

Using gorse compost as a peat-free growing substrate for organic strawberry production

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ABSTRACT

The demand for peatfree organic growing media has increased and green compost provide an attractive option within a circular economy. To take advantage of the inherent nutrient content, the nutrient dynamics needs to be carefully considered when evaluating the agronomic potential of the compost for organic production. In this study the use of compost made from gorse (*Ulex europaeus* L.) was evaluated as a substrate for organic production of strawberries (*Fragaria x ananassa* Duch 'Selva'), investigating in particular availability of nutrients. Two gorse composts were used, gorse composted with poultry manure (5 % v/v) (PM100) and gorse composted on its own without manure (PM0). They were assessed in their original form and in formulations containing different proportions of each. A fertilised standard peat-based substrate was used as control. Both PM0 and PM100 exhibited acceptable physical properties and contained high concentrations of major nutrients (particularly PM100). The nutrient concentrations in the solutions from the different formulations decreased gradually during the growth of the crop, particularly N and K. Concentrations of N and chlorophyll levels were lower in plants grown in gorse compost formulations than in those grown in the control. There were, however, no substantial differences in fruit size or overall yield. The above-ground biomass in the compost-grown plants increased with increased proportions of PM100, but it was greater in the control plants. The gorse composts were recommended as effective peat substitutes for strawberry cultivation, although supplementary fertiliser should be applied at the fruit production stage to ensure optimal production.

Keywords: green waste; peat alternatives; poultry manure; renewable resources; *Ulex europaeus*.

Introduction

Peat has long been the most widely used substrate for containerised plant production, but in recent decades there has been an ongoing search for high-quality and inexpensive alternatives. The need to find effective replacements for peat has arisen from ecological concerns related to the role of peatlands in the sequestration of carbon dioxide (Maher et al. 2008) and because peat is a non-renewable resource that is being rapidly depleted. In addition, increased interest in waste recycling has fostered the re-use of organic

wastes and composts as ingredients in potting substrates. Gorse (*Ulex europaeus* L.), which is an evergreen flowering shrub belonging the Fabaceae family, grows in large areas and has been effectively used as raw material to make compost (Brito et al. 2010; López-López and López-Fabal 2016). Although gorse originated in Europe, it is also present in North America, New Zealand and Australia, where its pioneering, invasive potential has facilitated colonisation of degraded land and where it now occupies large areas. Exploitation of the gorse by cutting and removing it, can have added benefits in helping to prevent fires and facilitate grazing in the areas.

Composts made from some organic waste materials have been shown to have similar physical, physico-chemical and chemical properties as peat and can thus provide effective substitutes (Sánchez-Monedero et al. 2004). In fact, several studies have shown that composted organic residues can be very effectively used as growing media (Abad et al. 2001; Benito et al. 2005; Pérez-Murcia et al. 2006). Also, many organic materials contain inherent high levels of nutrients (Altieri et al. 2010) and can thus reduce the need to apply additional fertilisers, which is a central aim for sustainable production of many horticultural crops (Tagliavini et al. 1995). It is well known that composts can contribute a significant proportion of the nutrient requirements of plants grown in compost-containing media (Raviv 2013). However, the suitability of organic substrates for containerised plant production is strongly influenced by the ability of the substrate to supply the growing plants with adequate amounts of nutrients (Carmona et al. 2002; Caballero et al. 2007). The supply of nutrients depends not only on the elemental composition of the substrates, but also on other factors affecting the release and dynamics of the nutrient, such as adsorption capacity, pH, biological stability and the presence of dissolved organic compounds (Caballero et al. 2007). The material needs to be sufficiently stable to avoid adverse effects on plant growth, for example through N immobilisation, oxygen depletion or the presence of phytotoxic substances (Iglesias-Jimenez and Pérez-García 1989). Immature compost can immobilise substantial amounts of N, whereas stable compost acts largely as slow-release fertiliser (Raviv 2005).

Accurately diagnosing the status of crops grown in soilless systems entails assessing the substrates in relation to their outer environment (weather, plant material and growth stage, management regime), as well as the nutrient dynamics in the substrate and the nutrient uptake by the plant, aiming to adjust the availability of nutrients to be

synchronised with the requirements the plant (Stanley et al. 2003, Tagliavini et al. 2005, Bergstrand et al. 2020).

In response to a growing consumer demand for organic products, the acreage of organically managed land has, in recent years, gradually increased, to reach an overall 72.3 million ha worldwide in 2019 according to Willer et al. (2021). In 2019, Spain was the third greatest contributor to organic farming, with 2.35 million ha (Willer et al. 2021); of which organically grown strawberries accounted for 212 ha (MAPA 2020). Unsurprisingly, organic producers require appropriate inputs for their production systems and the use of compost, apart from their environmental benefits, have been shown to provide the added advantage by suppressing some plant diseases (Noble and Coventry 2005; Brown et al 2013; López-López et al 2016); an attribute that is especially important in organic farming, where the use of synthetic products to protect horticultural crops is not permitted.

The aim of this work was to assess the use of gorse compost as a growing medium for organic strawberry production in containers, with special emphasis on ability of the compost to supply nutrients during the growth cycle of the crop and to meet the requirements of the plants without the need to apply additional fertilisers.

Materials and methods

Composts

The organic materials studied were obtained by composting green vegetation consisting mainly of 4 - 5 year-old gorse (*Ulex europaeus* L) shrubs (stems, leaves, flowers and seed pods) harvested with a flail mower on a heathland in NW Spain. For this purpose, two pairs of identical stacks of the material, 6 m³ in volume, were composted for 9 months. Two stacks contained gorse only (PM0), whereas in the other two stacks the gorse was mixed with 5 % (v/v) of poultry manure (PM100); 5% poultry manure in volume implied an approximate dry weight ratio of 70 : 30 of the gorse : poultry manure. The poultry manure was obtained from an organic laying-hens unit, and the manure contained a small proportion of pine shavings used as bedding. The addition of manure was intended to facilitate the composting process by lowering the initial C:N ratio of the feedstock to about 30, and also to increase nutrient levels in the end-product. The addition of manure at 5 % (v/v) was thought to be sufficient for both purposes,

whilst avoiding the risk of increasing the salinity to an excessive level in the resulting compost. The composting material was mechanically turned using a wheel-loader during a 9-month period; approximately once a month at the beginning and then every 2 months later. Further details of the process can be found in López-López and López-Fabal (2016). At the end of the composting process, the compost was screened by means of a vibrating screen retaining the fraction < 6 mm for characterisation and plant growing trials.

Characterisation of composts

The composts were characterised in terms of their chemical, physico-chemical and physical properties. Electrical conductivity (EC), pH and soluble elements were determined in both saturated extract (water extracted from saturated media) and 1:5 (v/v, five volumes of distilled water per volume of substrate) extract (EN-13652 2001). Nitrate and ammonium were measured with an ion-selective electrode. P was determined by ultraviolet spectrophotometry at 880 nm (Olsen and Sommers 1982), and K, Ca, Mg, Na, Cu, Zn, Fe, Mn, Mo and B were quantified by atomic absorption or emission spectrophotometry (USEPA 1995).

Total contents of C, N and S were determined with a LECO TruSpec CHNS autoanalyser, and Cr, Cu, Cd, Pb, Zn, Hg and Ni by ICP-OES after digestion with HNO₃ in a microwave oven (USEPA 1995). Organic matter and ash in the substrates were also quantified (EN-13039 1999). The specific physical determinations included assessment of moisture retention curve in accordance with the method described by De Boodt et al. (1974); total porosity, bulk density, particle density and shrinkage value as per EN-13041 (1999); and packed bulk density in accordance with EN-13040 (2007).

The results for the two composts were compared via an independent two-sample *t*-test following checking for data normality with the Kolmogorov–Smirnov test and variance homoscedasticity with Levene’s test. All statistical calculations were done with the software PASW Statistic v.18.

Strawberry crop

PM0 and PM100 were mixed in various ratios to obtain three additional growing substrates (formulations), namely: PM25 (25% PM0 + 75% PM100), PM50 (50% PM0 + 50% PM100) and PM75 (75% PM0 + 25% PM100). The five formulations were tested

as growing media for strawberry production in an organically managed experimental greenhouse located in the university campus of Lugo city (NW Spain). This is a rigid-frame greenhouse covered with glass, 3 m wall height, naturally ventilated by side doors and butterfly vents on the roof and equipped with shade mesh to prevent excessive temperatures. A completely randomised layout with 20 replicates per substrate was used, each replicate involving growing one plant in a 0.6 L pot. A standard peat-based substrate (Pindstrup Peat Moss 5-20 mm) was used as control, to which 21.4 g per pot of 6-month slow-release fertilizer Osmocote[®] 14-13-13 was added in order to supply each plant with 3 g N.

The plant material consisted of strawberry (*Fragaria x ananassa* Duch. 'Selva') plants that had been uprooted, evenly trimmed and refrigerated and were transplanted as bare-root transplants as they were beginning to resprout. The crop was established on April 29 and finished 5 months later. Drip irrigation with one dripper per plant and several daily applications were used. The water dose was adjusted based on the weight loss of the pots on a frequent basis in order to minimise leaching losses. No additional inputs were applied during the crop cycle.

Crop monitoring

Crop nutrient status: Samples of the solutions from the growing substrates were taken with a Rhizon[®] (Eijkelkamp Soil & Water, The Netherlands) sampler equipped with a syringe. To this end, 6 randomly chosen pots per substrate were selected for extraction and these samples were mixed by pairs to obtain three samples of sufficient volume for the analyses. Samples were always collected at least 2 h after irrigation in order to ensure equilibration of added water with the substrate. Samples were collected at a total of 11 dates: on a weekly basis initially and then every two weeks once the properties started to change more slowly. EC, pH, NH₄⁺, NO₃⁻, K, Ca, Mg and P were analysed on all sampling dates, whereas micronutrients (Mn, Fe, Zn, B, Cu and Mo) were determined only twice during the growing period. EC and pH were analysed as described above. Nitrate and ammonium were measured with an ion-selective electrode; P by ultraviolet spectrophotometry at 880 nm (Olsen and Sommers 1982); K, Ca and Mg by atomic absorption or emission spectrophotometry (USEPA 1995); Cu and Mo by ICP-MS; and Mn, Fe, Zn and B by ICP-OES.

Chlorophyll index was measured 6 times during the crop cycle, using a CCM-200 meter from Opti-Sciences Inc. (Hudson, NH, USA) manufacture. Measurements were made on fully developed young leaves, twice on each strawberry plant.

Concentration of total elements of the leaves were determined twice: at the main harvest on the youngest fully developed leaves; and at the end of cropping period on all foliage that remained green. In both cases, harvested material was dried at 60 °C in an oven for 9 days and milled. The milled material was then calcined in a furnace at 500 °C and digested with a 2 M HCl solution, the digest being analysed for total Mn, Fe, Zn, Mo, Cu, B, Mg, Na, P, K and N by optical ICP spectroscopy.

Crop growth and production: Strawberry fruits were collected periodically at ripeness (that is, immediately after their colour changed to red) to determine the fresh weight by plant and substrate. At the end of the growing period, the above ground and below ground parts of all plants were separated and cleaned to determine the dry weight of each portion after drying in an oven at 60 °C.

Statistical analyses.

The cropping test results were processed by univariate analysis of variance (ANOVA), using the proportion of poultry manure in the compost as factor (independent variable). Differences at the $p < 0.05$ level between data pairs in Tukey's post-hoc test were deemed statistically significant. Data normality was previously confirmed with the Kolmogorov–Smirnov test and variance homoscedasticity with Levene's test. All statistical calculations were done with the software PASW Statistic v. 18.

Results and discussion

Composts

Adding poultry manure to gorse resulted in substantial differences in the chemical characteristics between the two composts (Tables 1 and 2). The differences were less apparent in the 1:5 extract (Table 2) than in the water extract of saturated media (Table 1). The manure-containing composts (PM100) exhibited higher pH, salinity (EC) and concentrations of major nutrients (N-NO_3^- , N-NH_4^+ , P and K), but lower concentration of Mn, than PM0.

A comparison of the chemical properties of the saturation extract (Table 1) with the values reported by Abad et al. (1993) as optimum for an 'ideal' substrate, revealed that the gorse compost was quite suitable for use as a growing substrate. The pH of PM100 was at the high end of the range recommended Abad et al. (1993), whereas that of PM0 was too low. Overall, the concentrations of nutrients of the composts were high. The EC, NO_3^- , NH_4^+ , P and K values of both composts exceeded the respective optimum values, whereas those of soluble Mg, Cu Zn, Mn and B were within the optimum ranges. Only the Ca and Fe contents of the two composts, and the Mo content of PM0, were below optimal.

The concentrations of NO_3^- in the 1:5 (v/v) extracts from the two composts were above the range of recommended values for compost to be used as a substrate for pot or transplant production (ADAS 1988), as was the concentration of K in the extract from PM100 (Table 2). The concentrations of soluble NH_4^+ and P were within the recommended range in PM100, but slightly below it in PM0, which contradicted the results of the saturation extract. Again, the pH of the 1:5 (v/v) extract from PM0 was very low, whereas that of the MP100 extract was acceptable. EC in the PM100 extract was above the optimum range for a 1:6 extract (ADAS 1988) and was slightly higher than the current limit for award of a growing substrate ecolabel (EU Commission 2015).

Both substrates thus had high concentrations of crop-available mineral elements, which has also been reported for other composts made from nutrient-rich materials (Bustamante et al. 2008; Raviv et al. 2005). Based on the concentrations of soluble nutrients in the saturation extract (Table 1), the N : P_2O_5 : K_2O (m/m) ratios in PM0 and PM100 were 1 : 0.3 : 3.1 and 1 : 0.3 : 3.7, respectively, while the N : P : K ratio (meq L^{-1}) were 1 : 0.1 : 0.9 and 1 : 0.1 : 1.1 respectively, and hence presumably adequate for strawberry production (Sarooshi and Creswell 1994; Cantliffe et al. 2007; Preciado-Rangel et al. 2020). The low levels of Fe in the compost might result in chlorosis, whereas those of Ca might detract from fruit firmness and resistance to biotic and abiotic stress (Trejo-Téllez and Gómez-Merino 2014). However, the effect of calcium depends more markedly on the $\text{K}^+ : \text{Ca}^{2+}$ ratio, or even the $\text{K}^+ : (\text{Ca}^{2+} + \text{Mg}^{2+})$ ratio, than on the absolute concentration of Ca^{2+} in solution (Andriolo et al. 2009). Also, the high salinity of the two composts, but particularly in PM100, could have an adverse effect on a sensitive crop such as strawberry (Ferreira et al. 2019; Bani et al. 2021). Increased concentrations of soluble nutrients resulting in salt stress can reduce plant growth and

production, but may improve fruit quality characteristics such as acidity and the contents in soluble solids (Andriolo et al. 2009, Bidaki et al. 2019).

The composts had low concentrations of organic matter (OM), presumably as a result of the high mineral content of the raw materials and the intensity of the composting process, which have been shown to result in the loss of about 77% of the initial amount of OM (López-López and López-Fabal 2016). Also, the OM content of PM100 was much lower than that of PM0 (Table 3), which was consistent with the increased mineral content of the former by the effect of the content in the poultry manure. The decreased OM content of PM100 was also consistent with the lower concentration of total N; though this result was apparently contradictory to the high N content of the N-rich material such as poultry manure included in PM100, but was consistent with the lower C:N ratio, suggesting that organic matter contained abundant N. Despite their differences due to their raw materials, both composts had a low C:N ratio falling below the range recommended by Abad et al. (1993) (20-40), but within the broader range (< 25) proposed by proposed by Chen et al. (2020). This was a result of efficient composting of N-rich raw materials and was also suggestive of an efficient maturation process (Antil et al. 2013), a necessary condition for compost to be used as a growing substrate. Similarly low values were previously obtained for mixtures of poultry litter with hardwood chips or pine sawdust as bulking agents (Preusch et al. 2004), and also with a mixture of gorse and the solid fraction of pig slurry (Brito et al. 2010). By contrast, gorse-only compost had slightly higher values (Iglesias-Díaz et al. 2009).

The concentrations of five of the seven heavy metals studied (Cd, Cr, Cu, Hg, Ni, Pb and Zn) were substantially higher in the manure-containing compost (PM100) (Table 3). However, these concentrations were all low and well below the limits established for the growing medium category in the EU regulation on fertilising products (EU Parliament 2019) and for award of the growing substrate ecolabel (EU Commission 2015); also, they amply met the requirements for class A, which is the most demanding compost class in Spanish substrate regulations (BOE 2010).

As can be seen from Table 4, the compost containing poultry manure (PM100) had significantly higher bulk density and particle density than that containing none (PM0) by effect of the increased mineral content of the former. As a result, total porosity in PM100 was significantly lower, but still high and adequate, than that in PM0. The difference was only apparent in the pore fraction holding the most strongly

retained water (UW), with the compost containing manure (PM100) having the lower values. The bulk density, particle density, total porosity and shrinkage values of both composts fell within the optimum ranges for ideal growing substrates (Abad et al. 1993). By contrast, easily available water (EAW) and water buffer capacity (WBC) were below optimal, and aeration capacity was excessive (up to 15% higher than that desirable). These results were consistent with those for other substrate components such as green residues (Fornes et al. 2013), switchgrass (Altland and Krause 2009) and bracken (Pitman and Webber 2013). Because of their low EAW values, the composts will require frequent irrigation with small amounts of water. In practice, the differences in the physical properties between the two composts may not result in different crop responses, and it was concluded that both could essentially be managed in an identical way.

Crop nutrition

As can be seen from Figure 1, the chemical properties of the solutions extracted from the compost-based substrates differed from those obtained in their initial characterisation (Tables 1 and 2) already at the first sampling date, which was 26 days after transplanting (26 DAT). Thus, the pH was near-neutral (6 for PM0) and scarcely influenced by the presence of poultry manure, so significant differences were only found for PM0 over the first four samplings (until 47 DAT). This was the individual parameter differing most markedly between the initial characterisation and the measurements made in the solutions as obtained with the suction samplers. However, the increased differences may in part have been spurious as a result of the solutions being altered by degassing through suction during the sampling operation. Thus, the resulting reduction in dissolved CO₂ levels (Morell and Sánchez 1998) may have shifted equilibrium to carbonic acid and raised the pH of the solutions as a result. The control sample was invariably acidic, probably by effect of its increased buffer capacity.

Electrical conductivity (EC) on the first sampling was lower than 1.2 dS m⁻¹ in all samples. These results suggested reduced concentrations of elements in the substrate solution relative to the saturation extract from the starting composts. Also, the concentrations of all nutrients in the substrate solutions were markedly lower (particularly those of K⁺, Mg²⁺ and NO₃⁻). Since leaching losses were minimised, this result suggested absorption of the three nutrients during the 26 days preceding the first

sampling. However, no substantial extraction of nutrients was to be expected at this early growth stage (Molina et al. 1993), but rather after flowering (Choi et al. 2013), with a peak at the fruit production stage (Albregts and Howard 1980). The fruit harvest began 6 weeks after transplanting.

As can be seen from the variation of EC in Figure 1, all composts exhibited sustained dilution of the substrate solution throughout the experiment. Overall, the concentrations of soluble elements were slightly higher in the composts containing the highest proportions of poultry manure than in the others, and significant differences were only found at the two first sampling dates: PM100, PM75 and PM50 were significantly higher at 26 DAT) and PM100 and PM75 were significantly higher at 33 DAT. However, all composts exhibited a decrease in EC throughout. In fact, the decline in electrical conductivity was apparent already on the first sampling date (26 DAT), but diminished as EC values fell. The overall and individual ionic concentrations evolved as a result of the release of soluble elements by the material (compost or peat containing slow-release fertiliser) being offset by crop uptake largely in the absence of leaching losses. The concentrations of some nutrients in the substrate solution of the composts treatments gradually decreased to very low levels (Figure 1); this was especially so with NO_3^- and K, which were the most abundant nutrients initially, but also the most strongly utilised by the crop, their concentrations rapidly falling to rather low levels from the second half of the cropping cycle. In addition, the differences in the way the concentrations of the ions changed altered their equilibria.

Virtually all soluble N was in the form of N-NO_3^- throughout the sampling period and NH_4^+ ion was scarcely present in solution. A near-neutral pH and good aeration by effect of the favourable physical properties of the compost led to efficient nitrification. As a result, virtually all mineral N remained in solution and the mineralisation of the compost was the only mechanism capable of generating mineral N to compensate for the utilisation by the plant, but the intensity of the mineralisation was not sufficient. The N requirements during the vegetative growth stage and the start of the fruit formation stage caused nitrate levels to drop until 41 DAT and then to even lower levels 75 DAT.; coinciding with the high demand typical of the fruit production stage (Molina et al. 1993).

The fruit production stage increased the utilisation of K (Molina et al. 1993), the concentration of which also fell gradually and remained at very low levels beyond 89 DAT. Mobilising K^+ stocks in the exchange complex usually offsets solution losses of

this ion; however, losses were incompletely countered here and the K concentration in solution was lower than that absorbed by the crop. P levels also decreased during the sampling period, albeit less markedly than K levels. The greatest decline was observed at 41 DAT and was followed by a less marked decrease. The difference from N and K was a result not only of decreased extraction of P but also of more complex mobilisation by desorption and solubilisation, and more difficult leaching (Christiansen et al. 2020).

Other elements such as Ca and Mg remained at virtually unchanged concentrations in solution throughout the growing period, which suggested that they were gradually released from the exchange complex of the compost or even solubilised, particularly Ca, which is more strongly absorbed by strawberry. (Tagliavini et al. 2005).

The nutrient concentrations in the solution from the control material, which consisted of peat with slow-released fertiliser, increased roughly over the first two months and then decreased more or less gradually, unlike that in the composts-based substrates, however, no nutrients were depleted in most cases. N and P availability exhibited the greatest differences from the composts; by contrast, K availability was similar to that in the composts containing the greatest amounts of poultry manure (PM75 and PM100). The Ca and Mg concentrations in the solution from the control material exceed those in the compost extracts at the early growth stages but were similar (Ca) or even lower (Mg) by the end. Mobilisation of nutrients from the slow-release fertiliser took less than the expected 3–4 months as a result of the high temperature and moisture.

Table 5 shows the micronutrient concentrations in the substrate solution at two dates during the strawberry growing period (at 106 DAT and 145 DAT). There was no clear-cut trend for the gorse composts as a whole; with the exception of the concentration of B, which differed between the two samplings in all composts, though the differences between the two sampling dates were not statistically verified. The concentrations of Cu, Mo, Mn and Zn in the control substrate decreased, whereas those of Fe and B increased, between the two sampling dates.

Regarding concentrations of minerals in the plant tissue (Table 6), N was the individual element most strongly affected by the particular substrate. Thus, N was present in greater concentrations in the plants grown in peat than in those grown in the composts, the differences increasing with decreased content of poultry manure in the compost. Although this result was obtained at both sampling dates, the differences between the composts decreased, whereas those from the control substrate increased, at

the end of the process. This finding was consistent with the changes in solution concentrations, which were higher in the control substrate than they were in the composts beyond 33 DAT (Figure 1), and the initial differences between the composts gradually vanishing with time. Also, the concentrations of N of the plants were invariably low, in fact, even those of the peat-grown plants fell below the acceptable levels.

The differences in the concentrations of P between the plants grown in the different substrates were similar to those for N. However, none of the P values were below the optimum range and some even exceeded the upper limit. This suggested that the decreased availability of P in the composts throughout the sampling period resulted in less marked, though not necessarily inadequate, absorption by plants relative to the control substrate. However, the differences in P among substrate solutions were not echoed by that in the plant leaves.

Unlike the previous elements, K was present in lower concentrations in plants grown in peat than in those grown in the compost-based substrates and there were only small differences (non-significant) between the composts irrespective of their proportion of poultry manure. This result may have arisen from the high initial K contents of the compost-based substrates and the K concentrations in the corresponding solutions being comparable to those for the control substrate despite the reduction in soluble K in solution during crop growth. The differences in plant-available soluble K^+ concentrations observed during most of the growing period were not echoed by the total K content in leaves.

As the fruit is a major sink of N, P, K, the concentrations of these elements in leaves can be expected to fall during the fruit production stage (Bottoms et al. 2013) resulting in a significant effect of production season on the composition of all macronutrients (Domínguez et al. 2020). This expectation was consistent with the reduction in soluble element concentrations in the substrate solutions during that stage (Figure 1); however, no similar reduction in leaf levels was observed when comparing the results for the two sampling dates. In fact, only the N concentration was lower on the second date in all substrates, P and K exhibiting similar or even high levels at the end of the growing period than mid-way the harvesting period.

The concentrations of Ca and Mg in the leaf tissue were generally adequate for all substrates and somewhat higher on the second sampling date than on the first one. The plants grown in the compost-based substrates were similar in this respect but

differed from those grown in the control substrate, the latter having the lowest concentrations on the first sampling date even though the Ca levels in solution were much higher in the preceding period.

All micronutrient levels fell within the acceptable ranges, but they differed among the substrates. Thus, B and Cu levels were especially low in the peat-grown plants, whereas the Zn and Fe levels were similar in all. Manganese levels peaked in the compost containing no poultry manure (PM0) and decreased gradually with increasing manure content. By contrast, Mo levels exhibited the opposite trend, which is consistent with differences in these elements between composts (see Table 2).

Table 7 illustrates the differences in the chlorophyll index of the gorse composts with their differing manure content, as compared to the control (peat) substrate. The chlorophyll index is widely used to assess the N nutritional status of plants, being simpler and more rapid than tissue analysis (Guler et al. 2006; Shibaeva et al. 2020) and for strawberry, the chlorophyll index has also been related to fruit quality parameters such as the total concentrations of phenols or anthocyanins (Pestana et al. 2010; Martínez et al. 2017). All substrates had similar chlorophyll values (indicating N levels) at the first sampling date (22 DAT.), which coincided with a period of fairly high concentrations of mineral N in the substrate extracts (Figure 1). Chlorophyll values (N levels) were subsequently slightly higher in all materials, but especially in the control substrate, as a result of the N concentrations in the extracts from the compost-based substrates gradually decreasing with time. In fact, the poorest substrates showed symptoms of inadequate N availability at 94 DAT. In fact, the plants grown on peat exhibited the highest chlorophyll levels and only those grown on the composts containing the largest amounts of manure (PM100 and PM75) had comparable levels. Beyond that point in time, the chlorophyll index of the peat-grown plants remained constant, whereas that of the compost-grown plants decreased gradually in response to the low N availability. In fact, the chlorophyll values for the composts 104 DAT were all similar and lower than those for the control substrate; on the other hand, the values for leaves on that sampling date exposed slight differences in total N content among composts (Table 7). The availability of inorganic N from the slow-release fertiliser decreased until 104 DAT and then levelled off at low values but still higher than those for the composts and seemingly adequate to prevent a decrease in chlorophyll levels, which suggested that no N deficiency occurred. In fact, the greatest difference in chlorophyll levels between the composts and the control substrate was observed at the

end of the growing period, which is consistent with the results of the second plant analysis.

Crop growth and production

Nutrient accumulation in strawberry has two critical stages, namely: (1) the active growth stage, and (2) stolon formation and fruiting (Cooper and Vaile 1945). The gradual decrease in available nutrient levels, which was faster in the compost-based substrates, restricted vegetative growth in the plants and delayed leaf development relative to the control substrate after the 7th week (results not shown), concurrently with faster growth. As can be seen from Figure 2, the peat-grown plants exhibited more marked growth in the form of substantially increased amounts of aerial biomass relative to the gorse composts (28.38 vs 13.73 g plant⁻¹). Also, aerial biomass increased with increasing proportion of poultry manure in the composts. These results can be associated to changes in the availability of N in the form of NH₄⁺ and NO₃⁻, the changes being more marked in the control substrate than in the compost-based substrates, and also in the composts containing some poultry manure (PM100) than in those containing none (PM0) (see Tables 1 and 2), which was bound to have delayed restrictions on plant growth.

There were, however, no significant differences in root growth (specifically, root dry weight) between the substrates. The average dry weight for the substrates was approximately 5 g plant⁻¹, which is somewhat smaller than previously reported values, e.g. 7.4 g plant⁻¹ by Yavari et al. (2008).

There were no significant differences in strawberry fruit weight or total yield between plants grown in the different substrates (Figure 3). This was consistent with the results of Bottoms et al. (2013) in a field study on 53 commercial strawberry fields under different management regimes, where fruit yield was unrelated to the N, P and K application rates. Kuisma et al. (2014) assessed the potential of various substrates as peat substitutes and found greater aerial growth in peat-grown plants but no differences in fruit yield or fruit weight. The average fruit weight ranged from 8.3 to 9 g and was thus very similar to previously reported values such as those of Ameri et al. (2012) (10 g for the Selva variety) and Yavari et al. (2008) (10 g with various mixed substrates made from residues). The mean total strawberry production was 70–90 g plant⁻¹ and hence lower than the value reported by Ameri et al. (2012), 170 g plant⁻¹, but much

higher than that obtained by Yavari et al. (2008): 45 g plant⁻¹. Although strawberry production spanned the period from June to September, in the compost-based substrates most of it occurred in the last month, by contrast, more than 50% of fruit production in the control substrate occurred in June (Figure 3).

Conclusions

The two types of gorse compost studied, particularly the compost containing poultry manure (PM100), were shown to supply large amounts of major nutrients. Also, their physical properties were acceptable, apart from the water holding capacity, which was relatively low. The nutrient concentrations in the solutions from the compost-based substrates decreased gradually during strawberry growth, particularly those of N and K, which remained at very low levels during the fruit production stage. The differences in soluble element concentrations of the substrate solutions between the composts were fairly small. By contrast, the control substrate exhibited substantial release of nutrients from the 6th to 9th week of cropping. Leaf analyses showed N to be the nutrient at the most limited concentration in the compost-grown plants relative to the control substrate and the chlorophyll measurements echoed this result. The amounts of aerial biomass in compost-grown plants increased with increased proportions of poultry manure in the substrate, but they were smaller than that of the plants grown in the control substrate. There were no substantial differences in root biomass, overall production or fruit size, however.

The green composts studied were considered as effective peat substitutes for organic strawberry cultivation. Although the initial nutrient contents of the composts were adequate for strawberry cropping, some nutrients such as N and K were inadequately mobilised to offset their uptake by the plants during the fruit production stage, even in the poultry manure-containing composts. Therefore, although there was no significant decrease in production compared to control, addition of supplementary fertiliser in this period may therefore be required in order to offset the increased uptake of nutrients by plants and to ensure that optimal production is achieved.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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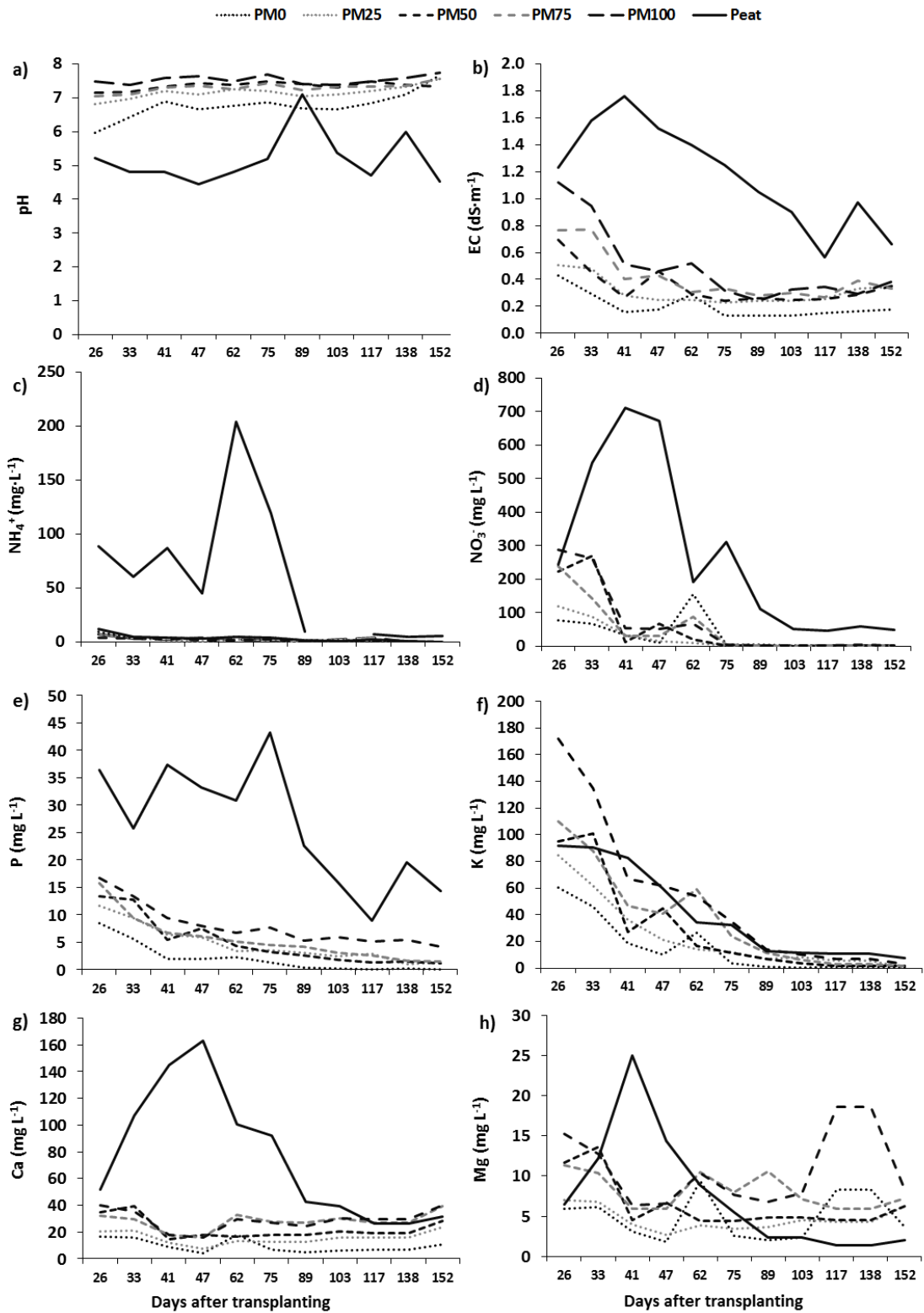


Figure 1. Changes in selected properties of the substrate solution during strawberry cropping under greenhouse conditions as a function of the proportion of poultry manure in the mixed composts.

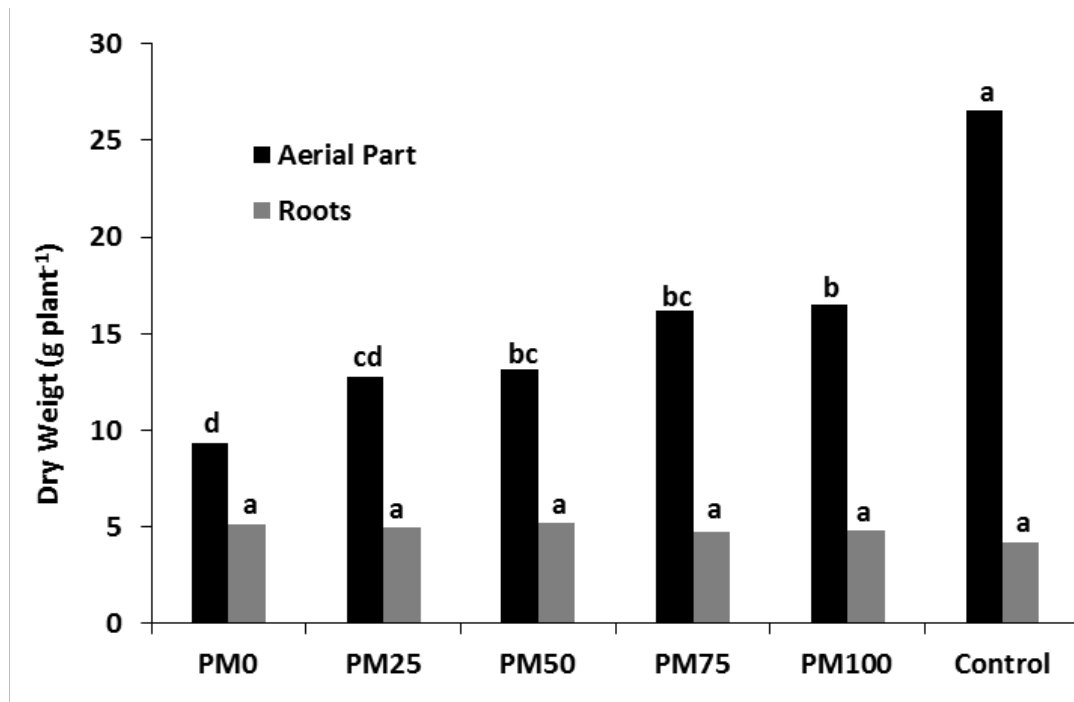


Figure 2. Average dry weight of the aerial part and roots of strawberry plants by substrate. Identical letters for the same parameter indicate non-significant differences between treatments (Tukey's post-hoc test at $p < 0.05$).

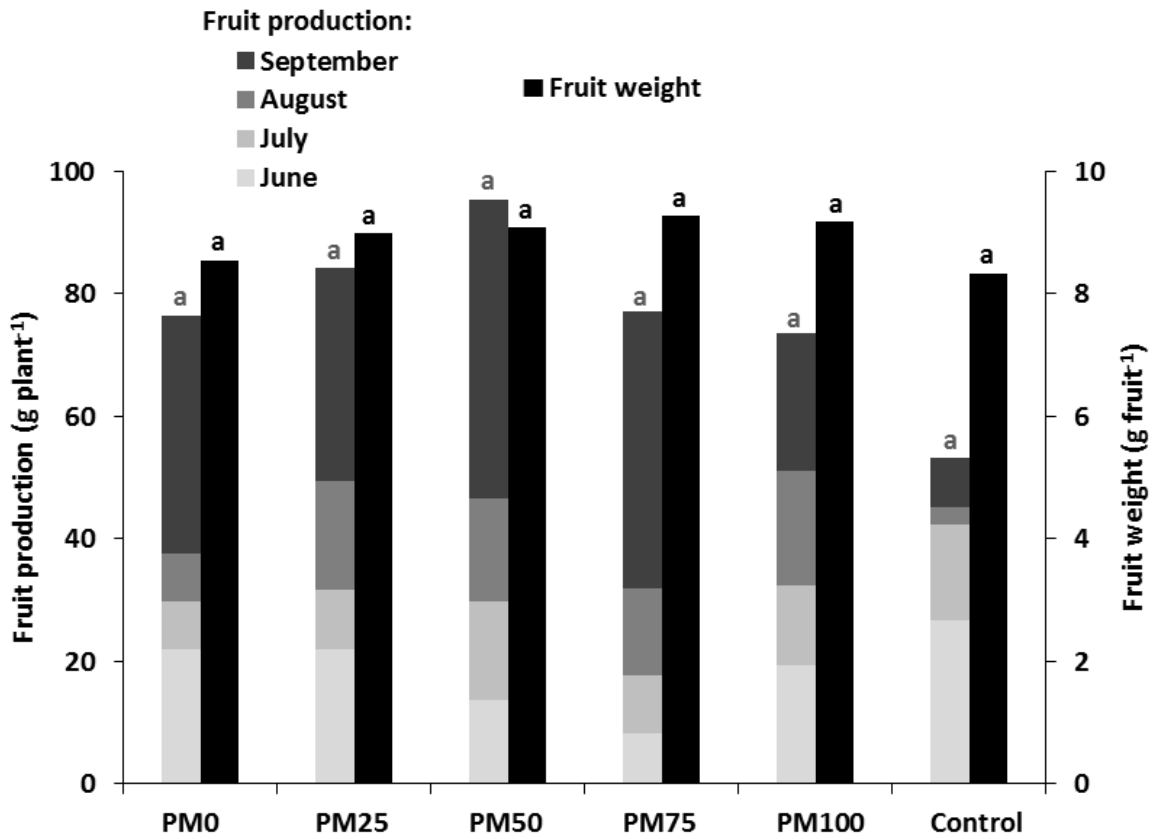


Figure 3. Average weight of fruit and monthly production per plant according to treatments. Identical letters for fruit weight or total production indicate non-significant differences between treatments (Tukey's post hoc test at $p < 0.05$).

Table 1. Analysis of the compost saturation extracts (water extract of saturated media) for pH, EC (electrical conductivity) and soluble elements.

	PM0	PM100	<i>p</i>-value	Optimum¹
pH	3.89 ± 0.19	6.25 ± 0.19	0.000	5.2 – 6.3
EC (ds m ⁻¹)	3.86 ± 0.13	6.49 ± 1.62	0.018	0.75 – 3.5
NO ₃ ⁻ (mg L ⁻¹ extr)	538.09 ± 85.80	837.30 ± 136.02	0.010	100 – 200
NH ₄ ⁺ (mg L ⁻¹ extr)	37.62 ± 9.20	63.75 ± 13.07	0.017	0 – 20
P (mg L ⁻¹ extr)	22.04 ± 4.58	29.51 ± 1.84	0.023	6 – 10
Ca (mg L ⁻¹ extr)	39.05 ± 1.82	77.68 ± 22.91	0.015	> 200
Mg (mg L ⁻¹ extr)	102.63 ± 7.19	113.50 ± 21.64	0.377	> 70
K (mg L ⁻¹ extr)	385.15 ± 98.71	732.35 ± 74.49	0.001	150 – 200
Na (mg L ⁻¹ extr)	97.63 ± 4.54	194.88 ± 56.62	0.014	
Cu (mg L ⁻¹ extr)	0.02 ± 0.00	0.02 ± 0.01	0.303	0.001 – 0.5
Zn (mg L ⁻¹ extr)	0.73 ± 0.36	0.34 ± 0.06	0.139	0.3 – 3
Fe (mg L ⁻¹ extr)	0.12 ± 0.04	0.04 ± 0.01	0.634	0.3 – 3
Mn (mg L ⁻¹ extr)	2.48 ± 0.70	0.07 ± 0.01	0.002	0.02 – 3
Mo (mg L ⁻¹ extr)	0.00 ± 0.00	0.01 ± 0.00	0.013	0.01 – 0.1
B (mg L ⁻¹ extr)	0.37 ± 0.11	0.38 ± 0.03	0.600	0.05 – 0.5

Notes: PM0 = composts with no poultry manure; PM100 = composts containing poultry manure.

¹Recommended values for an ideal substrate (Abad et al. 1993). Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter

Table 2. Analysis of the compost 1:5 (v/v) aqueous extracts for pH, EC (electrical conductivity) and soluble elements in relation to substrate volume (mg L⁻¹ substrate).

	PM0	PM100	<i>p</i> -value	Optimum ¹ (Maximum) ²
pH	4.11 ± 0.31	6.00 ± 0.20	0.000	5.3 – 6.5
EC (ds m ⁻¹)	0.76 ± 0.08	1.10 ± 0.33	0.097	0.4 – 0.9 (1.0)
NO ₃ ⁻ (mg L ⁻¹ sub)	310.95 ± 92.88	591.99 ± 79.04	0.004	81 – 200
NH ₄ ⁺ (mg L ⁻¹ sub)	44.49 ± 2.23	69.57 ± 17.13	0.027	51 – 150
P (mg L ⁻¹ sub)	26.38 ± 3.95	42.03 ± 4.99	0.003	29 – 100
Ca (mg L ⁻¹ sub)	198.03 ± 12.47	214.55 ± 76.49	0.685	
Mg (mg L ⁻¹ sub)	96.68 ± 5.61	86.08 ± 32.76	0.547	16 – 150
K (mg L ⁻¹ sub)	527.00 ± 109.40	692.50 ± 149.30	0.124	101 – 650
Na (mg L ⁻¹ sub)	95.43 ± 19.35	199.95 ± 83.18	0.050	
Cu (mg L ⁻¹ sub)	0.07 ± 0.03	0.07 ± 0.01	0.703	
Zn (mg L ⁻¹ sub)	1.99 ± 0.54	0.86 ± 0.42	0.060	
Fe (mg L ⁻¹ sub)	0.27 ± 0.05	0.26 ± 0.08	0.977	
Mn (mg L ⁻¹ sub)	1.49 ± 0.23	0.06 ± 0.07	0.001	
Mo (mg L ⁻¹ sub)	0.00 ± 0.00	0.02 ± 0.01	0.008	
B (mg L ⁻¹ sub)	0.61 ± 4.85	0.69 ± 0.07	0.574	

Notes: PM0 = compost with no poultry manure; PM100 = compost containing poultry manure

¹Optimum = recommended for potting and transplanting growing media (based on 1:6 v/v extraction) (ADAS 1988). ²Maximum = limit for award of the EU Ecolabel for growing media (EU Commission 2015). Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter.

Table 3. Composition of the composts before planting on a dry matter (dm) basis

	PM0	PM100	<i>p</i>-value	Optimum¹ (Maximum)²
OM (g kg ⁻¹ dm)	537.6 ± 25.3	387.8 ± 16.3	0.000	> 800
Ashes (g kg ⁻¹ dm)	462.4 ± 25.3	612.2 ± 16.3	0.000	< 200
N (g kg ⁻¹ dm)	2.01 ± 0.12	1.76 ± 0.06	0.002	1 – 3
C:N	14.62 ± 0.12	11.80 ± 0.07	0.000	20 – 40
Cd (mg kg ⁻¹ dm)	0.06 ± 0.01	0.07 ± 0.00	0.077	(1)
Cr (mg kg ⁻¹ dm)	12.60 ± 3.15	18.86 ± 1.74	0.013	(100)
Cu (mg kg ⁻¹ dm)	19.18 ± 3.07	33.71 ± 1.32	0.000	(100)
Hg (mg kg ⁻¹ dm)	0.03 ± 0.01	0.03 ± 0.01	0.882	(1)
Ni (mg kg ⁻¹ dm)	9.20 ± 1.77	14.15 ± 1.14	0.003	(50)
Pb (mg kg ⁻¹ dm)	7.19 ± 0.97	11.41 ± 0.48	0.000	(100)
Zn (mg kg ⁻¹ dm)	68.63 ± 8.01	120.46 ± 1.29	0.000	(300)

Notes: PM0 = compost with no poultry manure; PM100 = compost containing poultry manure. OM = Organic Matter. dm = dry matter. ¹Recommended values for an ‘ideal’ substrate (Abad et al. 1993).

²Limit for award of EU ecolabel (EU Commission 2015). Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter.

Table 4. Physical properties of the composts.

	PM0	PM100	<i>p</i>-value	Optimum¹
BD (g cm ⁻³)	0.19 ± 0.01	0.26 ± 0.01	0.000	< 0.4
PD (g cm ⁻³)	1.92 ± 0.02	2.08 ± 0.02	0.000	1.45 – 2.65
TP (% v/v)	90.29 ± 0.37	87.47 ± 0.68	0.000	> 85
AC (% v/v)	48.74 ± 1.45	47.22 ± 2.84	0.269	10 – 30
EAW (% v/v)	10.77 ± 0.93	11.43 ± 1.84	0.449	20 – 30
WBC (% v/v)	2.52 ± 0.15	2.35 ± 0.18	0.103	4 – 10
UW (% v/v)	28.27 ± 1.17	26.47 ± 1.39	0.037	
R (kPa)	0.93 ± 0.03	0.93 ± 0.06	0.931	1 – 3
S (% v/v)	16.86 ± 1.43	19.28 ± 3.40	0.140	< 30

Notes: PM0 = compost with no poultry manure; PM100 = compost containing poultry manure
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 equilibrating the water and air contents. ¹ Optimum values for an 'ideal' substrate (Abad et al. 1993; Abad et al. 2001; Noguera et al. 2003). Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter.

Table 5. Concentration of selected micro-nutrients in the solution sucked out of the substrates tested at two dates of the strawberry cultivation: 106 and 145 days after transplanting (DAT) (main harvest and end of cropping period).

	106 DAT		145 DAT		106 DAT		145 DAT	
	Mn (mg L⁻¹)				Fe (mg L⁻¹)			
PM0	0.022 ± 0.038	a	0.006 ± 0.006	a	0.059 ± 0.035	a	0.051 ± 0.036	a
PM25	0.003 ± 0.002	a	0.006 ± 0.005	a	0.064 ± 0.051	a	0.123 ± 0.093	a
PM50	0.002 ± 0.001	a	0.002 ± 0.001	a	0.033 ± 0.010	a	0.038 ± 0.019	a
PM75	0.004 ± 0.004	a	0.010 ± 0.020	a	0.031 ± 0.012	a	0.035 ± 0.029	a
PM100	0.005 ± 0.003	a	0.003 ± 0.001	a	0.029 ± 0.013	a	0.033 ± 0.021	a
Peat	0.146 ± 0.126	b	0.039 ± 0.015	b	0.062 ± 0.027	a	0.115 ± 0.091	a
	Zn (mg L⁻¹)				B (mg L⁻¹)			
PM0	0.172 ± 0.130	a	0.073	0.034 a	0.045 ± 0.037	a	0.089 ± 0.013	a
PM25	0.118 ± 0.144	a	0.173	0.105 ab	0.042 ± 0.041	a	0.119 ± 0.024	a
PM50	0.055 ± 0.043	a	0.076	0.062 a	0.039 ± 0.034	a	0.100 ± 0.016	a
PM75	0.036 ± 0.031	a	0.036	0.020 a	0.054 ± 0.036	a	0.092 ± 0.020	a
PM100	0.216 ± 0.416	a	0.084	0.080 a	0.070 ± 0.054	a	0.111 ± 0.033	a
Peat	1.915 ± 1.278	b	0.274	0.095 b	0.030 ± 0.053	a	0.092 ± 0.020	a
	Cu (µg L⁻¹)				Mo (µg L⁻¹)			
PM0	4.551 ± 2.972	a	3.161 ± 1.711	a	0.608 ± 0.285	a	0.722 ± 0.258	a
PM25	5.779 ± 3.862	a	8.807 ± 6.524	a	0.990 ± 0.594	a	1.525 ± 0.845	ab
PM50	4.484 ± 1.544	a	5.024 ± 2.853	a	1.302 ± 0.615	a	1.680 ± 0.802	ab
PM75	4.453 ± 2.764	a	3.276 ± 1.625	a	1.866 ± 0.919	a	1.507 ± 0.841	ab
PM100	7.341 ± 3.021	a	6.373 ± 4.387	a	4.034 ± 1.439	b	4.561 ± 3.288	b
Peat	8.342 ± 2.613	a	5.842 ± 3.129	a	4.003 ± 1.749	b	3.774 ± 3.313	ab

Notes: Mean ± standard deviation and Tukey's post-hoc test. Identical letters for the same parameter and date indicate non-significant differences at $p < 0.05$ between treatments.

Table 6. Concentration of total elements in the strawberry leaf tissue at main harvest (104) and at the end of cropping period (153) days after transplanting (DAT).

104 DAT	PM0	PM25	PM50	PM75	PM100	PEAT	Opt¹
N (g kg ⁻¹)	13.18 d	13.74 cd	14.09 bcd	15.72 bc	16.49 b	22.44 a	24 – 40
P (g kg ⁻¹)	2.28 b	3.34 ab	3.06 ab	3.43 ab	3.18 ab	3.76 a	2 – 4
K (g kg ⁻¹)	15.82 ab	19.11 a	18.72 ab	17.40 ab	17.43 ab	13.09 b	11 – 25
Ca (g kg ⁻¹)	8.75 ab	10.63 a	9.77 a	8.68 ab	8.53 ab	5.79 b	4 – 23
Mg (g kg ⁻¹)	3.19 a	2.97 a	2.54 a	2.62 a	2.60 a	1.69 b	2 – 4.5
Na (g kg ⁻¹)	0.068 a	0.085 a	0.041 a	0.042 a	0.031 a	0.035 a	< 1
B (mg kg ⁻¹)	47.67 a	50.67 a	44.75 a	48.42 a	48.11 a	25.51 b	20 – 77
Zn (mg kg ⁻¹)	22.61 a	24.79 a	13.15 a	28.75 a	23.18 a	33.45 a	12 – 50
Mn (mg kg ⁻¹)	280.90 b	114.58 a	37.69 a	46.59 a	48.90 a	73.53 a	25 – 300
Fe (mg kg ⁻¹)	93.12 a	78.46 a	54.09 a	73.50 a	55.14 a	55.67 a	50 – 300
Cu (mg kg ⁻¹)	3.36 ab	3.87 ab	4.64 ab	7.89 a	5.10 ab	2.54 b	2.5 – 15
Mo (mg kg ⁻¹)	0.85 b	1.21 b	1.79 b	1.31 b	3.38 a	0.79 b	0.5 – 0.8
153 DAT	PM0	PM25	PM50	PM75	PM100	PEAT	Opt¹
N (g kg ⁻¹)	12.07 b	12.72 b	13.26 b	14.10 b	14.37 b	22.11 a	24 – 40
P (g kg ⁻¹)	2.91 b	4.59 b	4.36 b	4.73 b	4.43 b	6.85 a	2 – 4
K (g kg ⁻¹)	20.09 ab	22.63 a	22.94 a	23.81 a	22.43 a	16.42 b	11 – 25
Ca (g kg ⁻¹)	15.70 c	17.30 bc	17.13 bc	17.98 ab	16.26 bc	19.42 a	4 – 23
Mg (g kg ⁻¹)	4.14 a	3.60 abc	3.53 bc	3.79 ab	3.78 ab	3.21 c	2 – 4.5
Na (g kg ⁻¹)	0.025 a	0.023 a	0.022 a	0.023 a	0.022 a	0.022 a	< 1
B (mg kg ⁻¹)	64.12 a	63.77 a	66.77 a	68.70 a	71.15 a	39.46 b	20 – 77
Zn (mg kg ⁻¹)	23.51 a	33.95 a	26.52 a	22.36 a	24.29 a	29.97 a	12 – 50
Mn (mg kg ⁻¹)	445.66 a	156.45 b	67.52 b	69.10 b	79.09 b	233.70 b	25 – 300
Fe (mg kg ⁻¹)	168.79 a	180.33 a	145.87 a	129.12 a	146.30 a	133.70 a	50 – 300
Cu (mg kg ⁻¹)	4.12 a	5.08 a	4.82 a	5.07 a	5.80 a	1.99 b	2.5 – 15
Mo (mg kg ⁻¹)	1.62 a	2.20 a	3.28 a	2.36 a	2.54 a	1.96 a	0.5 – 0.8

Notes: ¹ Compiled from data of Bottoms et al. (2013) (full harvest, leaf blade); Hochmuth and Albregts (2019) (full harvest, full leaves); Campbell and Miner (2000) (full harvest, full leaves); Ulrich et al. (1980) (unspecified time, leaf blade); and Whipker (2014) (unspecific time, full leaves). Means and Tukey's post-hoc test. Identical letters for the same parameter and date indicate non-significant differences at $p < 0.05$ between treatments.

Table 7. Chlorophyll index for strawberry leaves on six different dates during the crop cycle (DAT = days after transplanting) (22 DAT: vegetative growth; 36 DAT: flowering; 94-104-119 DAT: fruit production; 146 DAT: end of cropping period)

	22 DAT	36 DAT	94 DAT
PM0	17.40 ± 3.23 a	18.50 ± 2.52 ab	18.53 ± 3.68 b
PM25	17.80 ± 2.75 a	18.04 ± 2.51 ab	18.38 ± 3.32 b
PM50	17.59 ± 2.47 a	16.86 ± 2.72 b	19.13 ± 4.38 b
PM75	18.47 ± 2.75 a	17.27 ± 2.67 b	20.51 ± 3.01 ab
PM100	17.33 ± 4.09 a	16.74 ± 2.22 b	21.77 ± 5.29 ab
Peat	17.31 ± 2.91 a	18.70 ± 2.94 a	21.82 ± 4.68 a
	104 DAT	119 DAT	146 DAT
PM0	17.33 ± 3.69 b	15.78 ± 2.06 b	16.09 ± 1.51 bc
PM25	17.98 ± 2.98 b	17.36 ± 3.64 b	17.51 ± 2.85 ab
PM50	17.11 ± 4.37 b	16.03 ± 4.55 b	15.75 ± 3.06 bc
PM75	16.25 ± 2.75 b	14.65 ± 3.57 b	14.71 ± 2.10 c
PM100	17.80 ± 4.18 b	16.58 ± 6.00 b	16.54 ± 4.03 bc
Peat	22.61 ± 7.02 a	21.63 ± 6.51 a	21.56 ± 5.72 a

Notes: Mean values ± standard deviation and Tukey's post-hoc test. Identical letters for each date indicate non-significant differences at $p < 0.05$ between treatments.