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*Original Research*

# Production and Characterization of Compost Made from Garden and Other Waste

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**Abstract**

Different types of compost were made in a pilot plant, from pruning remains (percentages in volume ranging between 40-60%), leaf litter (20-30%), sewage sludge (0-10%), and biomass ash (0-20%). The aim of our study was to promote the utilization of plant remains to produce compost that, once stabilized and sanitized, could be used as an organic amendment and/or substrate. After six and a half months, all of the composts produced were stable, sanitized, and did not contain phytotoxic substances. However, the composts containing sludge and ash became stabilized and sanitized more rapidly than the others, and generally contained higher quantities of nutrients. The highest quality compost was produced by mixing 20% leaf litter, 10% sludge, 10% ash, and 60% pruning remains (% volume), and supplied highest quantities of phosphorus, calcium, magnesium, and potassium. This compost was categorized as class B, on the basis of the contents of chromium and zinc, i.e. it can be used as potting compost or mixed with other materials to lower the contents of chromium and zinc.

**Keywords:** biomass ash, composting, garden type waste, sewage sludge

## Introduction

The huge amounts of waste produced in developed countries is a serious environmental concern. In this context, the objective of the European Union [1] is to reduce the amount of biodegradable waste disposed by landfill. Biodegradable urban waste (BUW) is considered as waste that may decompose aerobically or anaerobically under landfill conditions, as occurs with food waste, sewage sludge, and garden waste. This type of waste makes up more than 35% of urban waste generated in the EU [2]. The European ruling was incorporated into Spanish law by Royal Decree 1481/2001 [3], which established that a maximum of 4,071,550 t of BUW can be sent to landfills in 2016.

The increase in both public and private landscaped areas has led to an increase in garden-type waste (prunings) generated during the maintenance of such areas. Quantification of this waste is difficult, as it differs in both amount and type in different sites. However, it generally comprises pruning waste and leaf litter, which although variable in composition are all characterized by high contents of carbon and nutrients such as nitrogen, calcium, magnesium, and potassium [4].

Sewage sludge is also generated in large quantities in cities. ECC Directive 91/271 [5] requires treatment of urban wastewater in population nuclei with more than 2000 inhabitants. In Spain, it is envisaged that by 2011, 70% of all sewage sludge produced will be used for agricultural purposes [6]. This waste material is rich in organic matter, contains large amounts of nitrogen and phosphorus [6, 7], and acts as a stimulant of microbial activity, which promotes degradation of organic matter [8].

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The production and management of both garden waste and sewage sludge can be considered as very important, the former because of the increase in green spaces and the latter for legal reasons. Composting is considered the best option for recycling these types of waste because of the particular characteristics of the waste [9-11] and also because the composting process is technologically and economically viable.

The ash generated from the combustion of biomass is also suitable for composting [8, 12] and has been used to reduce the unpleasant odors associated with other types of waste [13]. Because of its alkaline nature, ash may also be used to condition certain types of acidic materials that are not suitable for composting.

To carry out the composting process, the waste material and the composting technique must be selected, and the parameters that affect the process (pH, temperature, moisture content, oxygen, C:N) must be controlled [14]. The composting process should ideally use large quantities of waste (input material), and any atmospheric emissions and leachates produced during the process should have very little impact on the environment. Finally, monitoring (of T, pH, $CO_2$ emissions, stability, and pathogenic microorganisms) should be carried out to ensure that the final product is stable, hygienic, and contains organic matter and nutrients.

The main aim of the present study was to determine the optimal proportions of pruning waste, dead leaves, sewage sludge and biomass ash (all generated within the same urban environment) for making compost. A further aim was to produce a material that would promote the consumption of plant biomass, and that once stabilized and sanitized, could be used as an organic amendment and/or substrate. The compost was elaborated in full-scale piles in a purpose-built pilot plant.

## Experimental Procedures

The following material was used to make the compost:

- Green waste comprised of pruning remains and leaf litter from landscaped sites in the city of Lugo (NW Spain) and surrounding areas. The pruning waste mainly originated from species of the genera *Aligustre*, *Platanus*, and *Thujas*. The dead leaves were mainly from *Quercus* and *Platanus*.
- Sludge generated in the wastewater treatment plant in the city of Lugo.
- Biomass ash generated in a cogeneration energy plant where wood bark remains are burned to generate the energy required to power a factory located close to the city of Lugo.

The basic infrastructure that was used to produce the compost included:

- A covered shed, to protect the composting materials from rains as the mean annual precipitation in the study region is 1,066 mm. The shed floor was made from rubble from different types of rock, which was compacted and covered with a layer (10 cm) of aggregate.
- A chipper (Johli HW 420 D-SO) to process woody material of between 5 and 20 cm long.

Table 1. Proportions (percentage volumes) of the materials in the different compost piles.

| Pile | Leaf litter | Sewage sludge | Ash | Pruning remains |
|---|---|---|---|---|
| *A* | 20 | 10 | 10 | 60 |
| *B* | 30 | 10 | 0 | 60 |
| *C* | 30 | 0 | 10 | 60 |
| *D* | 30 | 10 | 10 | 50 |
| *E* | 30 | 10 | 20 | 40 |

- A mechanical loader, with a bucket of volume 1 $m^3$, for mixing and turning the piles.
- A temperature probe with a metal sensor of length 1.2 m (Desin Instruments). Measurements are taken along the length of the probe and the mean temperature is recorded on a dedicated datalogger (Desin Instruments, DAS8000).
- A watertight cupboard for storing data recording equipment.

### Preparation of the Mixtures

Selection of the proportion of materials was made on the basis of the results obtained in previous laboratory studies (unpublished data), to provide a C:N ratio of between 25 and 35 and a pH close to 7, which are considered suitable for compositing [15]. At the same time, the aim was to use as large a volume of pruning waste and leaf litter as possible. The proportions of material finally selected are shown in Table 1.

The materials were mixed with the aid of the mechanical loader in the following order: powdered material was first mixed with pasty material (ash with sludge), before the leaf litter and finally the pruning remains were added. Subsamples were removed during preparation of the mixture, to make a representative sample used to characterize the raw materials.

### Preparation for Composting Process

The windrow method was used to make the compost because of its low cost, ease of handling, and high quality of the final product. Five piles were made (one for each mixture of material); each pile was of volume 10 $m^3$, length 4 m, width 2.5 m, and height 2 m. Replicate piles were not made as the size of the piles was sufficient to be representative of each mixture. The piles were made as follows:

a) a sheet of strong polythene was placed on the ground to prevent loss of leachates, which would run off because of the slight slope of the ground, and which were channeled to a separate collector for each pile
b) a 20 cm deep base of interlaced branches was placed on top of the plastic sheet to promote entrance of air and prevent waterlogging

c) a measured volume of pruning waste (which was discounted from the total volume) was placed on top of the branches to prevent the network of branches from becoming blocked
d) finally, the mixture of material was placed on top of the pruning waste.

## Maintenance of Moisture and Temperature Conditions

The moisture content was maintained throughout the experiment at between 40 and 60% (as recommended by Day and Shaw [15]). A field method was initially used to determine when water should be added (briefly, a small sample of compost was squeezed by hand, and if after it was release it maintained its shape it was assumed to contain around 50% moisture; if it disaggregated slowly on release, it was assumed to contain around 40% moisture and water was added; if the mixture released drops of water it was considered to be too moist). After this test was carried out, samples of the compost were transported to the laboratory for more accurate determination of the moisture content, by drying the material to constant weight at 105ºC and calculating the difference in weight.

When necessary, water was added, using a 32 mm hose fitted with a flow meter to measure the amount of water required to maintain the moisture within the optimal range, when the piles were turned.

A temperature probe was inserted in the centre of each pile. The probe was connected to a datalogger that periodically sent data to a portable computer. When the temperature was observed to decrease, the piles were turned; overall, the piles were turned 9 times during the six-and-a-half month composting period (on days 5, 12, 19, 36, 54, 70, 103, 146, and 191).

## Determination of pH and Redox Potential (Eh) in the Field

pH was measured weekly by direct determination with a field potentiometer fitted with a special electrode for solid samples, which was placed – with the aid of an extension tube – in the centre of the piles. The measurements were made at an intermediate height, at three different points in each pile. The redox potential was also measured weekly at three heights (upper, intermediate, lower) in order to detect any possible gradients in different zones of the piles.

## Characterization of the Raw Materials and Compost

The samples of compost were collected in the field when the piles were turned, to ensure their representativeness. Samples of approximately 2 kg were taken from each pile. The samples were taken at an intermediate height from three different points in each pile (one in the centre and one at each extreme). The samples were stored in sealed plastic bags and transported to the laboratory, where they were homogenized and divided into two parts: one for analysis of fresh material (stored at -4ºC) and the other for analysis of dried material (at 60ºC for a minimum of 3 days, then milled to <0.5 mm to homogenize the samples). The analytical results are expressed on a dry-weight basis for reproducibility of the results.

The organic carbon was determined by the method of Sauerlandt, modified by Guitián and Carballas [16], based on the oxidation of organic matter with potassium dichromate and sulphuric acid. The excess potassium dichromate was titrated with Mohr salt. Total nitrogen was determined by the Kjeldahl method [16].

The total contents of nutrients and potentially toxic elements were determined after digestion of the samples with nitric acid (low in Hg) in a microwave oven (ETHOS 900 Microwave Labstation), with five established cycles of duration under running conditions of between 250 and 800 W, and 10 and 17 bars. The concentrations of P, Ca, Mg, K, Zn, Mn, Ni, Cu, Co, Cd, Cr, Pb, B, As, Mo, and S in the extract were measured by ICP-OES. In this case, the determinations were not made during all samplings, but only at the start of the experiment and when the piles were turned for the 2$^{nd}$, 4$^{th}$, 6$^{th}$, and 9$^{th}$ times.

## Tests of Stability, Phytotoxicity, and Determination of *E. coli* in Composts

The composts were obtained after a period of 190 days, knowing that the process was not finalized until the composts were mature. Nevertheless, once this stage was reached, and before the compost was characterized, some parameters were determined in order to ensure the stability of the product. As there is no single accepted method for determining compost maturity measuring substrate stability [17-20], some of the most common methods (autoheating test, relationship between humic and fulvic acids) were carried out with rapid test kits (Solvita®).

Stability was also tested indirectly by the autoheating method [21], and by use of the Solvita® Compost Maturity test (Woods End Research Laboratory Inc., Mt. Vernon, Maine, USA).

To determine fulvic and humic acid contents, the samples were subjected to alkaline extraction with 0.1M pyrophosphate-0.1N caustic soda to obtain total humic extract; the humic acids in this extract were then precipitated at pH<2 with sulphuric acid. The content of organic carbon was determined in both the humic extract and in the precipitate [22].

The phytotoxicity was determined by the test described by Zucconi et al. [23], with seeds of Lactuca sativa [24].

The most probable number of *E. coli* was determined with a commercial test kit (Petrifilm™ Select *E. coli*), according to the manufacturer's instructions. The system is based on the enzymatic activity of β-glucuronidase (GUD), which is produced by approximately 97% of *E. coli* strains, and which reacts with an indicator dye in the Petrifilm, which makes the colonies turn dark green to blue-green. Briefly, a 1:10 dilution was prepared aseptically, with 25

Table 2. Characteristics of the raw materials.

| | pH | C (%) | C:N |
|---|---|---|---|
| Pruning remains | 7.04 | 51.89 | 44.7 |
| Leaf litter | 6.77 | 38.45 | 20.7 |
| Sludge | 8.42 | 24.45 | 13.1 |
| Ash | 9.45 | 32.78 | 93.7 |

grams of each sample plus 250 ml of buffered peptone water (ISO 6887). The diluted samples were homogenized in a Stomacher® blender, and 1 ml of sample was placed perpendicularly in the centre of a Petrifilm plate. The Petrifilm plates were incubated at 44ºC for 24 hours and dark green to blue-green colonies were counted for each sample. Representative colonies from each sample were isolated for confirmation of the presence of, e.g., *E. coli* by standard biochemical procedures (such as glucose positive, $SH_2$ negative, citrate negative, urease positive, and indol positive).

## Results and Discussion

### General Characterization of the Raw Materials

From the characterization carried out, only the most important parameters from the point of view of use of the material for composting are shown.

#### *Biomass Ash*

The batch of ash used consisted of a mixture of coarse and fine particles, most (51.48% of the total weight) of size between 0.5 and 2 mm, although 12.35% were larger than 5 mm, most of which were partially burned and some of which were unburned particles. The material was alkaline (Table 2), with characteristics similar to those described by other authors [25-28]. The carbon content of the material was high, suggesting inefficient combustion, which would lead to less oxidation [29]. By contrast, the nitrogen values were very low, and similar to those reported [30]. The C:N ratio was therefore very high.

#### *Waste Water Treatment Sludge*

According to Royal Decree 824/2005 [31] on fertilizer products, treated sewage sludge (as defined and regulated by Royal Decree 1310/1990 [32]) can be used as a raw material for composting.

The sewage sludge was alkaline and contained a large amount of water (73%) (Table 2); the nitrogen content was 1.90% and the C:N ratio was low. The use of sludges in producing compost helps balance the high C:N ratios of other materials such as ash. In addition, the texture of sludge may help to bind certain mixtures, such as those containing leaf litter and pruning remains.

#### *Pruning Remains and Dead Leaves*

The pH of both the pruning remains and the dead leaves was close to neutral (Table 2). The C:N ratio of the pruning waste was similar to that reported [33] and that of the leaf litter was lower, although similar to that reported [34] for similar types of material.

### Monitoring the Composting Process: Changes in Control Parameters

#### *Temperature*

In all cases, once the piles were formed, the temperature rose rapidly, reaching the thermophilic phase in the first few days (Fig. 1), even though the surrounding temperature was very low [35]. The temperature of pile C reached just over 60ºC, whereas those of piles B and E surpassed 70ºC, that of pile A reached 75ºC, and that of pile D initially reached

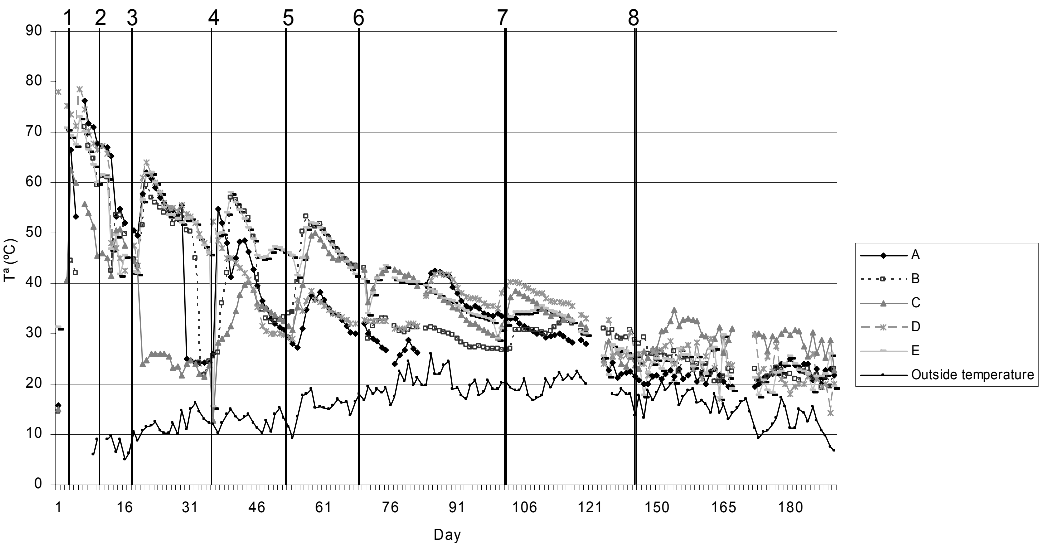


Fig. 1. Changes in temperature in the different piles during the composting process. The dates when the piles were turned are marked with vertical lines.

close to 80ºC. Temperatures of around 70ºC guarantee sanitization of the material, as they decrease or even eliminate pathogens, [36, 37] demonstrated that such temperatures were reached in piles comprised of only pruning remains or only dead leaves, but that the temperature then decreased to around 42ºC and did not increase again. This type of control pile was therefore not constructed in the present study.

In general, there was a positive response after the first six times of turning the piles, i.e. there was an increase in temperature each time. Such a thermal increase indicates that biological activity had not ceased. However, the temperature of the piles did not increase in response to later turnings, indicating the absence of a significant amount of microbial activity [38]. The exception to this was pile C, in which the temperature varied almost until the end of the study. At the final stage of maturation, the temperature of the piles ranged between 20 and 30ºC. These results indicate on one hand that a sludge content of 10% is sufficient to increase the initial temperature of the mixture to 70ºC (or more), at which the respiratory coefficient is high [39] and therefore to increase the degradation and stabilization of organic matter by thermophilic organisms. On the other hand, comparison between pile B and the other piles showed that although the addition of ash did not accelerate the initial increase in temperature, the mixtures containing ash reached higher temperatures in half the time, similar to that reported by Koivula et al. [30].

Ash also greatly reduced the odors released during the composting process, as the addition of alkaline substances prevents the formation of acidic compounds that are responsible for the bad smell of compost, as also found by Koivula et al. [30].

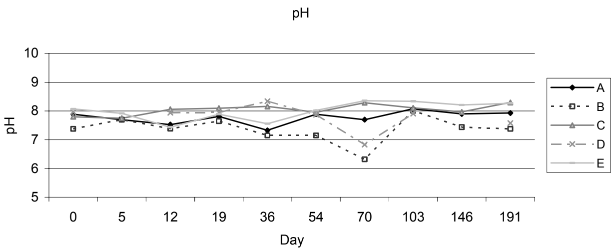


Fig. 2. Changes in pH in the different piles during the composting process.

The temperatures reached were in all cases sufficiently high for sanitization of the compost, as they met the criteria established in Anon [40], i.e. the maintenance of temperatures higher than 50ºC for a minimum of 5 days, with peak temperatures of more than 55ºC for at least 4 hours. With the exception of pile B, the other piles complied with stricter criteria, such as those applied in Germany, i.e. the maintenance of temperatures above 55ºC for two weeks or 60ºC for one week [41], or in Austria, i.e. maintenance of temperatures 60ºC for six days or above 65ºC for three days [42].

### *pH*

The initial pH of four of the five piles was approximately 8 (Fig. 2), whereas the initial pH of the pile that did not contain ash (B) was approximately 7.4. Although there were some variations, the pH remained at approximately 7-8 (considered the optimal pH range) throughout the incubation [43]. The lowest pH values were observed in the pile that did not contain ash, and the highest values in the pile that contained the most ash (E). The decrease in pH is due to the release of acidic substances during the composting process ($CO_2$ and organic acids), which are partly neutralized by the $NH_3$ generated [44], and in the present study by the use of alkaline materials such as the sludge, and particularly the ash, which decompose slowly [45], so that the pH remains high throughout the process.

### *Eh*

The redox potential can be used to monitor the composting process [46]. In the present study, the Eh values in the piles indicated humid, aerated conditions (Fig. 3), and slightly lower values were only observed in pile E, although the conditions in this pile were more oxidizing throughout the incubation, as the ash helped increased the porosity of the sludge, thus favoring oxygen flow in the compost [30]. It therefore appears that the highest dose of ash produced a more porous material, which favored gas exchange in the pile. In general, the lowest Eh values were observed in piles B (no ash) and C (no sludge). Although there were some fluctuations in the values, the Eh tended to remain stable or increase over time, in contrast to the findings of Khalil et al. [46], who reported a decrease in Eh as the composting process progressed.

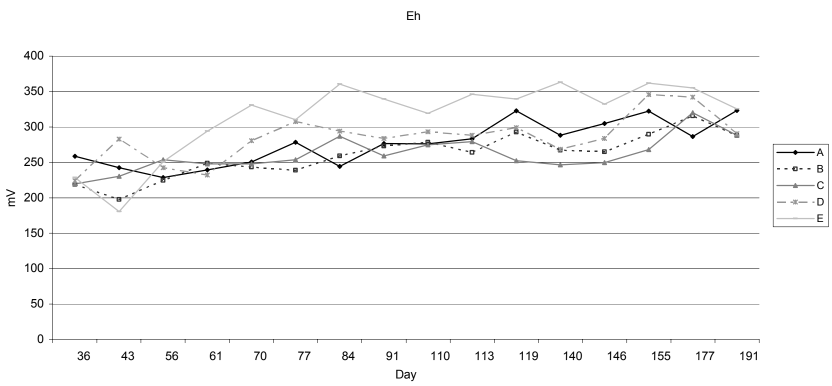


Fig. 3. Changes in Eh in the different piles during the composting process.

*C:N Ratio*

Although many authors consider the C:N ratio as a key factor in estimating the maturity of compost, others disagree with this because of the different biodegradability and bioavailability of the different materials [15]. Moreover, other authors believe that maturity is indicated by changes in the C:N ratio rather than by specific values of the ratio itself [47]. A value of 12 is reported as ideal by Bernal et al. [48], although a final C:N ratio of between 15 and 20 is commonly accepted [49]. In the present study, the initial values were very different, with the highest value corresponding to pile C, followed by pile E, i.e. those mixtures that did not contain sludge (which contains large amounts of nitrogen) or that contained a high proportion of ash (which contains large amounts of carbon); in both cases these materials influenced the C:N ratio (Fig. 4). At the end of the process, the C:N ratio in all of the composts was between 15 and 20, except in pile B, in which the value was somewhat higher (20.6). In all cases, the levels established by Anon [40], as regards the C:N ratio and the total nitrogen content (higher than 0.8%), were reached.

*Leachates*

The strict control of the amount of water used to moisten the compost led to very low production of leachates in the piles. To prevent the loss of leachates, each time that the piles were turned, the leachates were returned to the compost along with the water required to maintain the moisture content, as recommended by Forgie et al. [50].

## Final Characterization of the Compost Mixtures

*Maturity, Phytotoxicity and Sanitization of the Compost Mixtures*

The Dewar, or self-heating test [21], is an indirect method of obtaining information about the respiration index (Woods End Research Laboratory). Moreover, it is the most useful method for testing the maturity of compost made from biosolids [38]. In the present study, after the sixth time that the piles were turned there was almost no difference between the temperature inside and outside of the Dewar flask, indicating that the composts were totally stable (V degree of maturity) and that most of the biodegradable material had been transformed [51]. However, the temperature inside the compost piles was not consistent with this, as it continued to increase after the piles were turned, although to a lesser degree than after the first few turns. Other criteria, such as the contents of fulvic and humic acids were therefore used to determine the maturity of the compost.

The Solvita test was only used at the end of the process, and the results indicated that all of the composts were class 8, i.e. stable.

Changes in the amounts of fulvic acids or humic acids can be used as criteria for estimating the maturity of compost [52, 53]. The ratio between the amounts of humic and fulvic acids is also considered as an indicator of the maturity of compost [54]. The initial content of fulvic acids in the piles ranged from 1.5% to 2% (Fig. 5). The FA content varied during the composting process before stabilizing at around 1% in the different piles. In contrast, the humic acids were initially present in very low proportions, of between 0.65% and 0.91%, but in the final compost it increased to more than 1%, except in pile E. In other words, while the amounts of fulvic acids decreased and the amounts of humic acids increased during the composting period (as also observed [55-57]), as reflected by the HA:FA ratio (Fig. 4). In conclusion, the degree of decrease in the amount of fulvic acids is indicative the degree of maturity of the compost.

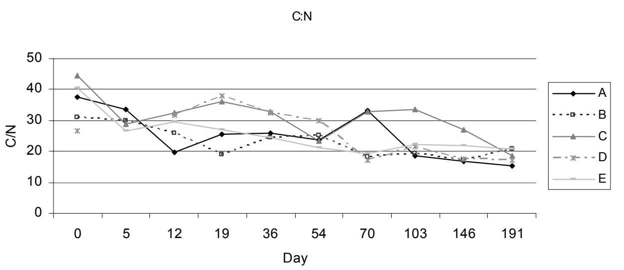


Fig. 4. Changes in the C:N ratio in the different piles during the composting process.

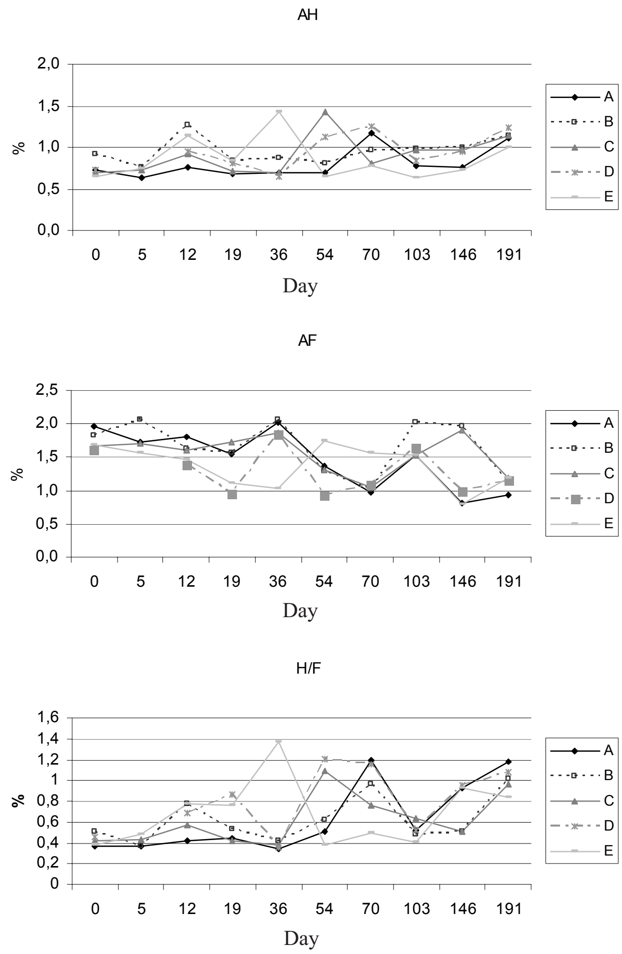


Fig. 5. Changes in the concentrations of humic acids (HA), fulvic acids (FA), and the HA:FA ratio.

The presence of phytotoxic compounds (short chain organic acids, phenolic compounds, salts, etc.) may inhibit the germination of seeds and/or development of plants. Plants show different degrees of sensitivity to these compounds, but composting generally leads to a decrease in the amounts of the compounds. One of the most commonly used tests for detecting the inhibition of germination by phytotoxic substances is that developed by Zucconi et al. [23]. According to the results of this test, the germination indices for the different composts produced in the present study were between 83% and 94%, which indicates the almost total absence of phytotoxic substances.

In all of the piles, after the second time of turning the compost, the most probable number (MPN) of *E. coli*·$g^{-1}$ was less than 1000, which indicates that the compost was sanitized, as established in the Royal Decree on fertilizing products [31]. The number was even lower at the end of incubation (MPN <10 *E. coli*·$g^{-1}$).

*Phosphorus*

The total concentrations of phosphorus at the end of the composting process ranged between 1,674 mg·$kg^{-1}$ (compost C) and 4,782 mg·$kg^{-1}$ (compost B). The highest P concentrations were reached in the composts containing sludge and the lowest in the compost that did not contain sludge. This is because the sludge generated in urban wastewater treatment plants is particularly rich in phosphorus [58] and obviously contributes to enriching the composts with this element (Fig. 6). The amounts are similar to those reported [8] for a compost made from wood ash and organic wastes.

Anderson [59] considered that the C:P ratio in the organic matter determines whether mineralization reactions predominate over immobilization reactions, and proposed a critical level of 200 for this ratio. Higher values (high contents of carbon) indicate a predominance of immobilization reactions and lower values (low contents of carbon), plus a predominance of mineralization reactions. The C:P ratios were lower than 200 in all composts at the beginning and end of the process, except in compost C (no sludge) at the start of the study. The value of the C:P ratio in the same compost at the end of the study was 155, which although lower than 200 (Table 3), was high in comparison with the values in the other composts (55-70). In other words, mineralization reactions predominated over immobilization reactions. Moreover, the concentration of phosphorus varied during the composting process (Fig. 6), partly because of the mineralization of composted materials and partly because it was precipitated as calcium and magnesium phosphates, via reactions that are favored at the pH of the composts.

Table 3. C:P and C:S ratios in the different composts at the initial and final stages of the composting process.

| Compost | C:P | | C:S | |
|---|---|---|---|---|
| | Initial | Final | Initial | Final |
| A | 195 | 56 | 126 | 65 |
| B | 81 | 66 | 102 | 77 |
| C | 397 | 155 | 109 | 96 |
| D | 134 | 66 | 104 | 76 |
| E | 177 | 70 | 155 | 66 |

*Calcium and Magnesium*

At both the start and the end of the process, the lowest concentrations of calcium were observed in the compost that did not contain ash (B) and the compost that did not contain sludge (C) (Fig. 6). At the start of the composting process the highest concentration of Ca was observed in the compost containing most ash (E), whereas at the end of the process the highest concentrations of Ca were observed in the compost containing equal amounts of ash and sludge (D), and the compost containing most ash (E). This can be explained by the composition of the ash, which depends on both the nature of the burned material and the combustion conditions [29], although in this case the biomass had been unevenly combusted (so that the ash contained slightly

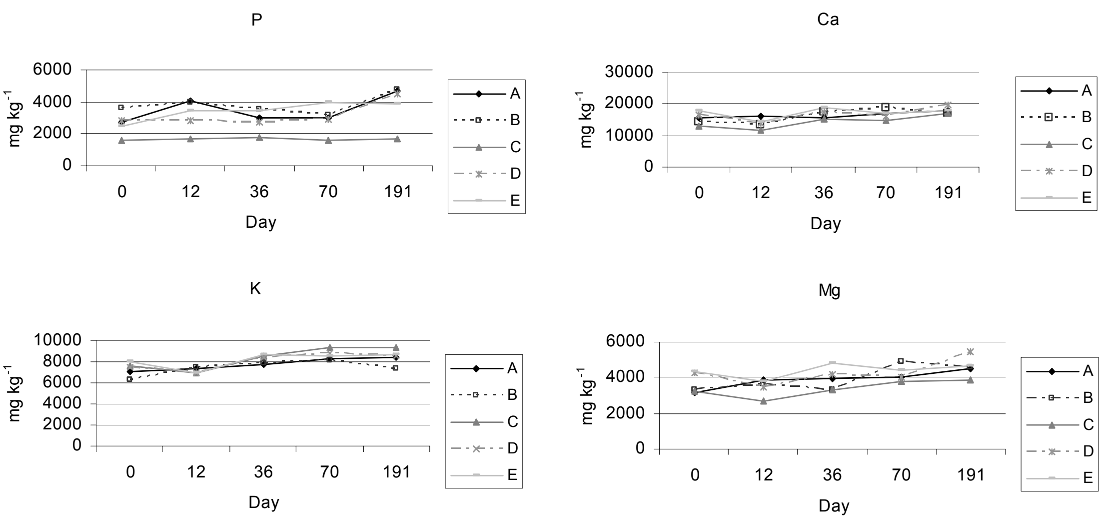

Fig. 6. Evolution of phosphorous, calcium, potassium, and magnesium in different composts during composting.

Table 4. Micronutrients and potentially toxic heavy metals in the different composts (mg·kg$^{-1}$).

| Compost | As | B | Cd | Co | Cr | Cu | Mn | Mo | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *A* | 14.80 | 20.23 | 0.31 | 4.38 | 85.44 | 43.05 | 417.67 | 2.25 | 17.56 | 21.99 | 232.95 |
| *B* | 12.50 | 16.64 | 0.29 | 4.57 | 81.88 | 42.57 | 362.09 | 2.50 | 16.72 | 25.01 | 232.49 |
| *C* | 16.70 | 20.39 | 0.32 | 3.01 | 39.66 | 20.67 | 450.75 | 2.56 | 11.03 | 7.38 | 69.79 |
| *D* | 11.30 | 20.30 | 0.27 | 4.77 | 140.39 | 45.52 | 453.75 | 6.60 | 47.69 | 28.87 | 234.42 |
| *E* | 14.80 | 24.19 | 0.29 | 4.66 | 79.68 | 37.36 | 640.22 | 1.70 | 19.48 | 18.25 | 191.14 |
| Class A* | | | 0.70 | | 70.00 | 70.00 | | | 25.00 | 45.00 | 200.00 |
| Class B* | | | 2.00 | | 250.00 | 300.00 | | | 90.00 | 150.00 | 500.00 |

* According to R.D. 824/2005

burned and totally combusted particles). This is important as when the material is combusted at low temperatures (600ºC), $CaCO_3$ and $K_2Ca\ (CO_3)_2$ predominate in the ash, whereas when the temperature reaches 1300ºC, CaO and MgO predominate, as potassium begins to be volatized at 800-900ºC [60].

On the other hand, sewage sludge is usually rich in calcium [58] because, independent of its initial composition, Ca is added *via* the materials used to stabilize the sludge [61].

The concentrations of magnesium followed a similar pattern to those of calcium, although the former were much lower. The highest concentrations of Mg at both the beginning and the end of the incubation were observed in composts D and E. The concentrations in the other composts were fairly similar.

### *Sulphur*

The amounts of sulphur were similar in all of the composts (approximately 0.40%), except for the compost that did not contain sludge (C), in which it was only 0.22%. The amounts of sulphur are similar to those reported for a compost made from cotton waste, and the lower value (0.22%) is the same as that found for the compost in its initial state [62].

As regards the C:S ratio, Beltrame et al., [63] reported that values higher than 300 indicate a predominance of immobilization reactions, whereas values lower than 100 indicate a predominance of mineralization reactions. In the present study, the values were higher than 100 at the start of the experiment (Table 3), with the highest values corresponding to the compost containing most ash, and the lower to the compost that did not contain any ash. At the end of the study period, the values for all of the composts were lower than 100, with the highest value corresponding to the compost without sludge and one of the lowest values corresponding to the compost containing most ash.

### *Micronutrients and Potentially Dangerous Metals*

As regards elements restricted by Royal Decree 824/2005 [31], in which compost is classified into three categories on the basis of the heavy metal content, all of the composts were categorized as class B fertilizer materials (because of their contents of Cr and Zn), except compost C, which was categorized as class A fertilizer (Table 4). Furthermore, the use as substrate of these composts has been studied previously [64]. As regards the other elements, arsenic was present at similar concentrations reported by Baki et al. [65], where Co and Mo were less abundant and Mn was more abundant than in a compost extract obtained from urban solid waste [65].

## Conclusions

After six and a half months all of the composts were stable, sanitized, and did not contain phytotoxic substances. However, the composts containing sludge and ash became stabilized and sanitized more rapidly than the others, and generally contained more nutrients. The compost made from 20% leaf litter, 10% sludge, 10% ash, and 60% pruning remains (% in volume), was of particularly high quality, as it was readily mineralizable and supplied phosphorus, calcium, magnesium, and potassium. This compost was categorized as class B on the basis of the contents of chromium and zinc, i.e. it can be used as a potting compost or mixed with other materials in order to lower the content of these metals.

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