

## **Compost based ecological growing media according EU eco-label requirements.**

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## **Abstract**

Green compost is seen as one of the best solutions for peat replacement in growing media and for increasing their sustainability. However, the poor quality of many composts has restricted their use as substrate components. The EU Ecolabel may be awarded to products and services that have a reduced environmental impact throughout their life cycle. It is voluntary and ensures certain aspects of the origin and quality. The primary aim of this work was to obtain a gorse compost-based substrate fulfilling the requirements for award of the eco-label.

Forest biomass consisting mainly of gorse was composted in dynamic piles with or without irrigation (I) at the beginning and with or without addition of 5% v/v poultry manure (PM). There were thus four different composting treatments that were designated PM0I, PM5I, PM5 and PM0. Temperature, moisture, pH and the C/N ratio of the composting biomass were monitored over a period of nearly 10 months. The resulting composts were characterized in physical, chemical and biological terms, and evaluated for compliance with the requirements of the European Union eco-label for growing media. All composts were found to be mature, stable and pathogen-free. All of them were suitable for use as growing media, exhibiting a high aeration and drainage capacity, little water retention and adequate level of available nutrients. In general they also met the requirements of the EU eco-label, although not all were weed seed-free, which was possibly the sole unfulfilled EU eco-label requirement.

**Key words :** Substrate, poultry manure, forest biomass, gorse, *Ulex europaeus* L

## **Highlights**

Growing media based on gorse compost fulfilling EU-ecolabel requirements was obtained

All the composts obtained were mature and stable enough and were properly sanitized.

The piles containing manure reached higher temperatures than those not containing it.

The composts had a high aeration and drainage capacity but little available water.

Windrows should be enough isolated to avoid re-infestation by weed seeds.

## 1. Introduction

Whether alone or in mixtures, peat is the substrate most commonly used in horticulture to grow seedlings and soilless plants. But quality peat is a scarce resource in southern Europe, where there is a significant soilless crop production sector. Peat must therefore be imported from northern and central Europe and recently has become more expensive (Ribeiro et al., 2007), but resort to low cost products involves problems of quality and heterogeneity. In addition, peat is a very slowly renewable natural resource and its exploitation entails C emissions which could greatly influence climate change (Boldrin et al., 2010), so environmental pressure against its extraction has risen.

In response to these concerns and the need for efficient recycling of wastes, the EU Commission (2006) has established the ecological criteria for the award of the Community's eco-label to growing media. The EU Ecolabel is a voluntary scheme promoting environmental excellence which can be trusted. It may be awarded to products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal. To apply for the European Eco-label the products have to meet requirements for raw materials, hazardous substances, contaminants, nutrient loadings, product performance and product safety.

A growing media shall only be considered for the award of the eco-label if it does not contain peat and its organic matter content is derived from the processing and/or re-use of waste. In the organic constituents content of heavy metals (Zn, Cu, Ni, Cd, Pb, Hg and Cr) is limited, and also other hazardous substances (Mo, Se, As and F) for products containing materials from industrial processes. Products have to show low level of primary pathogens (absence of salmonella and helminth ova and *E. coli* <1000 MPN g<sup>-1</sup>) and of viable weed seed/propagules (<2 units L<sup>-1</sup>). Besides, growing media must not adversely affect plant emergence or subsequent growth and its electrical conductivity must not exceed 1.5 dS m<sup>-1</sup>.

Although it will not be the sole solution, green compost has an important role to play in peat replacement or the transition to sustainable growing media. However some users of growing media have never had confidence in the use of green compost and others have had their confidence in its use dented through past use of poor quality compost (Knight, 2012). Lack of uniformity, less-than-optimal physical properties, high salinity, low pH, occasional phytotoxicity and threats as human or plant pathogens are the most frequent constraints of green compost to be used as growing media component (Raviv, 2013). Therefore quality assurance is key to promote the inclusion of compost in substrates and progress in reducing the use of peat.

The literature abounds with studies on the potential of various types of compost as growing media and nutrient sources (Fiasconaro et al., 2015; Papafotiou et al., 2004) the best among which might fulfil the EU eco-label requirements. However, none of the 63 substrates currently holding the eco-label consists solely of compost; also, pine bark-based substrates aside, those containing any compost account for less than 10 % of all (EU Commission, 2015).

Organic residues successfully used as growing media include compost from green waste such as pruning (Aleandri et al., 2015; Benito et al., 2005; Morales-Corts, 2014,) or forestry cleaning residues (Ribeiro et al., 2007). Galicia, a region in NW Spain, has a number of forest areas abounding with scrub bush largely consisting of gorse (*Ulex europaeus* L.). Although gorse originated in central and western Europe, and the British Isles, it is also present in North America, New Zealand and Australia, where it was introduced as an ornamental plant and now occupies large areas and is considered a highly invasive species. It is therefore a material available in good quantities around the world. The aim of this work was to obtain a gorse compost-based substrate fulfilling the requirements for award of the European Union eco-label.

## **2. Material and methods**

### **2.1. Composting process**

Forest scrub was used to obtain four different composts. The shrubs, consisting mainly of 4-5 year's old gorse (*Ulex europaeus* L) plants, were collected and chopped with a flail forage harvester. An experimental design consisting of two factors at two levels each was used. The two factors were irrigation (I) at the beginning of the process and the addition of 5% (v/v) poultry manure (PM) from an organic egg producing farm. The addition of manure was intended to facilitate the process by lowering the C/N ratio to about 30 at the start, and also to increase nutrient levels in the end-product. A proportion of 5 % (v/v) was thought to suffice in order to fulfil both aims while reducing the risk of too high salinity in the composted material. Irrigation was intended to increase moisture and reduce salt contents as far as possible in the starting gorse. Layers of the material 25 cm thick received 175 L m<sup>-2</sup> of tap water and then were left to drain two days. There were thus four different treatments, namely: PM0I (irrigation without addition of PM), PM5I (irrigation plus addition of PM), PM5 (addition of PM but no irrigation) and PM0 (no irrigation neither PM).

Composting was started in July and followed by maturation. The overall process thus lasted 9 months. Piles were frustoconically shaped and approximately 6 m<sup>3</sup> in volume and 2 m high. They were mechanically turned over about once a month at the beginning and every 2 months later. Moisture was maintained by hose irrigation beginning two weeks after the start of the experiment;

and the piles were covered during the periods of increased precipitation. Pile temperature was measured at three different depths (0.2, 0.4 and 0.6 m) by inserting a thermometer through a side of the pile-roughly at the middle of total height- to the centre.

## **2.2. Laboratory analyses**

### *2.2.1. Analysis of raw materials*

The materials examined included the gorse before and after irrigation, and the poultry manure. pH was measured in their saturation extracts and moisture contents by oven drying at 105 °C to a constant weight. The total contents in C, N and S were determined with a LECO TruSpec CHNS autoanalyzer and those in Ca, Mg, Na, K and P by ICP-OES after digestion of finely ground samples of each material with HNO<sub>3</sub> (USEPA, 1995).

### *2.2.2. Monitoring of the composting process*

Samples were periodically obtained from the piles to determine pH, electrical conductivity (EC), moisture content, and total C and N. EC and pH were measured in the saturation extracts, moisture content was determined by oven drying, and total C and N by using the LECO TruSpec CHNS autoanalyzer.

### *2.2.3. Characterization of the final compost*

The obtained composts were fully characterized prior to use as growing media. A representative portion of each compost pile was sieved to 6 mm and transferred to the laboratory for comprehensive physical, chemical, physico-chemical and biological analyses with a view to assessing the potential of the composts for organic agriculture.

#### *2.2.3.1. Physical properties*

The specific physical properties determined were the moisture retention curve (De Boodt et al., 1974), total porosity, bulk density, particle density and shrinkage value (EN-13041,1999), compacted bulk density (EN-13040, 2007) and particle size.

#### *2.2.3.2. Chemical and physico-chemical properties*

EC, pH and soluble elements were assessed in both saturation extracts and 1:5 (v/v) extracts (EN-13652, 2001). Also, C and N were determined as described in Section 2.1, and the total content in Ca, Mg, K, P, Cr, Cu, Cd, Pb, Zn, Hg and Ni were determined by ICP-OES after digestion with HNO<sub>3</sub> (USEPA, 1995). The organic matter and ash contents (EN-13039: 1999), and the stability of organic matter (Saña et al., 1989), were also determined.

### 2.2.3.3. Biological properties

Compost maturity was assessed via the germination bioassay of Emino and Warman (2004) with slight modifications. To this end, 20 lettuce seeds (*Lactuca sativa* var. Reina de Mayo) were sown in Petri dishes between pieces of filter paper moistened with 6 mL of aqueous 1:10 (w/w) extract, using distilled water as control and four repetitions per treatment. The dishes were placed in the dark at 20 °C for 3 days, after which the number of germinated seeds in each was counted and root lengths were measured. The germination index (GI) was calculated as the product of the mean number of germinated seeds by the mean root length, both of them relative to the control (Zuconi et al., 1981).

A germination–growth bioassay was also conducted by using barley (*Hordeum vulgare* var. Scarlet) in accordance with the guidelines of FCQAO (1994). All composts and their 75/25, 50/50 and 25/75 % (v/v) mixtures with white sphagnum peat were tested, the peat being used as control (0 % compost). Four 450 mL pots per treatment were prepared and 50 seeds sown in each. After 12 days in a growth chamber, the number of germinated seeds was counted and the fresh and dry weight of the aerial part of the plants measured.

Trays containing 1 L of substrate each were allowed to stand under controlled light and temperature conditions for 1 month prior to counting germinated seeds. The amount of microorganisms for which the EU Commission (2006) has set limits in plant growing media (viz. salmonella, helminth eggs and *E. coli*) was also measured.

### 2.3. Statistical analysis

The two principal components (independent variables) examined were (a) wetting of the ground gorse material before piling and (b) the addition of poultry manure mixed with gorse in a 5% (v/v) proportion. The variation of the target parameters during the composting process was examined by using a Repeated Measures General Linear model with date as the between-subject variable. The characteristics of the composts obtained were processed by using Multivariate Analysis of Variance (MANOVA) for statistical analysis and Tukey's test for post-hoc analysis. Those differences between data pairs with a probability in the statistic  $F$  less than 0.05 were assumed to be significant. Data normality was previously confirmed in terms of the Kolmogorov–Smirnov test and variance homogeneity as determined with Levene's comparison test. All statistical calculations were done with the software PASW Statistics 18.

### 3. Results and discussion

#### 3.1. Characterization of raw materials

The composition of the raw materials is shown in Table 1. The gorse was more acidic (pH = 5,5-6) than that used in previous compost test (Brito et al., 2010) and also than most of the green waste used for composting (Belyaeva and Haynes, 2010; Belyaeva et al., 2012), which tends to be neutral, or even than other more lignified materials such as pruning residues (Estévez-Shwarz et al., 2012). Also, the gorse exhibited a high C/N ratio typical of a lignified green waste and exceeding the typically accepted levels for composting (Jhorar et al., 1991). Its chemical composition was comparable to that of gorse used as a bulking agent for composting (Brito et al., 2010), but poorer in N and, overall, poorer in nutrients than that of younger, less lignified gorse used as feed (Lambert et al., 1989). Irrigating it prior to composting raised its pH slightly but caused no substantial changes in total element contents, even though it increased the C/N ratio somewhat as a result of the loss of soluble substances lowering the N content and slightly raising the C content.

The poultry manure was near-neutral and had higher element contents —C excepted— than the gorse; such contents, however, were lower than those of materials used by other authors, possibly because of its increased proportion of pine shaving bedding. Based on the densities of the starting materials and on their moisture contents at the time the mixtures were prepared, adding 5 % v/v poultry manure led to a mixture of approximate composition 70:30 dry weight. Therefore, the initial C/N ratio in the mixtures containing PM was 28–32.5 depending on whether irrigated or dry gorse was used. These ratios are similar to the target value (30) and fall within the optimum range established at the beginning of the composting process: 25–35 (Jhorar et al., 1991).

#### 3.2. Monitoring of the composting process

##### 3.2.1. Temperature

Figure 1 shows the variation of the temperature at different depths in the composting piles (20, 40 and 60 cm). The highest temperature was recorded after 25 days in all treatments. The composts reaching the highest temperatures (> 60 °C at depths > 40 cm) were those that were previously irrigated (PMOI and PMI). The factor irrigation was significant at the depths 20 cm ( $p = 0.018$ ) and 40 cm ( $p = 0.040$ ). The piles initially wetted reached higher maximum temperature than the corresponding ones without initial irrigation. Although the natural moisture content of dry gorse may suffice for composting under some circumstances (Bueno et al., 2008), there is wide consensus that it should exceed 50% (Tiquia et al., 1996; Walker et al., 1999). In this work, moisture was a

determining factor by effect of the strong evaporation at the beginning of the composting process — which led to a more marked effect at lower depths.

The piles containing poultry manure (PMI5 and PM5) reached higher temperatures in the thermophilic phase than those not containing it (PM0I and PM0) ( $p = 0.037$  for period 7-26 days). The difference reached 8 °C between treatments with initial irrigation (PM0I and PM5I). Also, the thermophilic phase ( $T^a > 45^\circ\text{C}$  at 60 cm depth) was shorter in the manure-containing piles (60 vs 90 days) as a result of the latter having a higher proportion of readily microbe-available labile organic matter, and hence facilitating metabolic activity (Hassen et al., 2001) and a more rapid depletion of the labile organic substrate. Temperatures above 55° C for more than 3 days reduce and may even eliminate pathogen, thus ensuring the safety of the material (USEPA, 2003).

Pile temperature equilibrated with ambient temperature after about 200 days. This is consistent with previous results of Belayaeva and Haynes (2010) for the composting of green waste, and co-composting of green waste and chicken manure.

### 3.2.2. *Moisture*

The initial moisture contents in the four piles ranged from 40 to 60% and levelled off at 50-60 % at the end of the composting process (Fig. 2a). The irrigated piles exhibited an increased moisture only at the beginning, after which the moisture content was primarily dependent on the amount of water received. Overall, the piles containing no manure (PM0 and PM0I) retained more water, whether from irrigation or precipitation, and remained significantly wetter ( $p = 0.019$ ). In fact, their moisture levels were occasionally too high (> 60 %) and could limit aeration and microbial activity (Bueno et al., 2008, Tiquia et al., 1996) during the winter (after day 140) owing to the supply of rainwater and low evaporation even though the piles were covered during the rainiest periods. On the other hand, moisture in the piles containing poultry manure increased during the winter but never reached too high levels.

### 3.2.3. *pH*

The pH of the raw materials, which initially exceeded 5, rapidly increased to near-neutral values but later decreased again to acid levels (Fig. 2b). The initial pH need not have inhibited microbial activity on organic matter (Plana, 2009), since composting shredded leafy branches of  $\text{pH} < 5$  has been found to give a product with a near-neutral pH (Bakry et al. 2011). The presence of poultry manure resulted in significant differences ( $p = 0.002$ ); in fact, the piles containing it exhibited a higher pH than those excluding it throughout. Initially, differences were slight (roughly 1), and due to the increased N content and more marked release of ammonia through decomposition. After 140 days, however, the piles containing no poultry manure exhibited strong acidification ( $p = 0.001$ ) and

their pH was about 2 points lower than in the piles containing manure. The difference can be ascribed to excessive moisture in the piles containing no manure leading to anoxic conditions. Compost can occasionally undergo strong acidification by effect of the anaerobic conditions and the accumulation of short-chain fatty acids; these acids tend to lower the pH of the medium to an extent proportional to the importance of anaerobic processes occurring in the composting mass (Plana, 2009).

### 3.2.4. Organic matter, N and C/N

The release of CO<sub>2</sub> reduced the organic matter content of the materials considerably during composting (from 690 to about 390 g kg<sup>-1</sup> d.m. in the piles containing poultry manure and from 830 to 540 g kg<sup>-1</sup> d.m. in those excluding it) (see Tables 1 and 3). The materials also lost some N; however, the increased concentrations resulting from the loss of organic matter led to increased N contents in the composts (about 20 g kg<sup>-1</sup> d.m.) (Table 3) relative to the starting materials (1.1–1.6 g kg<sup>-1</sup> d.m. depending on the particular treatment) (Table 1).

The losses of organic matter and N from the piles during composting were calculated from the contents at the beginning (OM<sub>0</sub>, N<sub>0</sub>) and at each sampling date (OM<sub>i</sub>, N<sub>i</sub>), using the methodology of Paredes et al. (2000) and the equations:

$$\text{OM-loss} = \text{OM-lost} / \text{OM-initial} = 1 - [(1-OM_0) OM_i] / [(1-OM_i) OM_0]$$

$$\text{N-loss} = \text{N-lost} / \text{N-initial} = 1 - [(1-OM_0) N_i] / [(1-OM_i) N_0]$$

As can be seen from Fig. 2d, organic matter losses were accurately fitted to a two-fraction first-order kinetic model (Molina et al., 1980) based on the equation:

$$\text{OM-loss} = OM_1 (1-\exp(-k_1t)) + OM_2 (1-\exp(-k_2t))$$

where  $OM_1$  and  $OM_2$  denote maximum degradation of organic matter in each of the two fractions,  $k_1$  and  $k_2$  are the respective mineralization rate constants (days<sup>-1</sup>), and  $t$  is the composting time (days)

Overall, composting resulted in the loss of about 77% of the initial amount of OM present irrespective of treatment (Fig. 2 d). This proportion is high relative to previously reported values (Paredes et al., 2000; Brito et al., 2010). Despite converging on the same final value, in a first stage unirrigated piles (PM5 and PM10) lost less OM than irrigated piles (PM5I and PM0I), which exhibited a near-zero OM lost between days 14 and 46. This result suggests that the initial moisture content of the unirrigated piles was inadequate and restricted composting during that period, where the materials had only available their initial moisture.

The models obtained help to explain the behaviour of the composting process relating it with the parameters previously studied. The second term of the equation ( $OM_2$ ,  $k_2$ ) correspond to the most

labile fraction of the OM ( $k_2 > k_1$ ) which is intensely mineralized in the first stage of the process increasing the thermophilic phase; it accounted for the 30-38 % of the initial OM. Whereas the first term ( $OM_1, k_1$ ) correspond to a more mineralization-resistant fraction of the OM which is mineralized more gradually along the process and it was the 40-47 % of the initial OM.

The statistical comparison of the fittings according to the procedure described by Pérez-Cruzado et al. (2015) and using the  $\alpha$ -trimmed mean test and the Wilcoxon signed-rank test showed that the model obtained for treatment PM5I (with PM and initially irrigated) was significantly different ( $p < 0.04$ ) to that of PM0I (without PM and irrigated) and these two were significantly different ( $p < 0.04$ ) to those of unirrigated treatments (PM5 and PM0), which were equivalents ( $p > 0.50$ ). Also these unirrigated piles exhibiting a lower regression coefficient than the irrigated ones and, in fact, no two distinct OM fractions were identified because  $k$  was identical for both ( $k_1 = k_2$ ). This clearly reflects that the lack of water in the first stage limited the degradation of the most labile OM in the unirrigated piles and it was the major determinant of the process, preventing any effect of the addition of PM. By contrast, in piles initially irrigated, without such limitation, the manure contributed to the labile fraction so the degradation of OM in the first phase increased.

Nitrogen was lost throughout and losses amounted to 45% of the initial content, with no differences between treatments (results not shown). The amount of N lost through decomposition was much smaller than that of C lost as  $CO_2$ ; as a result, the C/N ratio decreased during the process (Fig. 2c). The initial C/N ratio differed markedly between piles: it peaked in the absence of manure (PM0 and PM0I) and the irrigated piles had higher values than corresponding ones without initial irrigation. However, the ratio decreased as soon as composting was started, albeit more abruptly in the irrigated piles by effect of increased metabolic activity in them. As a result, the ratio in the irrigated piles fell below that in the unirrigated piles within 2 weeks. The index levelled off after about 100 days, with final values of 11-16, indicating a high degree of stabilization was achieved (Sanchez-Monedero et al., 2001). Then the initial differences between the piles with and without PM remained ( $p = 0.016$ ), but those due to irrigation did not ( $p = 0.823$ ).

### **3.3. Characterization of composts**

#### *3.3.1. Physical properties*

Figure 3 shows the grain size distribution of each compost after sieving through 6 mm mesh. As a rule, the predominant fractions were those 2–5, 1–2 and 0.5–1 mm in size, which jointly accounted for 60–70% of the total material weight. Grain size distribution is the key to pore size distribution in the solid, porous matrix of this substrate, which in turn influences air–water relationships and other physical properties (Noguera et al., 2003). The most suitable grain size for an adequate air-water

balance in growing media is equivalent to the 0.25–2.5 mm fraction (Abad et al., 1993). The high proportion of coarse grains (> 1 mm) in the four composts (Fig. 3) was responsible for their high porosity (> 86.7 %) and for the presence of an also high proportion of non-capillary pores (macropores) (Abad et al., 2001), which caused materials possessed a high aeration capacity (AC > 40 %) but retained small water volumes even at very low pressures (<1 kPa) (Table 2). Mean values of  $R$  (viz. the pressure at which the water and air contents of the substrate were identical) were lower than 1 kPa in the four piles, which is also indicative of substrates highly aired but containing little easily available water (De Boodt et al., 1974).

Based on the foregoing, the composts had a high total porosity and aeration capacity, as well as a too low proportion of available water in relation to the ideal substrate. These results are consistent with those reported by Díaz et al. (2008) for gorse compost and those of Benito et al. (2005) for pruning waste compost. With AC > 20%, the substrates are suitable for epiphytic plants such as bromeliads or azaleas. Their low water availability would require their frequent, mild irrigation to ensure adequate amounts of plant available water and also to reduce drainage and its associated loss of nutrients. Since the amount of water retained by a given volume of substrate depends on the container height (Wallach, 2008), these substrates can be effectively used in containers less than 10 cm tall, where adequate aeration can be ensured. Besides, these composts can confer porosity and drainability to potting mixes, and they are suitable to be combined with materials with a good water retention capacity.

The particle density ( $d_p$ ) of the substrates ranged from 1.9 g cm<sup>-3</sup> for those containing no poultry manure to 2.1 for those containing it; the difference can be ascribed to the increased mineral content of the manure. According to Abad et al. (1993), the bulk density ( $d_b$ ) of a growing media should be less than 0.4 g cm<sup>-3</sup>; but potted plants of large size or under relatively strong wind require densities of up to 0.5–0.75 g cm<sup>-3</sup> (Ballester-Olmos, 1993). As can be seen from Table 2, all of the substrates had  $d_b < 0.25$  g cm<sup>-3</sup>, suitable for small plants grown in small pots. Also, the shrinkage values for the substrates fell below the upper limit recommended by Abad et al. (2001) and Noguera et al. (2003): < 30%. Volume shrinkage is important because it increases medium compaction and root damage, thereby reducing the efficiency of irrigation and plant quality.

### 3.2.2. Chemical properties

The organic matter contents of the four compost were comparable to other green composts made from low lignified materials (Morales-Corts et al., 2014) but they were much lower than typical of those made from lignified plant materials (Aleandri et al., 2015; Benito et al., 2005) and also fell below those of other gorse composts (Díaz et al., 2008) (Table 3). This result can be ascribed to the

young age of the gorse plants used and to the mineralization of the material during the long composting period used in this work

According to Abad et al. (1993), the C/N ratio of compost ranges from 20 to 40; according to Burés (1997), however, it spans the range 5–30 and a value below 20 is suggestive of compost maturity and stability. Based on these figures, our gorse composts possess an optimum C/N ratio (see Table 3). The fact that the piles containing PM had a lower C/N ratio than those excluding it was a result of the manure being richer in nitrogen than gorse (PM contains 2.3% nitrogen versus an average 1.4% for dry and wet gorse), of the total carbon content of gorse nearly doubling that of PM and of the PM-containing piles undergoing stronger decomposition of organic matter and consequent release of carbon as CO<sub>2</sub>.

Although interpreting the C/N ratio is made difficult by differences in element bioavailability and biodegradability, the values for our composts fall within the acceptable range for mature compost. The stability degree (SD) of organic matter affords a more accurate interpretation than the C/N ratio because it is determined with provision for biodegradability in organic matter fractions. Our composts had SD > 50% and were thus stable (Saña et al., 1989).

The four composts were acidic and only those containing manure had an appropriate pH in the saturation extract for use as growing media: 5.2–6.3 according to Abad et al. (1993). Specifically, their pH values fell in the range recommended by Escudero (1993) for horticultural crops: 5.5–6.8 (see Table 4).

Although the salt-sensitivity of plants depends on their age as well as on the particular environmental conditions, plant species and crop management practices, the four composts exhibited a high electrical conductivity (EC). Also, the PM-containing composts were additionally more saline by effect of the increased mineral content of the manure. The presence of excessive amounts of soluble elements is one of the greatest constraints to using compost as a growing media (Abad et al., 2008); therefore, any manure used should be added in small amounts (Burés, 1997). The EC values of the composts as measured in the 1:5 (v/v) extracts (Table 5) were in all cases lower than 1.5 dS m<sup>-1</sup>, which is the limit set by the EU Commission (2006) for award of the eco-label; but they exceeded the maximum level recommended by Noguera et al. (2003): 0.5 dS m<sup>-1</sup>. The EC values measured in the saturation extracts were too high for any plant species. According to Burés (1997), it should not exceed 3.5 dS m<sup>-1</sup> and, according to Abad et al. (1993) the optimum range is 0.75–3 dS m<sup>-1</sup>.

The soluble ammonium, phosphorus and potassium contents of the saturation extracts exceeded the optimum values established by Abad et al. (1993) in all composts (Table 4). The nitrate, ammonium and potassium contents were even higher in the PM-containing composts. On the other hand, the

Mg contents in the composts fell within the range recommended by these authors. The Ca contents were low even in the manure-containing composts (PM5 and PM5I) despite the increased levels of this element in the manure (Table 1) —which is suggestive of the presence of insoluble Ca forms. Soluble Na content was moderately high, especially in compost with PM, related with it increased EC; it could limit some uses since Na values exceeding 30 ppm in saturated media extract could be harmful for seedlings (Styer and Koranski, 1997) and values over 250 mg L<sup>-1</sup> substrate (based on 1:5 extraction) showed a negative effect on cutting propagation (Fornes et al., 2013)

The compost containing poultry manure (PM5I, PM5) showed levels significantly higher of Mo and lower of Mn than those without it (PM0I, PM0). However the contents in Cu, Mn, Mo, B and Zn fell in the recommended ranges (Abad et al., 1993), whereas those in Fe were slightly lower than optimal.

The four composts were suitable as growing media for potting and transplantation, according to ADAS guidelines (1988). Only nitrate among the soluble nutrients in the 1:5 water extracts exceeded the levels proposed for these uses, whichever the treatment (Table 5). Potassium levels were also high in all cases, but only in compost PM5I did they exceed the proposed maximum. Phosphorus and ammonium levels were adequate overall, albeit somewhat low in the composts containing no manure (PM0I, PM0); on the other hand, Mg contents were adequate in all composts. None of the heavy metals studied (Cd, Cr, Cu, Zn, Hg, Ni and Pb) was present at levels exceeding the limits for award of the eco-label (EU Commission, 2006) (Table 3). In fact, all were present at levels well below the limit —by exception, the Zn content was nearly one-half the accepted limit, possibly because layer feed is usually supplemented with this micronutrient.

### 3.2.3. *Biological properties*

There were no significant differences ( $p < 0.05$ ) in the number of germinated seeds of spring barley between the different compost–peat mixtures (Fig. 4a). Also, there were no signs of leaf chlorosis or necrosis (results not shown); therefore, the composts can be deemed plant-tolerated. Also, the plants grown in all mixtures reached at least 90% of the weight they exhibited in the control substrate (Fig. 4b), so the composts can be used as soil improvers or fertilizers, and also in mixtures for garden and crop humus (FCQAO, 1994). The substrates containing compost alone also yielded very high fresh weights relative to peat; therefore, the composts can be used as single-component substrates.

Based on their high germination index (Fig. 5), our gorse composts are mature (GI > 80%) (Zucconi et al., 1981); also, they are germination triggers and boosters (GI > 100%) which may indicate the presence of biostimulant substances frequent in mature compost (Canellas et al., 2015). Belyaeva and Haynes (2010) previously obtained composts consisting of green waste with or without poultry

manure whose germination index was slightly lower than 100%. In this work GI was over 100% for all the treatments, so no negative effect of salinity or Na content on germination was observed; they could be responsible for the slightly lower GI values of the manure-containing composts, but any possible negative impact was surpassed by the biostimulant effect, which has been seen that can alleviate salt stress (Calvo et al., 2014; Canellas et al., 2015)

None of our four composts exceeded the primary pathogen limits set by the EU Commission (2006) for award of its eco-label to growing media. No salmonella was detected in 25 g of material and only 10 MPN of *E. coli* per gram were encountered (the accepted limit is 1000 MPN). Also, no helminth eggs were found in 1.5 g of material (results not shown). These results are consistent with the variation of temperature in the piles since hygienization is the combined result of a high temperature and a long exposure time. A temperature of 55 °C for 1 h or one of 60 °C for an even shorter time is lethal for these microorganisms (Day and Shaw, 2001); however, the deleterious effect of a high temperature may have been compounded with other factors such as the moisture content or C/N ratio of the materials (Singh et al., 2011). According to US EPA (2003), 55 °C for a minimum of 3 consecutive days suffices to destroy animal and human pathogens not resisting high temperatures in windrow composting systems; the material, however, must be turned over frequently during the thermophilic phase in order to ensure uniform exposure of the whole mass. Gantzer et al. (2001) found composting at 50–55 °C in different times of year for 4 weeks —and hence under milder conditions than here— to suffice in order to destroy Salmonella, inactivate helminth eggs and dramatically reduce *E. coli* counts.

However, except for PM5, which was completely seed-free, all composts contained more than 2 units of weed seeds or vegetative propagation materials per litre, which is the limit set by the EU Commission (2006) for award of its eco-label (results not shown). Weed seeds should not survive a composting process reaching 55 °C over 3 days; also, any seeds surviving will do as a result of localized “cool spots” resulting from inefficient turnover of the windrow or by entering the outer parts of the windrow after the thermophilic phase, especially by wind-blown species (Grundy et al., 1998). The variation of temperature during the composting process, the removal of pathogens and the differences in weed germination between the manure-containing piles, which exhibited a very similar temperature variation pattern, are suggestive of subsequent re-infestation by effect of the piles being outdoors and in contact with the soil —and hence near grasses and other plants. The materials should thus be efficiently isolated from their environment in order to avoid contamination, preserve the hygienization achieved with composting and obtain compost containing no weed propagules

#### **4. Conclusions**

The composts obtained are mature and stable enough. They have a high aeration and drainage capacity and little plant-available water so they will require careful irrigation and also they can be used as aerating component in potting mixtures. The fact that they are all highly saline is no constraint to their obtaining the eco-label and it did not result in negative effect on seed germination or seedling growth, which was promoted. The content of soluble nutrients of the composts was quite high, but it may be unbalanced for some crops and then they would require to be adequately corrected by fertilization.

The addition of poultry manure resulted in substantial changes in the properties of the substrates, which contained less organic matter and had a lower C/N ratio, a nearer-neutral pH, higher contents in soluble elements and an increased salinity.

All the composts fulfil the requirements of the European norm for award of an eco-label except for the content in weed seeds of PMI5, PM0 and PMOI owing to contamination after composting. This underlies the importance of strict control in preserving hygienic conditions achieved during the composting process.

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Table 1. Composition of the raw materials.

	<b>IG</b>	<b>DG</b>	<b>PM</b>
<b>Moisture (g g<sup>-1</sup>)</b>	0.62	0.47	0.39
<b>pH</b>	5.99	5.51	6.88
<b>C (g kg<sup>-1</sup> dm)</b>	484.0	478.0	215.5
<b>N (g kg<sup>-1</sup> dm)</b>	11.4	13.3	23.1
<b>C/N</b>	42.48	35.94	9.33
<b>S (g kg<sup>-1</sup> dm)</b>	1.08	1.25	1.45
<b>P (g kg<sup>-1</sup> dm)</b>	0.38	0.44	14.25
<b>K (g kg<sup>-1</sup> dm)</b>	5.13	6.80	9.34
<b>Ca (g kg<sup>-1</sup> dm)</b>	1.80	2.09	40.68
<b>Mg (g kg<sup>-1</sup> dm)</b>	0.92	0.88	5.06
<b>Na (g kg<sup>-1</sup> dm)</b>	1.08	1.23	2.97

IG = irrigated gorse, DG = dry gorse, PM = poultry manure.  
Mean values. pH in saturation extract and all elements on a dry matter basis.

Table 2. Physical properties of the composts.

	PM0I	PM5I	PM5	PM0	Optimum <sup>1</sup>
<b>BD (g cm<sup>-3</sup>)</b>	0.18 ± 0.00 c	0.27 ± 0.00 a	0.25 ± 0.00 b	0.18 ± 0.01 c	<0.4
<b>PD(g cm<sup>-3</sup>)</b>	1.9 ± 0.0 b	2.1 ± 0.0 a	2.1 ± 0.0 a	1.9 ± 0.0 b	1.45–2.65
<b>S (% v/v)</b>	17.7 ± 1.6 a	18.1 ± 4.7 a	20.4 ± 1.6 a	16.4 ± 0.8 a	<30
<b>TP (% v/v)</b>	90.1 ± 0.2 a	86.9 ± 0.3 c	88.1 ± 0.2 b	90.5 ± 0.3 a	>85
<b>AC (% v/v)</b>	48.8 ± 1.5 a	49.7 ± 1.5 a	44.8 ± 0.4 a	48.7 ± 1.7 a	10–30
<b>EAW (% v/v)</b>	10.0 ± 0.6 c	9.8 ± 0.7 c	13.1 ± 0.4 a	11.5 ± 0.3 b	20–30
<b>WBC (% v/v)</b>	2.4 ± 0.1 ab	2.2 ± 0.1 b	2.51 ± 0.1 a	2.62 ± 0.1 a	4–10
<b>UW (% v/v)</b>	28.9 ± 0.8 a	25.2 ± 0.4 b	27.7 ± 0.1 a	27.7 ± 1.3 a	
<b>R (kPa)</b>	0.9 ± 0.0 b	0.9 ± 0.0 b	0.9 ± 0.0 b	0.9 ± 0.0 ab	1–3

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

BD = Bulk Density; PD = Particle Density; TP = Total Porosity; S = Shrinkage Value; AC = Aeration Capacity; EAW = Easily Available Water; WBC = Water Buffer Capacity; UW = Unavailable Water; R = suction that equalizes the water and air contents

<sup>1</sup> Optimum values for an ideal substrate (Abad et al., 1993; Abad et al., 2001; Noguera et al., 2003).

Mean values ± SD and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at  $p < 0.05$ .

Table 3. Total element contents of the composts on a dry matter basis.

	PM0I	PM5I	PM5	PM0	Optimum <sup>1</sup> (Maximum) <sup>2</sup>
<b>OM (g kg<sup>-1</sup> dm)</b>	558.6 ± 8.8 a	390.4 ± 22.4 c	385.2 ± 12.0 c	516.7 ± 14.3 b	>800
<b>Ash (g kg<sup>-1</sup> dm)</b>	441.4 ± 8.8 c	609 ± 22.4 a	614.8 ± 12.0 a	483.3 ± 14.3 b	<200
<b>SD (%)</b>	58.18 ± 0.76 a	53.62 ± 1.49 a	63.89 ± 7.60 a	63.30 ± 1.21 a	>50
<b>N (g kg<sup>-1</sup> dm)</b>	21.2 ± 0.1 a	18.2 ± 0.1 c	17.1 ± 0.1 d	18.9 ± 0.1 b	
<b>C/N</b>	14.06 ± 0.07 b	11.79 ± 0.07 c	11.81 ± 0.08 c	15.25 ± 0.11 a	20–40
<b>Cd (mg kg<sup>-1</sup> dm)</b>	0.05 ± 0.01 b	0.08 ± 0.00 a	0.07 ± 0.00 a	0.07 ± 0.00 a	(<1)
<b>Cr (mg kg<sup>-1</sup> dm)</b>	10.36 ± 2.86 b	19.22 ± 2.88 a	18.49 ± 0.56 ab	14.84 ± 1.26 ab	(<100)
<b>Cu (mg kg<sup>-1</sup> dm)</b>	17.22 ± 3.56 b	33.24 ± 1.91 a	34.17 ± 0.85 a	21.14 ± 0.56 b	(<100)
<b>Hg (mg kg<sup>-1</sup> dm)</b>	0.03 ± 0.01 a	0.03 ± 0.01 a	0.02 ± 0.00 a	0.02 ± 0.00 a	(<1)
<b>Ni (mg kg<sup>-1</sup> dm)</b>	8.12 ± 2.17 b	14.66 ± 1.46 a	13.64 ± 0.83 ab	10.28 ± 0.23 ab	(<50)
<b>Pb (mg kg<sup>-1</sup> dm)</b>	6.58 ± 1.16 b	11.69 ± 0.62 a	11.14 ± 0.05 a	7.80 ± 0.02 b	(<100)
<b>Zn (mg kg<sup>-1</sup> dm)</b>	65.11 ± 11.96 b	120.38 ± 2.07 a	120.55 ± 0.83 a	72.15 ± 0.05 b	(<300)

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

OM= Organic Matter; SD = Stability Degree.

<sup>1</sup> Recommended values for an ideal substrate (Abad et al., 1993; Saña et al., 1989)

<sup>2</sup> Limit established as ecological criteria for EU eco-label (EU Commission, 2006)

Mean values and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at  $p < 0.05$ .

Table 4. Analysis of the compost saturation extracts: pH, electrical conductivity (EC) and soluble elements.

	PM0I		PM5I		PM5		PM0		Optimum <sup>1</sup>
<b>pH</b>	3.74 ±0.10	b	6.09 ±0.07	a	6.40 ±0.08	a	4.05 ±0.06	b	5.2-6.3
<b>EC (dS m<sup>-1</sup>)</b>	3.78 ±0.16	c	7.87 ±0.49	a	5.11 ±0.06	b	3.95 ±0.05	c	0.75-3.5
<b>NO<sub>3</sub><sup>-</sup> (mg L<sup>-1</sup>)</b>	570.0 ±134.2	b	951.2 ±56.5	a	723.4 ±21.5	ab	506.1 ±0.0	b	100-200
<b>NH<sub>4</sub><sup>+</sup> (mg L<sup>-1</sup>)</b>	45.5 ±1.3	bc	74.3 ±8.2	a	53.2 ±1.5	b	29.7 ±1.4	c	0-20
<b>P (mg L<sup>-1</sup>)</b>	18.3 ±0.4	b	28.4 ±1.1	a	30.7 ±1.9	a	25.8 ±2.4	a	6-10
<b>Ca (mg L<sup>-1</sup>)</b>	39.5 ±0.1	b	96.3 ±13.9	a	59.1 ±1.0	b	38.7 ±3.0	b	>200
<b>Mg (mg L<sup>-1</sup>)</b>	105.3 ±3.9	a	129.4 ±19.6	a	97.6 ±3.4	a	100.0 ±10.6	a	>70
<b>K (mg L<sup>-1</sup>)</b>	300.5 ±23.3	c	703.5 ±112.4	ab	761.2 ±26.0	a	469.8 ±4.8	bc	150-250
<b>Na (mg L<sup>-1</sup>)</b>	98.6 ±0.2	b	240.8 ±34.6	a	149.0 ±0.7	b	96.6 ±7.6	b	
<b>Cu (µg L<sup>-1</sup>)</b>	20.53 ±0.60	a	31.60 ±13.46	a	27.27 ±0.67	a	18.45 ±1.22	a	1-500
<b>Mo (µg L<sup>-1</sup>)</b>	2.24 ±0.96	c	9.15 ±0.91	b	17.38 ±0.34	a	2.49 ±0.06	c	10-100
<b>Mn (mg L<sup>-1</sup>)</b>	2.81 ±0.99	a	0.06 ±0.02	c	0.08 ±0.01	bc	2.15 ±0.24	ab	0.02-3
<b>Fe (mg L<sup>-1</sup>)</b>	0.16 ±0.02	a	0.04 ±0.01	c	0.04 ±0.00	c	0.09 ±0.02	b	0.3-3
<b>Zn (mg L<sup>-1</sup>)</b>	0.91 ±0.49	a	0.31 ±0.07	a	0.37 ±0.04	a	0.54 ±0.04	a	0.3-3
<b>B (mg L<sup>-1</sup>)</b>	0.36 ±0.00	a	0.30 ±0.17	a	0.36 ±0.02	a	0.38 ±0.02	a	0.05-0.5

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

<sup>1</sup> Recommended values for an ideal substrate (Abad et al., 1993)

Mean values ± standard deviation and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at  $p < 0.05$ .

Table 5. Analysis of the compost 1:5 (v/v) extracts: pH, electrical conductivity (EC) and soluble elements content referred to substrate volume (mg L substrate<sup>-1</sup>)

	PM0I	PM5I	PM5	PM0	Optimum <sup>1</sup> (Maximun) <sup>2</sup>
<b>pH</b>	3.90 ± 0.06 b	5.88 ± 0.14 a	6.12 ± 0.21 a	4.32 ± 0.32 b	5.3-6.5
<b>EC (dS m<sup>-1</sup>)</b>	0.76 ± 0.04 b	1.39 ± 0.02 a	0.81 ± 0.06 b	0.77 ± 0.13 b	0.4-0.9 (1.5)
<b>NO<sub>3</sub><sup>-</sup> (mg Lsub<sup>-1</sup>)</b>	231.4 ± 20.6 d	660.0 ± 0.0 a	524.0 ± 15.6 b	390.5 ± 11.6 c	81-200
<b>NH<sub>4</sub><sup>+</sup> (mg Lsub<sup>-1</sup>)</b>	42.8 ± 1.2 a	79.6 ± 21.6 a	59.5 ± 3.3 a	46.2 ± 1.3 a	51-150
<b>P (mg Lsub<sup>-1</sup>)</b>	23.1 ± 1.8 b	40.8 ± 4.2 a	43.3 ± 7.1 a	29.7 ± 0.4 ab	29-100
<b>Ca (mg Lsub<sup>-1</sup>)</b>	194.0 ± 3.5 ab	277.9 ± 38.6 a	151.2 ± 3.1 b	202.1 ± 19.7 ab	
<b>Mg (mg Lsub<sup>-1</sup>)</b>	93.3 ± 5.3 ab	113.1 ± 16.7 a	59.1 ± 4.5 b	100.1 ± 4.4 a	16-150
<b>K (mg Lsub<sup>-1</sup>)</b>	620.0 ± 28.3 ab	792.0 ± 158.4 a	593.0 ± 46.7 ab	434.0 ± 22.6 b	101-650
<b>Na (mg Lsub<sup>-1</sup>)</b>	79.7 ± 2.1 b	269.7 ± 33.7 a	130.2 ± 12.7 b	111.2 ± 11.4 b	
<b>Cu (µg Lsub<sup>-1</sup>)</b>	30.66 ± 4.83 a	38.83 ± 6.37 a	31.71 ± 7.51 a	31.59 ± 21.48 a	
<b>Mo (µg Lsub<sup>-1</sup>)</b>	1.32 ± 0.31 c	17.23 ± 2.55 b	30.85 ± 2.50 a	3.58 ± 0.33 c	
<b>Mn (mg Lsub<sup>-1</sup>)</b>	1.63 ± 0.24 a	0.10 ± 0.10 b	0.01 ± 0.00 b	1.35 ± 0.13 a	
<b>Fe (mg Lsub<sup>-1</sup>)</b>	0.31 ± 0.00 a	0.23 ± 0.12 a	0.30 ± 0.02 a	0.23 ± 0.01 a	
<b>Zn (mg Lsub<sup>-1</sup>)</b>	1.91 ± 0.90 a	0.81 ± 0.70 a	0.90 ± 0.20 a	2.06 ± 0.2 a	
<b>B (mg Lsub<sup>-1</sup>)</b>	0.64 ± 0.01 a	0.74 ± 0.03 a	0.64 ± 0.05 a	0.57 ± 0.05 a	

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

<sup>1</sup> Optimun = recommendations for potting and transplanting growing media (based on 1:6 v/v extraction) (ADAS, 1988)

<sup>2</sup> Maximun = limit established as ecological criteria for growing media eco-label (EU Commission, 2006)

Mean values ± standard deviation and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at  $p < 0.05$ .

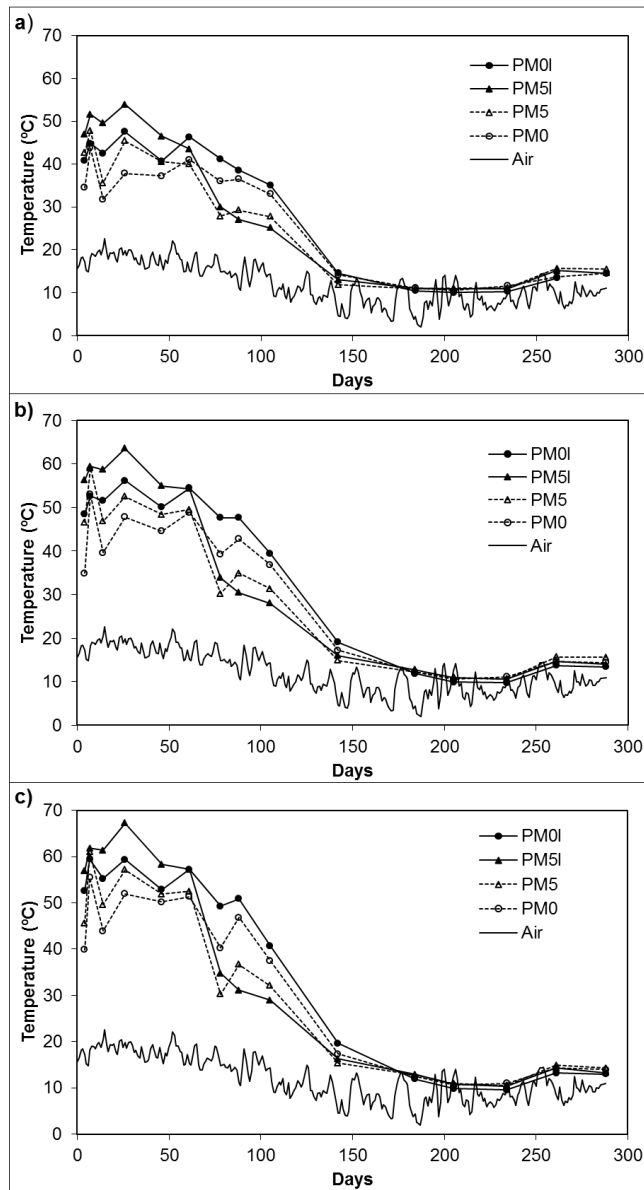


Fig.1. Variation of temperature (°C) in the air and inside the compost piles during the composting process. Depth: (a) 20 cm, (b) 40 cm and (c) 60 cm. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

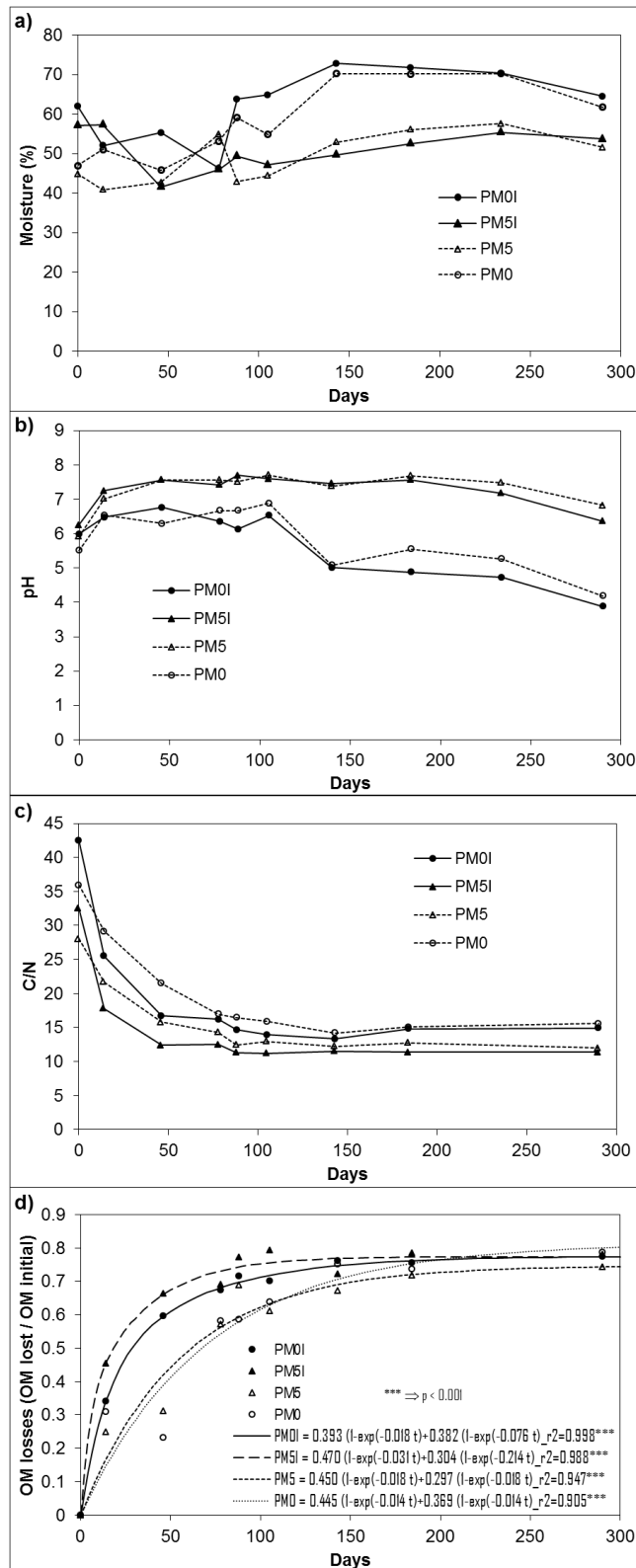


Fig. 2. Variation of (a) moisture (%), (b) pH, (c) C/N ratio and (d) losses of OM during the composting process. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

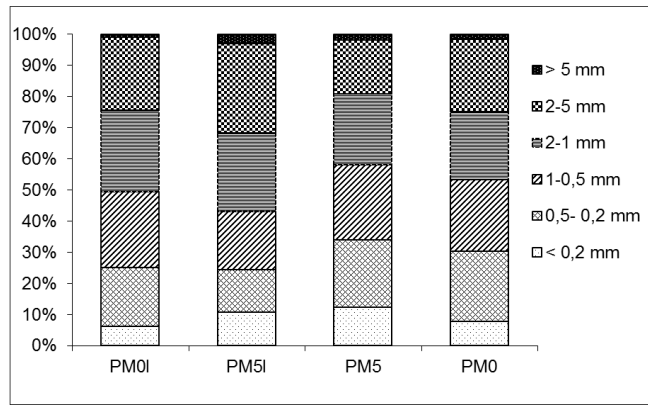


Fig. 3. Particle size distribution of the composts. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

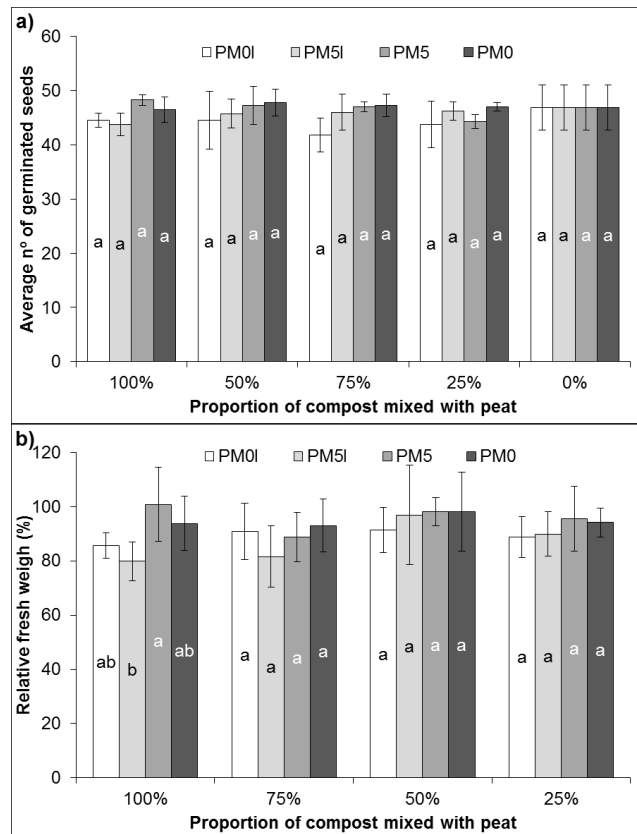


Fig. 4. Results of the barley seed germination bioassay. (a) Mean number of germinated seeds and (b) relative fresh weight (%). PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation. Mean values plus SD in error bars. For each proportion, columns with the same letters indicate not significant differences between treatments at  $p < 0.05$  (Tukey's post-hoc test).

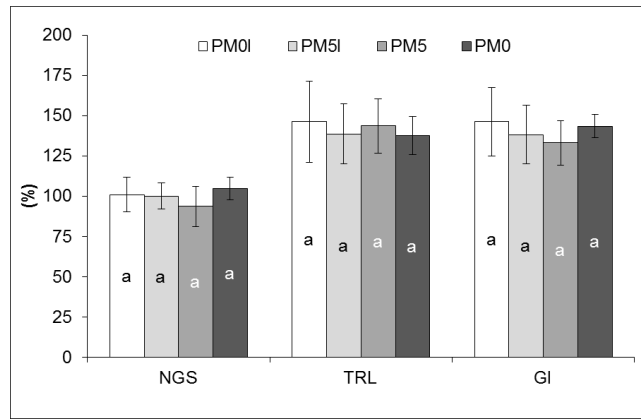


Fig. 5. NGS (number of germinated seeds) relative to the control, TRL (total root length of germinated seeds) relative to the control and GI (germination index) of the gorse composts. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation. Mean values plus SD in error bars. For each proportion, columns with the same letters indicate not significant differences between treatments at  $p < 0.05$  (Tukey's post-hoc test).