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ORIGINAL RESEARCH

Agricultural valorization of composts produced by recycling organic waste

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Abstract

Purpose This paper investigates the composting recovery of different bio-wastes and the use of the composts produced as soil fertilizer and organic amendment.

Method A composting process was carried out for 111 days using different organic wastes (fruits, vegetables, olive pomace, poultry, and cattle manure). The physicochemical properties of the generated compost were determined. The quality of the compost produced was evaluated by measuring pH, carbon/nitrogen (C/N), dry matter, and organic matter. A phytotoxicity test (germination test) was conducted to complete the analysis.

Results The results of the physicochemical properties complied with AFNOR standards. The pH ranged between 7.3 and 8.7. The C/N ratio was between 10.05 and 18.46, and organic matter content varied between 33.6 and 72.7%. The phytotoxicity test showed that the safety of compost as a soil amendment is related to the applied dose and the type of crop.

Conclusion The physicochemical parameters and phytotoxicity test showed that the compost obtained can be used as organic fertilizer due to its organic matter content and mineral elements.

Keywords Compost, Olive pomace, Organic waste, Recovery, Phytotoxicity test

Introduction

In Algeria, household and similar waste is disposed of by landfilling despite the nuisances caused by this mode of treatment, such as foul odors, emission of greenhouse gases, and leachate production. This practice is detrimental to the quality of the environment through water, air, and soil pollution (El Maguiri et al. 2016), and to the economy, as it requires exorbitant costs (Cheniti 2014).The fermentable fraction is the most dominant, with more than 60% compared to other types of waste (Sefouhi et al. 2010; Tahraoui Douma 2013; Guermoud and Addou 2014),which requires recovery by composting. The most appropriate management method is by treating the organic fraction in-situ (Bertolini 2003).

The extraction of oil from olives generates large quantities of pomace that are generally rejected in nature, threatening the environment due to its chemical composition loaded with pollutants (Sebban et al. 2004). Furthermore, poultry manure contains pathogenic microorganisms that can contaminate waterways via runoff if used by spreading on agricultural surfaces (Mishra et al. 2008; Jenkins et al. 2008; Brooks et al.

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2009). Hence, the interest in valuing this agricultural by-product by composting and using the compost as a fertilizer for crops (Cotinet et al. 2011). Compost produced from farmyard manure valorization is an indispensable source of organic matter to restore cultivated soils (Jemai et al. 2011).This study aimed to valorize the organic fraction of household and similar olive pomace and livestock by-products to produce compost that can be used as an organic amendment.

Materials and methods

Presentation of the study site

Our study was conducted for 111 days, from February 20 to June 10, 2019, on a composting platform in the oil mill AMRIOUI (Fig. 1), located in the village IGHIL Moho in the commune of Aït Yahia Moussa (36°38’28" north and 3°53'18" east), 20 km southwest of the city of Tizi-Ouzou (Algeria). The region’s climate is warm and temperate, characterized by strong temperature variations during the year. Monitoring the ambient temperature at the study site during the experimental period gave an average temperature of 23 °C.

Fig. 1 Oil mill and composting platform

Experimental protocol

The composted materials used in this experiment were green waste, mainly composed of fruit and vegetables brought from a wholesale market in 30-kg bags.They included olive pomace, a by-product of olive crushing activities at the oil mill; cattle manure, brought from a barn near the composting site; poultry manure, brought from a henhouse located near the composting site. Then, these wastes were placed in piles. To determine the volume of inputs, we used a wheelbarrow. Seventeen (17) piles were set up during this experiment. Following a pre-established protocol (Table 1), fifteen (15) piles were placed inside a greenhouse. The other two (2) were placed outside but covered with a tarp to protect them from climatic hazards. The parameters monitored in this experiment were temperature, pH, and humidity. For temperature, for the first two weeks, the temperatures of the piles were measured every four (4) days using a probe thermometer implanted in the center of the piles. The ambient temperature was also measured. After fifteen days, the temperatures were measured once a week. The pH was measured with a probe pH meter implanted in the center of the piles for 30 seconds until the pH meter indicated a stable value, and then the pH value was read directly from the device. The humidity was measured with a hygrometer.These three parameters were measured on the same day. To ensure the aeration of the piles, turning was done after each parameter measurement. Then, the piles with humidity below 50% were sprinkled with water, and the quantities of water used for sprinkling were mentioned.

Table 1 Experimental composting protocol

Pile	Volume (%)	Weight (kg)
FV1	50% Poultry manure + 50% Olive pomace	169
FV2	50% Poultry manure + 50% Olive pomace	186
FV3	50% Poultry manure + 50% Olive pomace	198
FV4	75% Poultry manure + 25% Olive pomace	203
FV5	75% Poultry manure + 25% Olive pomace	203
FV6	75% Poultry manure + 25% Olive pomace	222
FB1	50% Cattle manure + 50% Olive pomace	205
FB2	50% Cattle manure + 50% Olive pomace	230
FB3	50% Cattle manure + 50% Olive pomace	235
DO1	50% Organic waste + 50% Olive pomace	168
DO2	50% Organic waste + 50% Olive pomace	158
DO3	50% Organic waste + 50% Olive pomace	152
TT1	Control pile with 100% Poultry manure	228
TT2	Control pile with 100% Cattle manure	198
TT3	Control pile with 100% Olive pomace	204
WG1	Large pile with 50% organic waste (various) + 50% Olive pomace	1113
WG2	Large pile with 50% organic waste (carrots and turnips) + 50% Olive pomace	988

Compost quality analysis

To analyze the quality of the composts produced, six representative samples were taken and stored in sterilized jars after sieving the composts to 10 mm. They were used for the phytotoxicity test and the analysis of physico-chemical parameters. The phytotoxicity test was based on the germination power of seeds of two crops: wheat (*Triticum aestivum)* and tomato (*Solanum lycopersicum*), in the presence of compost (Attrassi et al. 2005). For each category of compost, 16 seeds of each crop were sown in cells containing a substrate with different proportions: 100%S, 100%C, 50%S+50%C, 75%S+25%C (S: sand, C: compost). After 10 days, germinated seeds were counted, and the maturity of the composts was assessed by calculating the germination rate compared to the controls by applying the following formula (1) (Tremier et al. 2007):

$$Germination\ index\ (GI) = (Number\ of\ germinated\ seeds\ /\ Total\ number\ of\ seeds) * 100 \quad (1)$$

The physico-chemical parameters were analyzed according to pre-established experimental protocols. For dry matter (DM), a quantity of 100 g of each sample was dried in an oven at 105 °C for 24 h, and the DM content was calculated according to Eq. (2) :

$$\%DM = [M0 - M1] * 100/M0 \quad (2)$$

where, M0 is the raw sample mass, and M1 is the mass of the sample after being dried in an oven. The measurement of the organic matter (OM) content was determined by the loss of mass during the calcination of the sample at 480°C for 6 h, and the percentage of total organic matter (TOM) was obtained by weighing the difference between the mass of the sample dried at

105°C (M1) and its mass after calcination at 480°C (M2) by applying Eq. (3):

$$\%TOM = [M1 - M2] * 100/M1 \quad (3)$$

The organic carbon content was measured by high-temperature combustion (at 680°C) under oxygen and then measurement of the released CO_2 by a non-dispersive infrared sensor (NDIR). High-temperature combustion was also used to determine the nitrogen content of the different composts. Potassium (K) and phosphorus (P) were analyzed by ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectrometry) after mineralization with aqua regia (HNO/HCl_3 with a ratio of 1 : 3). A mass of 100 g of dry matter was added to the solution in 100 ml of distilled water, and then the suspension was homogenized by magnetic stirring for 15 min to determine the pH. The pH measurement was done directly by reading on a pH meter at the combined electrode. The humidity was measured with a hygrometer.

Results and discussion

Monitoring of parameters

Figs 2, 3, and 4 indicate the results of monitoring the temperature evolution of the piles during the composting process. Figs 5, 6, and 7 show the results of the pH evolution of the piles.

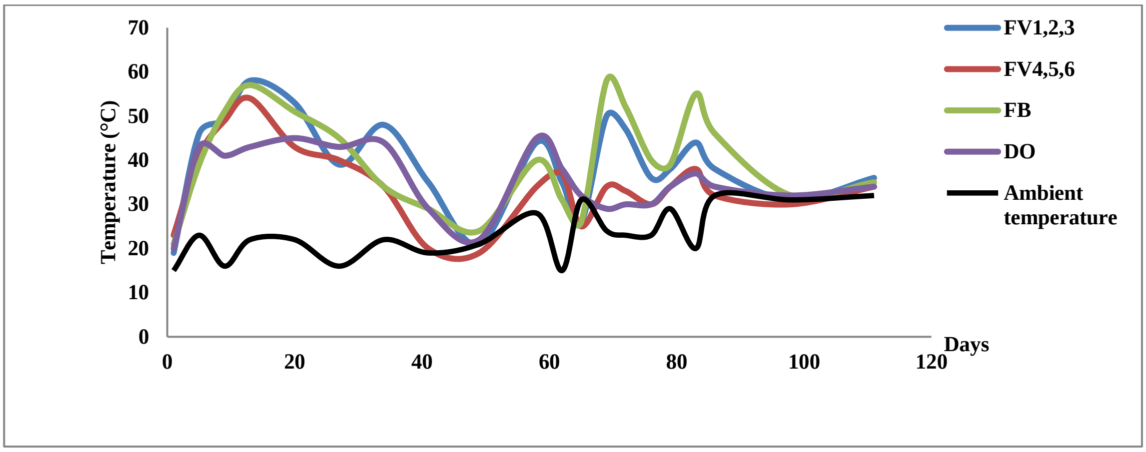

Fig. 2 Evolution of the average temperature of the smallest piles during the composting process

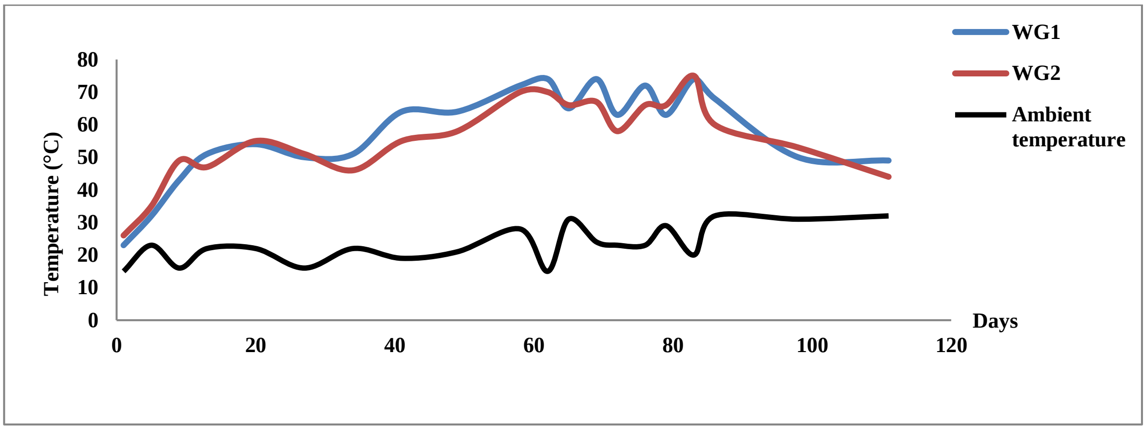

Fig. 3 Evolution of the average temperature of large piles during composting

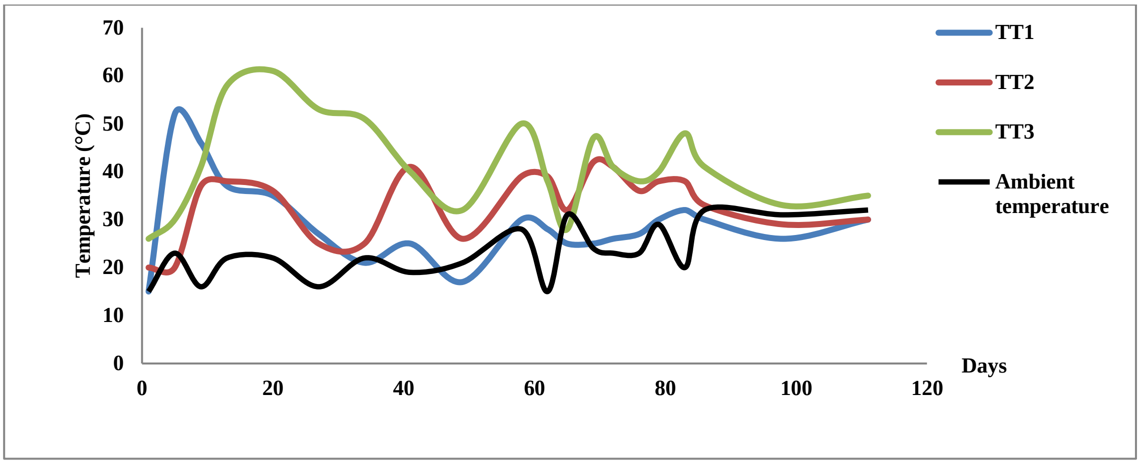

Fig. 4 Evolution of the average temperature of the control piles during composting

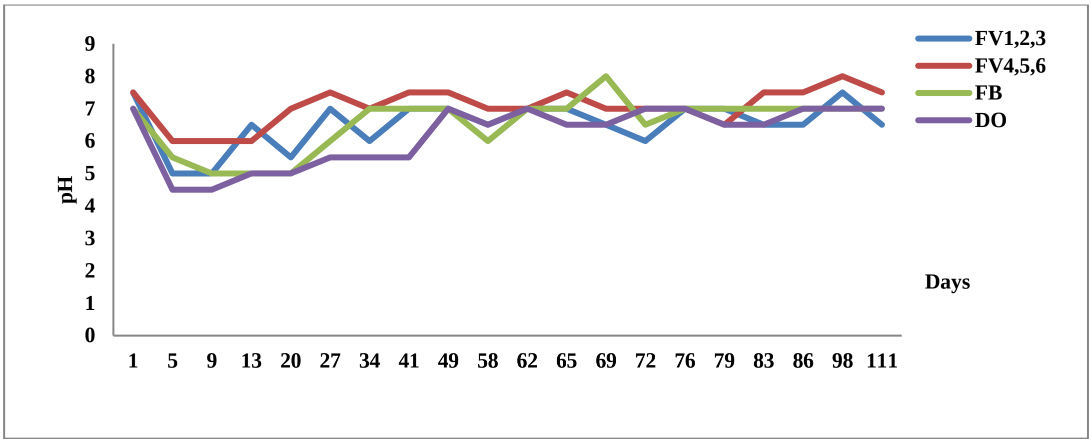

Fig. 5 Evolution of the average pH of the least voluminous piles

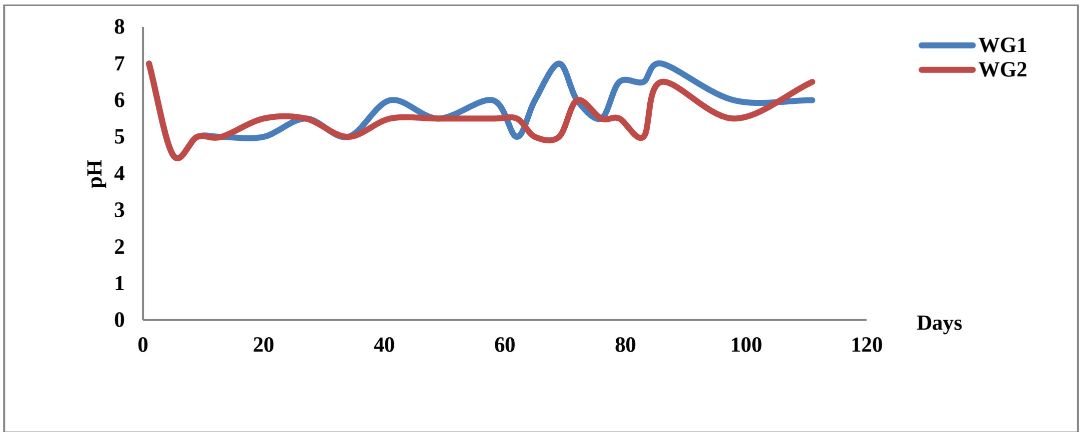

Fig. 6 Evolution of the pH of large piles

The results show that the temperature increases rapidly four (4) days after the waste was piled to mark the beginning of the mesophilic phase (Ben Ayed et al. 2005) to reach peaks after 13 days of composting in the smallest piles: on average, 56°C, 58°C and 43°C for poultry manure, cattle manure, and organic waste, respectively. For WG1 and WG2, after two months, the temperature peaks reached at 74°C and 70°C, respectively, and the thermophilic phase was reached. This difference would be due to the volume effect since the quantities of organic waste in the WG1 and WG2 piles were very large. The mass of waste to be composted is important,hindering the evacuation of the heat produced (Suler and Finstein 1977).

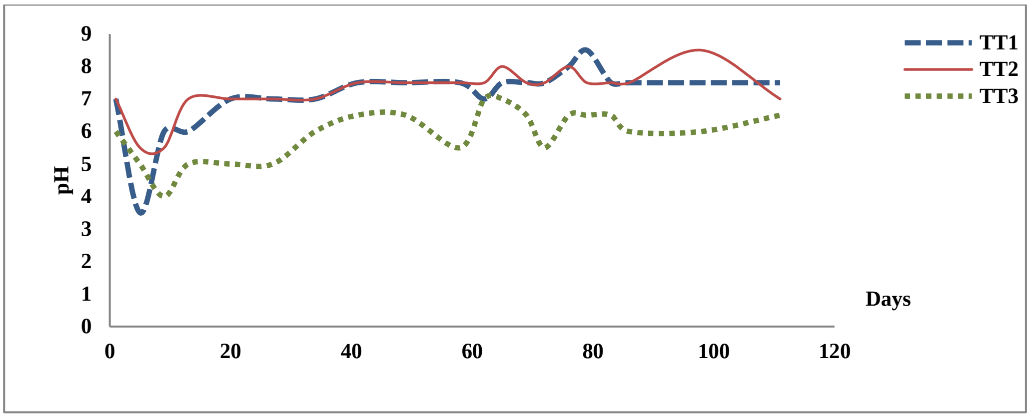

Fig. 7 Evolution of the pH of the control piles

According to Guene (1995) and Charnay (2005), the presence of organic matter easily degradable by micro-organisms would cause a rise in temperature due to the intense microbial activity. These organic matters are degraded by oxidation (Hassen et al. 2001) which allows the release of the energy contained in the chemical bonds of the substrate molecules (Ryckeboer et al. 2003). The thermophilic phase allows the destruction of pathogenic germs (Pujol 2012) and ensures the pasteurization of the compost (Larney et al. 2003). Ferreira et al. (2021) demonstrated a significant reduction of thermotolerant coliforms at the end of composting compared to the itinerary load. This reduction reached 100% and 99.80% in organic and conventional poultry litter, respectively. The destruction of germs could explain these reductions during the thermophilic phase. The temperatures reached 65°C. The thermophilic phase was followed by the maturation phase characterized by a drop in pile temperatures from day 20 for all the small piles and day 85 for the WG1 and WG2 piles. This difference would be due to the high temperatures (74°C and 70°C), which were harmful to some microorganisms responsible for the biodegradation of organic matter (Pujol 2012). According to Mckinley and Vestal (1985), the decomposition rate became low above 60°C, extending waste degradation time in WG1 and WG2 piles. During the last three weeks of the process, the temperatures of the piles approached the ambient temperature, which could be explained by the end of the degradation of the organic matter (Kapetanios et al. 1993). The results of the pH monitoring showed that at the beginning of the composting process, the initial pH was between 7 and 7.5. During the process, the pH went through three distinct phases, the first was the acidogenic phase, characterized by a slightly acidic pH (around 5), and this phase lasted between 15 and 20 days. The decrease in pH value was attributed to the production of organic acids such as lactic and acetic acids (Beck-Friis et al. 2001) and the release of carbon dioxide by hydrolysis (Charnay 2005). Around day 41, the pH moved to an alkalization phase with a value between 7.5 and 8. This increase would be due to ammonification reactions of nitrogen compounds (release of NH_3) (Pujol 2012).

The increase in pH improved organic matter degradation, which decreased the C/N ratio (Saghi et al. 2021). During the last week of the process, the pH decreased to reach neutrality which could be explained by the depletion of organic manners and nitrification reactions with the release of H^+ ions (de Guardia 2006). The evolution of pH during this experiment agrees with the work of Chennaoui et al. (2016) and corroborates with that of Ben Ayed et al. (2005).

Quality of composts

Table 2 presents the results of the phytotoxicity test. Table 3 lists the analysis results of the physicochemical parameters of the composts produced.

Table 2 Results of the germination test of both crops on different substrates

	Germination rate (Wheat)				Germination rate (Tomato)			
	100%S	**100%C**	**50%S+ 50%C**	**75%S+ 25%C**	**100%S**	**100%C**	**50%S+ 50%C**	**75%S+ 25%C**
FV1, 2,3	87.5%	0%	81.25%	87.5%	43.75%	0%	18.75%	43.75%
FV4, 5, 6	100%	0%	100%	100%	31.25%	0%	43.75%	37.5%
FB	81.25%	0%	68.75%	75%	37.5%	0%	25%	62.5%
DO	93.75%	0%	100%	87.5%	81.25%	6.25%	50%	6.25%
WG1	93.75%	0%	81.25%	75%	37.5%	0%	37.5%	25%
WG2	87.5%	0%	62 .5%	87.5%	50%	0%	62.5%	37.5%
Average	**90.62%**	**0%**	**82.29%**	**85.41%**	**46.87%**	**1.04%**	**39.58%**	**35.41%**

Table 3 Physicochemical parameters of the composts obtained

	FV1, 2,3	FV4, 5, 6	FB	DO	WG1	WG2	Dim.
pH	**8.5**	**8.0**	**8.1**	**8.7**	**8.0**	**7.3**	**-**
%H	**23**	**21**	**24**	**23**	**28**	**32**	**%**
OM	**33.6**	**34.0**	**45.9**	**49.7**	**55.7**	**72.7**	**% STI**
DM	**91.6**	**82.2**	**94.1**	**83.5**	**92.8**	**91.6**	**%**
C	**17.0**	**16.9**	**23.0**	**25.5**	**28.4**	**37.3**	**%ITS**
N	**1.51**	**1.68**	**1.60**	**1.91**	**1.75**	**2.02**	**%ITS**
P	**12800**	**17000**	**3210**	**2570**	**1550**	**1420**	**mg/kg STI**
K	**138.00**	**133.00**	**116.00**	**115.00**	**902.0**	**100.00**	**mg/kg STI**
C/N	**11.25**	**10.05**	**14.37**	**13.35**	**16.22**	**18.46**	**-**

Incorporating 25% compost into the soil resulted in germination rates of 85.41% for wheat and 35.41% for tomatoes. The addition of 50% compost gave germination rates of 82.29% and 39.58% for wheat and tomato, respectively. Cultivation on 100% compost substrate gave a very low germination rate for tomato (1.04%), and for wheat, no seed germinated. The addition of 25% and 50% compost gave the highest germination rates for wheat and below 50% for tomato. The use of compost alone as a growing medium is not recommended. According to Tremier et al. (2007) and Zucconi et al. (1981), a germination index above 50% means that phytotoxic effects are absent and that the compost is stable and mature. The low germination rates obtained would be related to the doses of compost applied and the type of crop and not only to the compost composition (de Haan 1981; Berjón et al. 1997; Compaore et al. 2010). Wheat seems to tolerate high doses of compost, unlike tomato. These results are in good agreement with those of Attrassi et al. (2005), where the highest germination rate was obtained for wheat (85.71%) against 62.42% for tomato (these crops were grown on a substrate composed of sand plus 1/3 compost) and with those of Chennaoui et al. (2016) with germination rates of 85% for wheat and 67% for tomato with the same substrate. According to the results obtained by Pellejero et al. (2021), the application of 60 Mg/ha and 80 Mg/ha compost doses on tomato (*Solanum lycopersicum*L.) significantly improved plant growth and fruit development. Bhatti et al. (2021) showed that incorporating composts significantly increased the yield of maize(*Zea mays* L.) crop yield and improved plant growth parameters. Bhatti et al. (2021) reported that adding fruit and vegetable compost combined with NPK fertilizer could increase macronutrient concentrations in maize leaves. For the physico-chemical characteristics of the composts obtained, the results showed that the pH values were between 7.3 and 8.7, according to the standard. According to Forster et al. (1993) and Avnimelech et al. (1996), mature compost has a pH between 7 and 9. Composts have C/N ratios between 10.05 and 18.46. In the literature, this indicator used in the evaluation of compost quality has values that differ from one author to another. Thus, for Roletto et al. (1985), a C/N ratio of less than 25 indicates that the compost is mature. For Jiménez and Garcia (1989), a C/N ratio of less than 20 and even 10 is preferable.

According to Namkoong et al. (1999), a C/N ratio between 10 and 15 corresponds to mature compost. This study showed that the C/N ratios obtained correspond to the standards defined by these authors, which indicates that the composts were mature and stable. This parameter is not sufficient to evaluate the maturity of the compost (Morel et al. 1986; Serra-Wittling 1995) because the C/N stabilized before the stabilization of the organic matter contained in the compost (Chen and Inbar 1993), hence the need to evaluate other parameters. Organic matter (OM) is consumed during composting by microorganisms (Tremier et al. 2007) and mineralized into stable compounds through microbial activities (Bernai et al. 1998). According to Charonnat et al. (2001), compost obtained from household waste with an OM rate between 37.6 and 42% DM is a stable and mature compost. For this study, all composts have OM levels close to the standard except for the WG1 and WG2 piles (55.7 and 72.7% DM, respectively). This exception could be explained by the large quantities of organic waste put into the compost compared to the other piles, which would require much more time for the organic compounds to be mineralized by the microorganisms, which would have led to a decrease in the organic matter levels.

According to the AFNOR standard NFU 44-051 (2006), compost with a dry matter (DM) content greater than or equal to 30% is stable and mature compost. The DM contents of the composts obtained in this study comply with this standard. The moisture content of the composts produced was between 21% and 32%, which is in line with the AFNOR standard (NFU 44-051), which indicates that a good compost had a moisture content less than or equal to 70% (Temgoua et al. 2014).

Carbon is an essential energy source for cell growth, and nitrogen is considered one of the major components of the proteins needed by microorganisms (Miller and Jones 1995). The nitrogen content of the composts produced was relatively higher than the FAO standard (0.4 - 0.5), which could be explained by the nature of the composted waste, which is essentially composed of fresh fruit and vegetables rich in nitrogen (FAO 2005).

Conclusion

This study highlighted that during the composting process, the evolution of temperature was strongly linked to the volume of the pile. Thus, the larger the volume, the higher the temperature during the thermophilic phase. Also, the evolution of the pH went through three different phases: an acidogenic phase, an alkalization phase, and finally, a neutrality phase towards the end of the process. The phytotoxicity test and the physico-chemical parameters measured showed that the composts obtained can be used as organic amendment and fertilizer since they are rich in organic matter and mineral elements (NPK). The use of the compost was conditioned by the dose to be applied and by the type of crop.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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