repeated three times, were carried out in the laboratory of the Regional Centre of Scientific Research in Rabat.

Germination index

Phytotoxicity is estimated using the germination index (GI) as described by Zucconi et al. (1985). It is determined by comparing the root development of each sprouted seed in the compost and deionized water. For this test, 10 g of powdered compost was mixed with 100 mL of deionized water and the solution was shaken for 2 hours. After agitating, the solution was left to stand for half an hour then diluted with distilled water at three different concentrations (25%, 50% and 100%) with clear supernatant. The control concentration (0%) included only distilled water. 5 mL of each compost solution was added to a petri dish containing cotton on which 25 watercress seeds were uniformly placed. The concentrations of each compost sample, including the control, were replicated three times. The Petri dishes were incubated under light for 48 hours at 25 °C. After the incubation period, the root length was measured in each germinated seed and the GI was estimated.

$$GI = \left(\frac{GB}{GT}\right) \cdot \left(\frac{LB}{LT}\right) \cdot 100 \tag{1}$$

where GB – Number of seeds germinated in the compost; GT – Number of seeds germinated in the control; LB – Length of roots in compost; LT – Length of roots in the control.

- If the GI is less than 60%, the compost must be applied 90 days before the crop is planted.
- If the GI is less than 50%, the compost is not yet ripe, it is recommended to continue composting.

Statistical analyzes

The obtained results correspond to the average of 3 repetitions. The experimental data were subjected to unidirectional variance analysis (ANOVA) and mean separations were made by the smallest difference (LSD) at the significance level of $P < 0.05$, using the Statgraphics centurion XVI program for Windows.

RESULTS AND DISCUSSION

Physico-chemical characterization of the primary material

The results of the physico-chemical analyses of the materials to be composted are presented in table (Table 1).

Table 1. Physical and chemical characteristics of the primary material

	Olive pomace	Poultry droppings	Cattle manure
pH	$5.28^{a} \pm 0.05$	$6.48^{b} \pm 0.13$	$8.56^{c} \pm 0.02$
EC (mS cm^{-1})	$1.883^{a} \pm 0.56$	$0.0039^{b} \pm 0.87$	$0.00261^{b} \pm 0.19$
Hum in %	$80.34^{a} \pm 0.072$	$88.6^{b} \pm 0.045$	$90.9 \pm {}^{c}0.083$
OM in %	$77.02^{a} \pm 0.08$	$63.75^{b} \pm 0.28$	$60.23^{c} \pm 0.13$
TOC in %	$49.72^{a} \pm 0.21$	$35.81^{b} \pm 0.18$	$16.36\ {}^{c} \pm 0.03$
TKN in %	$0.861^{a} \pm 2.19$	$1.713^{b} \pm 1.78$	$0.45^{a} \pm 2.57$
C/N	57.74	20.90	36.35

The values obtained represent the average of three repetitions; for each treatment, the averages in each line followed by the same letter are not significantly different at $P < 0.05$.

The pomace has an acid pH (5.28), a high electrical conductivity (1.883 mS cm^{-1}) following the use of salts for the conservation of olives before crushing. They are very humid (80.4%), rich in organic matter (77.02%), as well as in total organic carbon (49.72%). While their total nitrogen concentrations (0.861%) are low, resulting in a high C/N ratio.

Poultry droppings have a low acid pH (6.48), low electrical conductivity (0.00391 mS cm^{-1}), high organic matter content (63.75%), as well as organic carbon (35.81%). Their total nitrogen content is high (1.713%), while their C/N ratio is lower (20.90%) compared to other waste.

Cattle manure has a basic pH (8.56), low electrical conductivity (0.00261 mS cm^{-1}) and high humidity (90.9%). Its organic matter content is high (60.23%) as well as organic carbon (16.36%). These manures have a low total nitrogen concentration (0.45%) and a high C/N ratio (36.35%).

Compost monitoring

pH

The mixture of the four compost piles had a neutral pH between 7.3 and 7.9 (Fig. 1). This pH promotes the development of actinomycetes and bacteria (Mustin, 1987) responsible for the organic matter degradation.

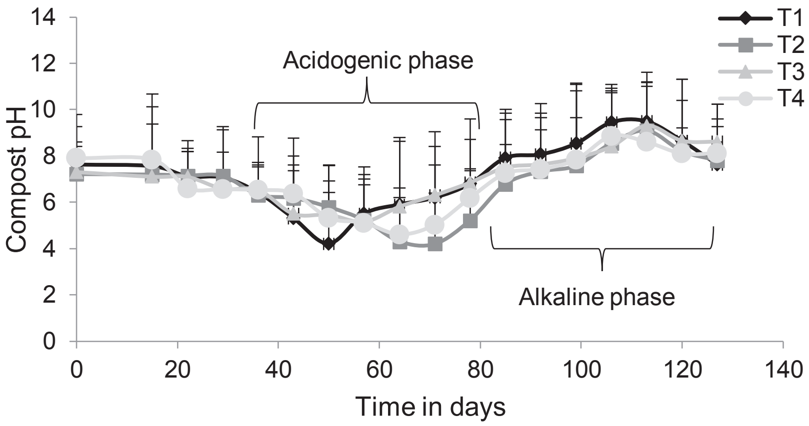

Figure 1. Temporal evolution of pH during composting.

At the beginning of composting, treatments based on raw pomace behave in the same way. Indeed, after 57 days of composting, the pH decreases rapidly to 4.21 for the mixture containing poultry droppings and 5.1 for the mixture of cattle manure. Then the pH of both treatments begins to increase until the end of the process to 8.11 for the treatment containing cattle manure and 7.8 for the treatment containing poultry droppings.

For the treatments based on ground pomace, the acidogenic phase lasted until day 71, reaching 4.2 for compost containing poultry droppings and 4.6 for the one with cattle manure. Thereafter the pH increases to alkalinity. Indeed, the composting process releases ammonia from the mineralization of proteins, amino acids and peptides, which explains this increase in pH (Gigliotti et al., 2012).

At the end of the process and for all four treatments, a slight decrease in pH begins to achieve neutrality: this is the maturation phase. Indeed, the micro-organisms activity responsible for pH variation is complete and pH remains constant (Godden, 1986; Gobat et al., 1998).

According to Mustin (1987), this decrease in pH can be explained by the production of organic acids following the degradation of carbohydrates, fats and other substances. As well as the production of CO_2 during aerobic degradation which contributes to the acidification of the environment by dissolving it in water and producing carbonic acid. This resulting drop in pH promotes fungi growth and the degradation of lignin and cellulose (Paredes et al., 1999).

The apparent phase shift between the treatment of raw and ground pomace can be explained by the fact that ground pomace has a compact environment that makes air circulation difficult and therefore the development of acidogenic bacteria, which somewhat slows down the acidogenic phase in the treatment of ground pomace.

The temperature evolution study during the composting process shows that the initial temperature is almost the same for all four treatments (Fig. 2). From the 22nd day, the temperature of the three composting piles C1, C2 and C3 starts to increase to 50.9 °C for C1 and 54.8 °C for C2 and 55.5 °C for C3, while the maximum temperature reached for the C4 treatment does not exceed 37.9 °C. The increase in temperature is attributed to the activity of thermophilic microorganisms (Mustin, 1987). However, this temperature remains below 70 °C, above which there is destruction of living organisms and therefore degradation of compost quality (Bernal et al., 2009). Aware that heat production by microorganisms is proportional to the mass of the pile (Godden, 1986), the C4 treatment pile was the smallest, which is why the maximum temperature reached remains lower than that of other treatments.

Likewise for pH, the phase shift in the C1–C3 and C2–C4 treatments for maximum tepmerature can be attributed to the compact texture of the ground pomace, which reduces the porosity of the compost (Cayuela et al., 2006;. Sánchez-Arias et al., 2008) and therefore the availability of oxygen and consequently slows down the composting process.

It can be considered that the maturation phase begins from the 113th day of composting since the last turning of the day 99 did not have a significant effect on the temperature increase.

At the end the temperature of the windrows merge with the ambient temperature of 19 °C to 20 °C, which shows that there is no longer any microbial activity, so the compost is ripe and ready for use (Fig. 2).

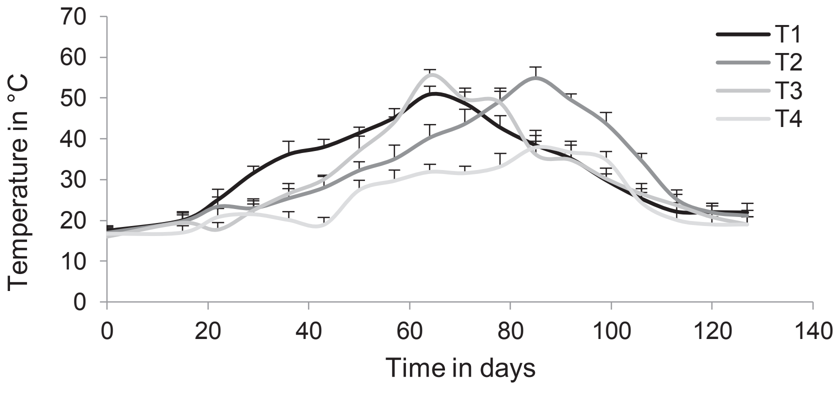

Figure 2. Time evolution of the temperature during composting.

Electrical conductivity

The electrical conductivity evolution (Fig. 3) shows that the different treatments start from high values (A), which can be explained by the high salinity of all the starting materials (Table 1).

During the composting process, the electrical conductivity of the various piles fluctuates due to the degradation of organic complexes. To find stability between 2.02 and 2.21 mS cm^{-1} from the 100^{th} day (C): this is the beginning of the maturity phase. In some pomace composting cases, final EC values were found to be lower (Abid & Sayadi, 2006; Makni et al., 2010). This is related to a leaching effect, which occurred when water was used for irrigation during the maturation phase. It should be noted that the leachate is recovered for possible treatment.

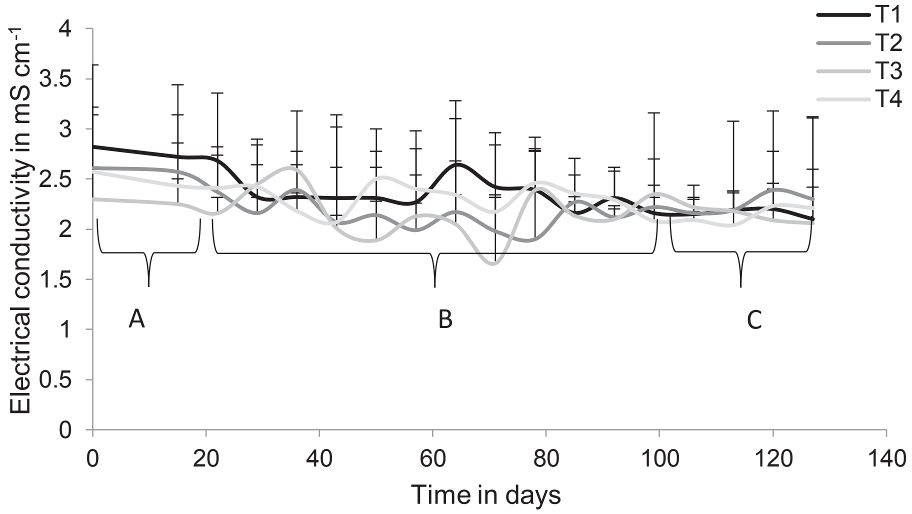

Figure 3. Electrical conductivity evolution during the composting process.

Humidity

The humidity of the four composting treatments is very high, as the pomace from the traditional system has high water content (Table 1). At the end of the 43^{rd} day (A) the composting process is slow and the humidity of the mixtures is almost similar to that of the start (Fig. 4). From the 43^{rd} day (B) the thermophilic phase already begins, and therefore excessive water consumption is expected, which is manifested by a decrease in the humidity level of the composts (Jemali et al., 1996). The humidity curve in the thermophilic phase is in sinusoidal form, it consists of a decrease in humidity resulting in water consumption, followed by an increase in humidity following watering. After the last watering before the 92^{nd} day (C), no decrease in humidity was observed, this is the beginning of maturation.

In terms of comparison between the four treatments, it can be seen that the variation in humidity is remarkable for the C1 and C2 treatments composed of poultry droppings, this can be attributed to the importance of microbial activity in the compost containing poultry droppings. Indeed, poultry droppings contain much more nitrogen than cattle manure (Table 1), which allows intense microbial reproduction and therefore significant activity.

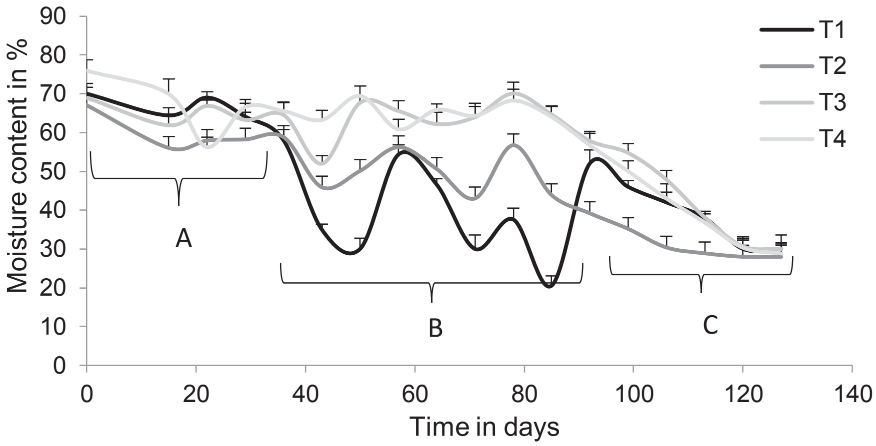

Figure 4. Humidity evolution during the composting process.

Organic matter evolution

The olive pomace subject to composting is rich in organic matter (77.02%) (Table 1), so the four initial treatments have a high concentration of organic matter. And since composting is a degradation of organic matter so a decrease in organic matter concentration is expected as the main result during composting, which is remarkable for all four treatments (Fig. 5). This significant loss of organic matter can be reflected in a decrease in volatile solids and total organic carbon throughout the process (Garcia-Gomez et al., 2003), which is due to the presence of relatively stable organic compounds probably represented by lipids, polyphenols, lignins, cellulose, hemicellulose and pectin (Aviani et al., 2010; Michailides et al., 2011a; Tortosa et al., 2012).

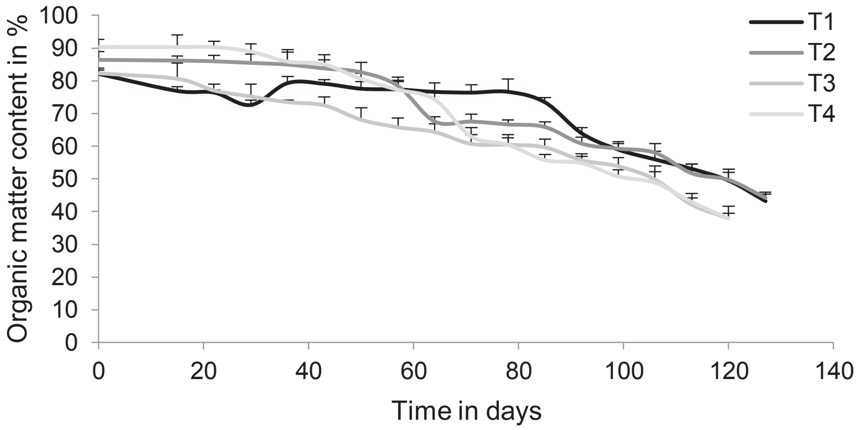

Figure 5. Organic matter evolution during the composting process.

The decrease in organic matter content is ensured by different groups of microorganisms that function according to the temperature and compost mass (Keener et al., 2000). Thus, bacteria conduct the composting phase early, while fungi are present throughout the process, but are very active when water levels are below 35% and inactive at temperatures above 60 °C (Bernal et al., 2009). During the maturation phase actinomycetes predominate, together with fungi, are capable of degrading highly resistant polymers (Bernal et al., 2009; Federici et al., 2011; Agnolucci et al., 2013).

Compost quality parameters

Physico-chemical quality

Compost quality parameters are based on a number of standards that vary considerably from one country to another. However, these standards converge towards a single objective: To produce compost that can be recycled without generating negative impacts on the environment quality and human as well as animal health.

Given the absence of Moroccan Standards in terms of compost quality, we will content with a technical sheet from the monthly information and liaison bulletin of the National Programme for Technology Transfer in Agriculture (NPTTA) elaborated by the Ministry of Agriculture, Rural Development and Maritime Fisheries of Morocco (Soudi, 2005).

The four composts pH is a neutral pH that tends towards basicity (7.63–8.61). This pH is high in relation to the quality objectives; in fact this can be attributed to the variation in composted waste as well as the quantity of ammonia released during the mineralization of proteins, amino acids and peptides (Abu Khayer et al., 2013). However, these values remain appropriate for agricultural applications (Gigliotti et al., 2012).

The abundant minerals in olive pomace increase the electrical conductivity of the final obtained composts, unlike composting of other organic materials in which the final compost conductivity does not exceed 1.5 mS cm^{-1} (Znaidi, 2002). Despite this increase in conductivity, it remains within the range of quality objectives. Given the high organic matter content of olive pomace, the concentration of organic matter remains high at the end of composting. Similar values (36%, 47%) were successively observed by Hachicha et al. (2009b) and Paredes et al. (2002). As well as for nitrogen, significant values were recorded in mature composts, resulting in lower C/N ratios.

The four treatments composts contain high levels of phosphorus (0.12–1.07%) and potassium (2.8–3.5%), which encourages their use as fertilizers (Hachicha et al., 2009c). Differences in mineral concentrations in the different composts could be attributed to the different composition of the initial materials.

Table 2. Physico-chemical properties of mature composts

	C1	C2	C3	C4	Compost quality objectives (Soudi, 2005)
pH	7.63 ± 0.12a	7.8 ± 0.1a	8.61 ± 0.03b	8.11 ± 0.22ab	5–7.5
Humidity (%)	30 ± 0.34a	28.2 ± 0.23b	30.4 ± 0.14a	28.9 ± 0.42ab	30–35
EC in mS cm^{-1}	2.1 ± 0.45a	2.3 ± 0.5a	2.06 ± 0.22a	2.21 ± 0.43a	2–5
OM in %	43.15 ± 0.15a	44.1 ± 0.36a	38.4 ± 0.76b	38 ± 1.27b	30–40
K_2O in %	2.9 ± 1.22a	3.5 ± 0.45b	2.8 ± 0.36a	3.2 ± 0.92ab	nd
TKN in %	1.5 ± 2.43a	1.9 ± 1.67ab	1.3 ± 1.89a	1.7 ± 0.26b	nd
P_2O_5 in %	0.3 ± 0.87a	1.07 ±0.45b	0.42 ± 0.86a	0.12 ± 1.34a	nd
TOC in %	25.09 ± 0.76a	25.65 ± 1.47a	22.32 ± 0.89b	22.09 ± 1.47b	nd
C/N in %	16.72	13.5	17.16	12.99	12–15

nd: Not defined; the values obtained represent the average of three repetitions; for each treatment, the averages in each line followed by the same letter are not significantly different at $P < 0.05$.

Compost phytotoxicity

Maturity is partly influenced by the relative stability of the composting material but it also describes the effect of other physical and chemical properties of compost on plant growth and development. Composts from immature olive pomace may contain high amounts of free ammonia, specific organic acids or other water-soluble compounds that can prevent seed germination and root development (Finstein et al., 1985). The mature compost that will be applied to agricultural land should be free of these potentially phytotoxic substances.

Table 3. Germination index (GI) of the four composts

Type of compost	C1	C2	C3	C4
The germination index (%)	75 ± 0.36a	78 ± 1.2b	73 ± 0.65a	74 ± 0.67a

The values obtained represent the average of three repetitions; for each treatment, the averages in each line followed by the same letter are not significantly different at $P < 0.05$.

The studied composts have optimal germination indices (Table 3), which reflects their maturity. These results corroborate with the physico–chemical analyses of the four composts. Indeed, according to Zucconi et al. (1985) the compost acceptable level of phytotoxicity must not exceed 80% with a minimum of 60%. Similar germination index values (71%, 72%, 74%) were obtained successively by Sánchez-Arias et al. (2008); Altieri& Esposito (2010) and Cayuela et al. (2010).

Summarizing the obtained results, we can say that: As compost will be applied to agricultural land, its physical and chemical parameters (i.e. pH, electrical conductivity and mineral concentrations) should be within a specific range to prevent any adverse effects on soil quality. So the compost of the four treatments initially had acid pH values, so much so that the final pH values are neutral and therefore ideal for agricultural applications (Gigliotti et al., 2012). The initial acid pH of the four treatments promotes the degradation of lignin and cellulose (Paredes et al., 1999). The compost of the four treatments has similar electrical conductivity values (2.1 mS cm^{-1}, 2.3 mS cm^{-1}, 2.06 mS cm^{-1} and 2.21 mS cm^{-1}) and which always remain below 4,000 mS cm^{-1} maximum tolerable values in agriculture (Lasaridi et al., 2006). Although values tend to increase during composting (since compost mass decreases) in our case during composting of olive pomace, electrical conductivity decreased due to mineral leaching a similar result has been observed by other authors (Paredes et al., 2002; Abid & Sayadi, 2006; Hachicha et al., 2009b; Makni et al., 2010; Gigliotti et al., 2012).

In addition to pH and conductivity, high levels of mineral nutrients such as phosphorus, potassium and nitrogen are essential to improve the quality of composts used for agricultural purposes. This is the case for compost in the four treatments, as there is an increase in these elements (Table 2), as is the case in many studies that report that olive-pomace-based composts have high levels of mineral nutrients (phosphorus: 0.1–3%; potassium: 0.12–4.4%; sodium: 0.05–4.1%) (Sanchez-Arias et al., 2008; Hachicha et al., 2009b; Michailides et al., 2011a).

CONCLUSIONS

Despite the olive pomace high moisture content and the presence of toxic chemicals (phenolic compounds), olive pomace composting took about 130 days. The organic matter content of the four mixtures decreased during composting and, at the end of the process, to values consistent with those generally desired for mature compost.

The four composts have optimal pH values, a C/N ratio of 13 to 17 and low phytotoxicity, these parameters fall within the defined limits for the quality of a compost. In addition, despite the compact texture of the ground pomace, and their high moisture content, their final composts are a high quality fertilizer from an agronomic point of view. As a result, these laboratory scale results can be replicated in full-scale installations by adjusting the forced ventilation according to the available equipment.

Finally, it can be said that composting olive pomace is the best method to benefit from its fertilizing power and guarantee farmers a stable, hygienic, less expensive and durable fertilizer.

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