Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar
http://dx.doi.org/10.5424/sjar/2013112-3304

Spanish Journal of Agricultural Research 2013 11(2), 518-528
ISSN: 1695-971-X
eISSN: 2171-9292

Compost *versus* vermicompost as substrate constituents for rooting shrub cuttings

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Abstract

The feasibility of composted (C), composted plus vermicomposted (V1) and straight vermicomposted (V2) tomato crop waste as component of rooting media for *Euonymus japonicus* 'Microphylla' and *Lavandula angustifolia* vegetative propagation was studied. Mixes of C, V1 and V2 with coir fibre (CF) at the proportions 100:0, 75:25, 50:50, 25:75, 0:100 (v:v) were assayed. Physical, physico-chemical and nutritional characteristics of all materials and mixes were determined and correlated with cutting rooting and growth performances. The compost and the two vermicomposts were markedly different from CF. They had higher bulk density and lower total porosity than CF. Compost had lower water-holding capacity and shrinkage in response to drying than vermicomposts and CF. Compost and vermicomposts were alkaline materials whilst CF was almost neutral. Electrical conductivity (EC) was low in CF and vermicomposts, and high in compost due to the high mineral contents, mainly of K^+, SO_4^{2-} and Na^+ in this material. EC and the ions contributing to it (K^+, SO_4^{2-}, Na^+) showed highly significative inverse correlations with rooting percentage for the two species and with root and shoot growth but only for *E. japonicus*. Due to its high EC, compost C (average rooting = 22.5%) performed worse than vermicomposts V1 (av. rooting = 97%) and V2 (av. rooting = 98%) whilst the latter performed similarly to CF control (av. rooting = 100%). Thus vermicomposts appeared to be more appropriate than compost as rooting media constituent.

Additional key words: composting; crop waste reclamation; rooting media; vegetative plant propagation; vermicomposting.

Introduction

The ornamental plant sector in Spain produced about 188 million units in 2009 (MAGRAMA, 2010). Exports to the European countries almost reached € 187 million in 2011, € 7.1 million corresponding to plants obtained by cutting propagation (FEPEX, 2011).

Cutting propagation is the most important means for clonal regeneration of many horticultural crops: ornamentals, fruits, nuts and vegetables, as well as for vegetative propagation of forestry plants (Hartmann *et al*., 2010). Adventitious root formation is a prerequisite to successful cutting propagation. For this purpose the rooting medium is of paramount importance. Apart from holding the cutting in place the medium has to provide the correct moisture degree to the cutting base whilst permitting aeration. Under these premises it is obvious that there is not an ideal rooting medium for cutting propagation as the requirements will depend on the species, type of cutting, season and available technology (moistening system, shadowing, etc).

Together with *Sphagnum* moss peat, coconut coir waste (short fibre and dust) is one of the most popular organic materials that are used in media for cutting propagation (Stoven & Kooima, 1999; Matysiak & Novak, 2008). Although coir has been described as similar to *Sphagnum* moss in looks and texture (Verdonck *et al*., 1983) it has also been described as highly variable in its physical properties (Abad *et al*., 2005) and in some chemical characteristics (*i.e.* salinity) (Noguera *et al*., 1997). Besides, some composts and vermicomposts also show physical and chemical characteristics which

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Received: 05-07-12. Accepted: 17-04-13.

Abbreviations used: C (compost); CF (coir fibre); DAP (days after planting); EC (electrical conductivity); MM (mineral matter); OM (organic matter) V1 (vermicompost obtained after initial composting); V2 (vermicompost obtained from straight vermicomposting); VR (visual rating).

are similar to peat, making them suitable as peat substitutes for growing media preparation (Atiyeh *et al.*, 2000; Arancon *et al.*, 2008; Bachman & Metzger, 2008). Nevertheless, though compost has been used as media constituent for cutting propagation (Guérin *et al.*, 2001; Iglesias-Díaz *et al.*, 2009; Li *et al.*, 2009) vermicompost has not been yet used for this purpose.

Intensive vegetable cropping systems produce large amounts of crop residues —unmarketable plant parts left on the soil after harvest—, which cannot be directly incorporated into the soil for the lack of time between crops. In Spain, more than four million tons of vegetable crop residues are generated yearly and accumulated in specific regions (Carrión *et al.*, 2008). Composting and vermicomposting, two well-known processes for solid organic waste reclamation, are good alternatives to burning or damping organic wastes. The final products, composts and vermicomposts, can be used as sources of organic matter for soil amendment, of nutrients for soil fertilization or as growing media constituents for soilless cultivation (González *et al.*, 2010). In fact, in recent years vegetable crop residues have been successfully recycled through composting for horticultural purposes (Kulcu & Yaldiz, 2004; Mazuela *et al.*, 2005; Carrión *et al.*, 2008). Both processes can be produced at the industrial scale, which allows the disposal of large quantities of waste (Lazcano *et al.*, 2008).

In contrast to composting, which reaches 70°C during the termophillic phase, one of the main objections to vermicomposting lies on the worm requirement for physiological temperature (25 to 40°C), which would not sanitize the vermicompost, and would not guarantee standards of human pathogen reduction in the final product. However, vermicompost is reported to have better visual appearance and higher nutrient content and microbial activity than compost (Tognetti *et al.*, 2005), though its price in market triples that of compost. Due to the above indicated objection to vermicomposting a combination of composting, which enables sanitization and elimination of toxic compounds, and vermicomposting, which rapidly reduces particle size and increases nutrient availability, has been considered as a way to improve final materials.

One of the most significant factors affecting the quality of composts and vermicomposts is the original raw material (Domínguez, 2004; Masaguer & Benito, 2007; Nogales *et al.*, 2007). Nevertheless, most published studies that compare compost and vermicompost did not process the same raw material (Tognetti *et al.*, 2005; Lazcano *et al.*, 2008) or did not test the quality of the compost and vermicompost through plant growth experiments (Ndegwa & Thomson, 2001). Thus, it must be treated as a priority to develop studies comparing the characteristics of composts and vermicomposts that have been obtained in parallel from the same organic batch and under the same conditions (climate, water quality, etc.) and to test their performance as cutting propagation media constituents.

The aim of this study was to compare the performance of one compost and two vermicomposts (one obtained after pre-composting and the other through straight vermicomposting) from the same horticultural waste batch as media constituents for cutting propagation and to determine which of the three processes is more suitable for this horticultural purpose.

Material and methods

Compost, vermicomposts and plant material

One compost (C) and two vermicomposts (V1 and V2) were assayed in this study. The three materials were prepared from an original mix of chopped air dried tomato crop waste and ground almond shell in a proportion of 75:25 (v:v).

Composting was carried out using a combined system of Rutgers static pile with forced aeration and controlled temperature plus pile turning (twice during the first month). The 2-m^3 pile was watered at the start of the process and during pile turning. The thermophile stage of composting, during which temperatures raised up to 70°C, ended on day 63. The pile was allowed to rest for another 117 days, at which time the compost was considered mature and stabilized either to be used as growing media or growing media constituent for soilless horticulture or to be used as soil amendment. See Fornes *et al.* (2012) for the properties of the original material and the final compost and vermicomposts.

For V1 production, a pre-composted raw mix (63 days of thermophilic phase) pile was transferred to a bed to which *Eisenia andrei* and *Eisenia fetida* worms were added. The final worm population in the mix was aimed at 25,000 individuals m^{-3}. The material was maintained at 25-30°C and 70-80% humidity throughout the vermicomposting process, which lasted 198 days.

In order to produce vermicompost V2 *E. andrei* and *E. fetida* worms were added directly to a 2-m^3 bed of raw material and subjected to the same conditions described for V1 during 261 days.

Cuttings of two ornamental shrubs were used in the experiments: *Euonymus japonicus* 'Microphylla' and *Lavandula angustifolia* 'Munstead'. Cuttings of about 5-cm length were obtained from lateral or terminal sprouts of mother plants which were growing on coconut fibre in large volume containers.

Treatments and experimental design

Treatments consisted of different mixes of C, V1 or V2 with a slightly fertilized coconut fibre (CF) (Coco®, Pelemix España S.L.). The same substrate design was used for the two species in the experiment. The assayed mixes were C:CF, V1:CF and V2:CF in the proportions: 100:0, 75:25, 50:50, 25:75 and 0:100 (Control), which added up to 13 treatments. Three 72 cell plastic rooting trays (cell volume = 62 mL) were filled with each of the mixes and distributed in a random block design.

Cutting rooting and plant growing conditions

The experiments were conducted in a glasshouse in a commercial nursery (Tenisplant, S.L.) located in Picassent, Spain. Before sticking the cutting in the substrate, its basal zone —1-cm from cut— was immersed in a commercial indolbutyric acid solution (Flower Hormonas Enraizantes, Codyesa). One cutting per cell was stuck in the substrate at the beginning of April. Cuttings were irrigated using a microsprinkler system (performance of 36 L h^{-1} m^2) at a regime of 5 min once a day, resulting in 0.6 L $tray^{-1}$ day^{-1}. Rooting and growth results were recorded 88 days after planting (DAP) for *Lavandula* and 98 DAP for *Euonymus*.

Physical characterization of the substrates

Bulk density and water capacity were determined using loosely packed cores and methods from EN 13041 (2011). For this study, steel cylinders measuring 40 mm height and 82.3 mm internal diameter (210 mL) were used. Shrinkage was the percentage of bulk volume which was lost after drying the material contained in the cylinder at 105°C (EN 13041, 2011).

Particle density (D_P) is an indirect estimate obtained from the organic matter content (OM) and the mineral content (MM) by applying the equation:

$$D_P\ (\text{kg m}^{-3}) = \frac{100}{\dfrac{\%\text{OM}}{1550} + \dfrac{\%\text{MM}}{2650}}$$

where 1,550 kg m^{-3} is the organic matter mean density and 2,650 kg m^{-3} is the mineral matter mean density (EN 13039, 2011). Total pore space is the percentage of volume of the material that can be filled with water. Air capacity is the difference —in percentage by volume— between the total pore space and the moisture content at a suction of 1 kPa [EN 13041 (2011)].

All determinations were performed three times.

Physico-chemical and chemical characterization of the substrates

The pH (EN 13037, 2011; EN 13040, 2008), electrical conductivity (EC) (EN 13038, 2011; EN 13040, 2008) and water soluble (available) mineral element concentration (EN 13652, 2001) of the mixes were determined in a 1:5 (v:v) material:water suspension. The pH was measured before filtration using a Crison mod. 2,000 pHmeter provided with a special pH electrode (Crison mod. 5000-20). The filtrate from the 1:5 (v:v) compost:water suspension was used for EC and mineral content determinations. EC was determined with a conductimeter (Crison mod. 522) using a PVC/graphite conductivity cell (Crison mod. 52-89), and corrected to 20°C. Water-soluble mineral nitrogen ($N_{min} = NO_3^-$ plus NH_4^+) was determined in a semiautomatic nitrogen analyzer using MgO and Devarda alloy (Puchades *et al.*, 1985). $H_2PO_4^-$, K^+, Ca^{2+}, Mg^{2+} SO_4^{2-}, Na^+ and Fe were determined by Atomic Emission Spectrophotometry with inductively coupled plasma (ICP-AES; Spectro flame, Spectro Analytical Instruments, Inc). Water soluble mineral contents were expressed as mg L^{-1} substrate.

All determinations were performed three times.

Evaluation of rooting and growth of cuttings

The number of rooted cuttings was determined at the end of the experiments. Results are presented as percentage of planted cuttings. At this time 15 plants of each replicate (45 plants per treatment) were collected and different parameters related to shoot growth (fresh and dry weight, length, stem diameter, number

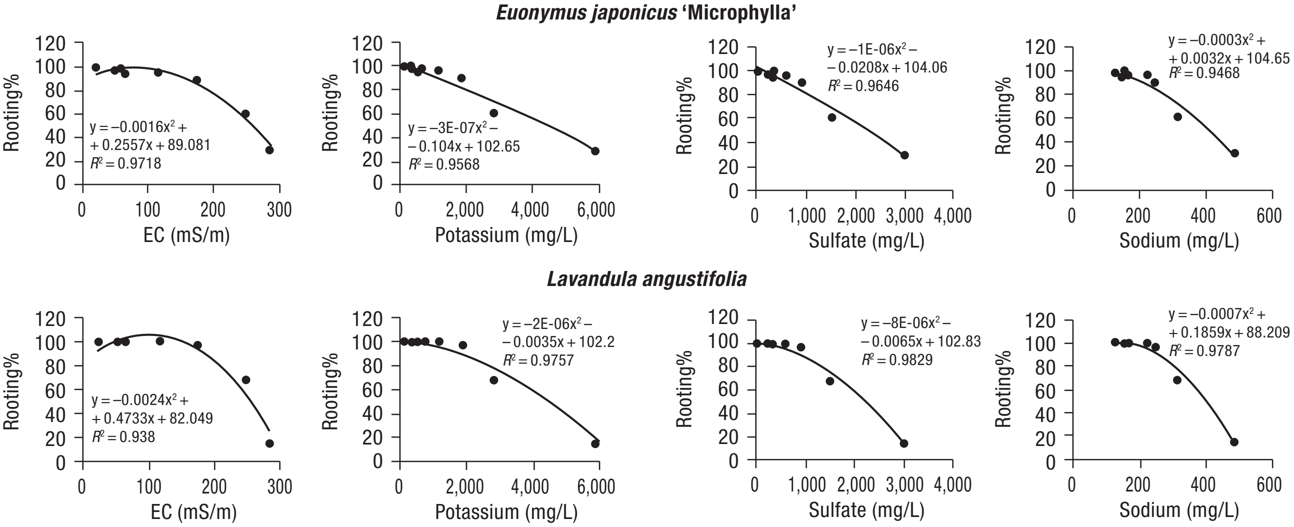

Figure 1. Relationship between cutting rooting percentage of *Euonymus japonicus* 'Microphylla' and *Lavandula angustifolia* and electrical conductivity (EC), potassium, sulfate and sodium contents in the rooting media.

of branches) and root growth (fresh and dry weight, longest-root length and a root size-visual rating (root size-VR) score on a 1-5 scale —value 1 representing roots which do not reach the surface of the substrate and value 5 representing a root system forming a compact mesh that colonizes the whole substrate (Fornes *et al.*, 2007)— were recorded. Only results of the most important parameters (*i.e.* percentage of rooted cuttings, shoot and root dry weight, shoot and root length, and root size-VR) are presented. The selection was made after observing that the other parameters showed equal differences between treatments than those finally chosen.

Shoot nutrient content determination

Oven-dry aerial tissue of cuttings was finely ground and analyzed after acid digestion for nitrogen and mineral elements. Nitrogen was determined following the Kjeldahl method whilst the $H_2PO_4^{2-}$, K^+, Ca^{2+} and Mg^{2+} contents were determined by Atomic Emission Spectrophotometry with inductively coupled plasma (ICP-AES; Spectro flame, Spectro Analytical Instruments, Inc). Results are expressed as % on a dry weight basis.

Data analysis

Analysis of variance was conducted to determine if the substrates significantly differed. Where significant differences existed, the Student-Newman-Keuls test at $p \leq 0.05$ was carried out to establish significant differences between means. In Figs. 1 and 2, determination coefficients (R^2) were obtained from the best-fitting polynomial regression analysis of the data.

Results

Physical, physico-chemical and nutritional characteristics of the substrates

The physical and physico-chemical properties of compost C, vermicomposts V1 and V2, coconut fibre (CF; control) and the different mixes are shown in Table 1 while the available nutrient contents are presented in Table 1. Compost C and vermicompost V1 and V2 were markedly different from CF and the properties of the mixes approached those of the material which dominated the proportion.

Bulk density (D_B) was on average 4.9 times larger in C, V1 and V2 than in CF decreasing significantly in the mixes as the proportion of CF increased. Particle density (D_P) reflected the same tendency as D_B but the differences between C, V1 and V2 relative to CF, though significant, were of lower magnitude. Total porosity (P_T) was inversely correlated to D_B being highest in CF and slightly but significantly higher in V1 than in C and V2. This parameter increased in the mixes as the proportion of CF increased. Total porosity affected aeration and water-holding capacity in substrates. Each of the materials showed different air-water relationships. CF showed larger V_{air} than compost C

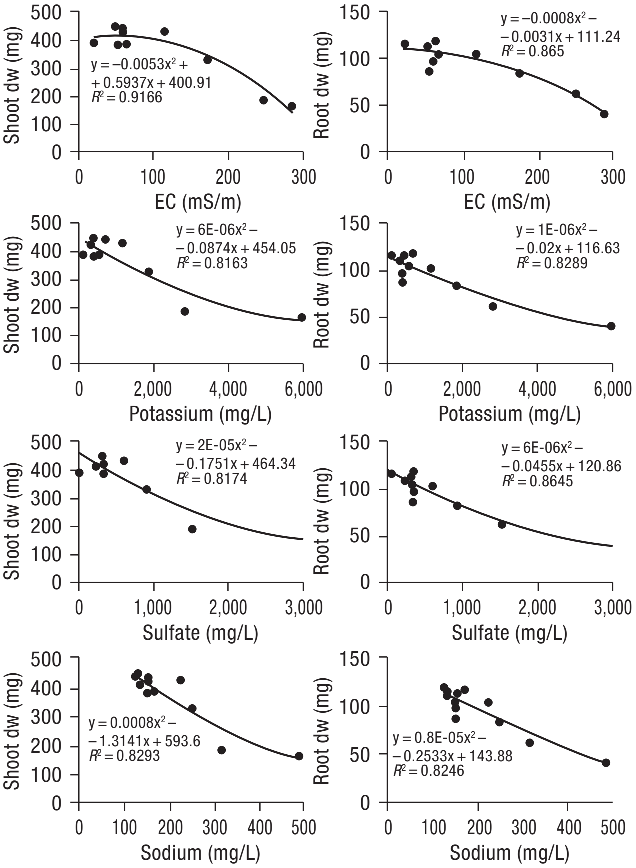

Figure 2. Relationship between cutting shoot and root dry biomass of *Euonymus japonicus* 'Microphylla', and electrical conductivity (EC), potassium, sulfate and sodium contents in the rooting media.

and the latter larger than both vermicomposts. When mixed with 25% or more CF compost and vermicompost V1 had the same V_{air} than CF on its own whereas V_{air} increased progressively as the proportion of CF increased in the mixes with vermicompost V2. Cyclic wetting and drying of growing media can cause shrinkage which compromises the irrigation process. This parameter was about half in C than in V1 and V2 which did not differ significantly from CF.

The pH was close to neutrality for the control of coconut fibre (6.8) while it was markedly alkaline for vermicompost V1 (8.6) and V2 (8.8) and compost C (8.9). The pH decreased significantly in the mixes as the proportion of CF increased but neutrality was never reached. Electrical conductivity (EC) was typically low in the CF (21 mS m^{-1}) whilst it was slightly larger in the vermicomposts (65 mS m^{-1}) and markedly larger in the compost (285 mS m^{-1}). EC markedly decreased in compost-based mixes as the proportion of CF increased. In vermicompost-based mixes EC also decreased, slightly but significantly, with the addition of CF.

Coconut fibre contained more organic matter (OM) (86%) than compost C (73%) and that the vermicomposts V1 and V2 (64% on average) (Table 1). Available (water-soluble) nutrient content was in general highest in C, followed by V1 and V2, CF being the poorest material, which was in accordance with their EC (Table 1). Mineral nitrogen content was greater in compost C (70 mg L^{-1}) than in vermicompost V1 (50 mg L^{-1}) whilst it was low in V2 (7.9 mg L^{-1}) and very low in CF (1.3 mg L^{-1}). $H_2PO_4^{2-}$ content was also greater in compost (60 mg L^{-1}) than in vermicomposts V1 and V2 (50 and 55 mg L^{-1}, respectively) or in CF (37 mg L^{-1}). Compost was especially rich in potassium (11 times larger than in vermicompost V1, 12.5 times larger than in V2 and 48 times larger than in CF) and sulfate (9 times larger than in vermicomposts and 197 times larger than in CF). Calcium, magnesium and sodium contents in C were double to triple those in V1 and V2 and they were 17, 41 and 3 times larger than in CF, respectively. Iron content was highest in compost and CF followed by V2, it being lowest in V1.

Rooting and growth of cuttings in the substrates

Table 2 shows the percentage of rooted cuttings (% of survival) as well as some parameters related to shoot and root growth for the two species used in this study and Table 3 shows the treatment (material and mix segregated) main effects on rooting and growth.

Comparing the performance in the four materials, the best results for *Euonymus* were obtained when cuttings were rooted in V1, V2 and the CF control substrate: rooting percentage (94-100%) and shoot growth (388-394 mg dw; 10.4-11.0 cm length) were maximum in these three materials though root dry weight, length and visual rating score were slightly larger in CF than in V1 and V2. Compost C resulted inadequate for the rooting of cuttings as the percentage of rooted cuttings was low (30%). Surviving (rooted) cuttings also performed worst in compost C. In general the mix of C, V1 and V2 with CF improved plant growth as compared to the pure materials. Some of the mixes showed greater shoot growth than the control.

For *Lavandula* rooting percentage was maximum for vermicomposts V1 and V2 and for CF as well as for all the mixes prepared with these three materials. Root-ball had higher visual rating score and the cutting-largest root was longer for the control substrate

Table 1. Selected physical and physico-chemical properties, organic matter and available (water soluble) nutrient content in compost C and vermicomposts V1 and V2 based growing media for cutting propagation

Growth media	D_B[1]	D_P	P_T	V_{air}	V_{water}	Shrink	pH	EC (mS m^{-1})	OM (%)	N_{min}	H_2PO_4	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Na^+	Fe
	(kg m^{-3})		(% v/v)							(mg L^{-1} substrate)							
C[2]-1[3]	349^{a}	$1,655^{abcd}$	79^{j}	39^{d}	40^{h}	10^{d}	8.93^{a}	285^{a}	73^{bcd}	69.3^{a}	60^{d}	$5,938^{a}$	235^{a}	162^{a}	$3,001^{a}$	485^{a}	1.75^{a}
C-2	254^{d}	$1,635^{bcd}$	84^{g}	43^{abc}	41^{h}	16^{abc}	8.89^{a}	248^{b}	75^{bcd}	24.8^{c}	61^{d}	$2,825^{b}$	103^{c}	56^{c}	$1,509^{b}$	315^{b}	1.08^{bcd}
C-3	197^{e}	$1,610^{cde}$	88^{e}	44^{abc}	44^{g}	15^{bc}	8.79^{b}	174^{c}	78^{bcd}	15.8^{cd}	54^{e}	$1,858^{c}$	65^{f}	33^{g}	906^{c}	248^{c}	0.74^{cd}
C-4	141^{f}	$1,583^{de}$	91^{c}	45^{ab}	47^{ef}	19^{a}	8.47^{d}	116^{d}	81^{ab}	7.8^{d}	61^{d}	$1,165^{d}$	43^{g}	18^{i}	598^{d}	224^{d}	$1.05b^{cd}$
V1-1	314^{b}	$1,719^{ab}$	82^{i}	20^{f}	62^{a}	19^{ab}	8.59^{c}	65^{e}	66^{de}	50.3^{b}	50^{e}	556^{f}	87^{d}	48^{d}	326^{e}	148^{f}	0.47^{d}
V1-2	251^{d}	$1,703^{abc}$	86^{f}	42^{abcd}	44^{g}	19^{ab}	8.17^{ef}	59^{ef}	68^{cde}	14.7^{cd}	54^{e}	688^{e}	82^{de}	42^{e}	328^{e}	124^{g}	0.51^{d}
V1-3	189^{e}	$1,720^{ab}$	89^{d}	44^{ab}	45^{fg}	17^{abc}	8.00^{g}	50^{f}	65^{de}	8.8^{d}	56^{de}	412^{h}	76^{e}	37^{f}	310^{e}	129^{g}	0.43^{d}
V1-4	119^{g}	$1,642^{bcd}$	93^{b}	41^{bcd}	51^{c}	19^{ab}	7.90^{h}	50^{f}	74^{bcd}	4.6^{d}	97^{b}	342^{i}	27^{h}	10^{j}	227^{e}	130^{g}	0.46^{d}
V2-1	357^{a}	$1,750^{a}$	80^{j}	22^{f}	58^{b}	19^{ab}	8.76^{b}	64^{e}	62^{e}	7.9^{d}	55^{e}	474^{g}	125^{b}	62^{b}	333^{e}	170^{e}	0.95^{bcd}
V2-2	288^{c}	$1,747^{a}$	84^{h}	36^{e}	47^{def}	18^{ab}	8.22^{e}	60^{ef}	63^{e}	7.1^{d}	62^{d}	365^{hi}	129^{b}	60^{b}	342^{e}	150^{f}	0.97^{bcd}
V2-3	201^{e}	$1,708^{abc}$	89^{d}	40^{cd}	49^{cde}	13^{cd}	8.12^{f}	54^{f}	67^{cde}	6.4^{d}	83^{c}	408^{h}	104^{c}	47^{d}	339^{e}	150^{f}	1.23^{abc}
V2-4	146^{f}	$1,706^{abc}$	91^{c}	42^{abcd}	50^{cd}	13^{cd}	7.91^{h}	52^{f}	67^{cde}	4.2^{d}	125^{a}	369^{hi}	60^{f}	23^{h}	304^{e}	152^{f}	1.76^{a}
Control	71^{h}	$1,545^{e}$	96^{a}	46^{a}	50^{c}	16^{abc}	6.83^{i}	21^{g}	86^{a}	1.3^{e}	37^{f}	124^{j}	14^{i}	4^{k}	15^{f}	160^{ef}	1.48^{ab}
p[4]	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

[1] D_B: bulk density; D_P: particle density; P_T: total porosity; V_{air}: air volume; V_{water}: water volume; EC: electrical conductivity; OM: organic matter; N_{min}: mineral nitrogen (NH_4^+-N + NO_3^--N). [2] C: composted material; V1: vermicompost produced on pre-composted material; V2; straight vermicomposted material. [3] Proportion (v/v) of compost or vermicompost to coconut fibre in the mix: 1 = 100/0; 2 = 75/25; 3 = 50/50; 4 = 25/75; Control = 0/100. [4] *** Indicate significant at $p \leq 0.001$. Different letters in columns differ at $p \leq 0.05$ (Student-Newman-Keuls test).

than for V1 and V2. Nevertheless, although root dry weight was also larger in CF than in V1 and V2 the difference was not statistically significant. Regarding the aerial part, growth was larger in V1 and V2 than in CF, decreasing as the proportion of CF in the mixes increased. With respect to compost C and its dilution with 25% of CF, these substrates were inadequate for *Lavandula* rooting since only 15% and 68%, of the cuttings, respectively, rooted. In these cases dry weight, length and visual rating of roots as well as shoot growth parameters reached the lowest values although they improved as the proportion of CF increased in the mix.

Correlation between rooting and growth of cuttings and the substrate characteristics

Correlations between the rooting and dry biomass data (Table 2) and the substrate physical, physico-chemical and nutritional data (Tables 1 and 2) were analyzed. Figs. 1 and 2 show the correlations with a determination coefficient larger than 0.8 (more than 80% of the changes of the dependent variable are explained by the changes in the independent variable). The percentage of cuttings that rooted was inversely correlated with EC and with the substrate content of the main cations contributing to EC (K^+, SO_4^{2-}, Na^+) for the two species (Fig. 1). In relation to the biomass parameters, a strong inverse correlation between root and shoot dry weights and EC, K^+, SO_4^{2-} and Na^+ was found (Fig. 2) for *Euonymus* but not for *Lavandula*. The rest of the correlations analyzed reached determination coefficient values lower than 0.6.

Nutritional status of the cuttings rooted in the substrates

Aerial part nutrient content of the two shrubs rooted on the different compost and vermicompost containing substrates is shown in Table 2.

For *Euonymus* shoot N content was not affected by substrate composition whilst $H_2PO_4^{2-}$ was only slightly affected. K^+ content was highest in CF and V2 followed by C and finally by V1. The content in this mineral increased in V1, decreased in C and did not change in V2 when these materials were mixed with CF. Ca^{2+} and Mg^{2+} contents were highest in V2 followed by CF, C and V1 in that order. These nutrients increased their content in V1 and decreased it in C as the materials were mixed with CF. In the case of V2 the content of Ca^{2+} increased whilst that of Mg^{2+} decreased when mixed with CF.

Lavandula shoots contained more N when grown in C, V1 and V2 than when grown in CF. Mixing the ma-

Table 2. Selected parameters showing rooting and growth of cuttings of *E. japonicus* 'Microphylla' and *L. angustifolia* 'Munstead' grown on different compost and vermicompost-based substrates

Rooting media[1]	Rooted cuttings (%)	Shoot		Root		
		Dry weight (mg/cutting)	Length (cm)	Dry weight (mg/cutting)	Length (cm)	Root size-VR[2] score
Euonymus japonicus 'Microphylla'						
C-1	30^{c}	166^{f}	5.0^{g}	41^{g}	3.7^{e}	1^{c}
C-2	61^{b}	189^{e}	6.9^{f}	62^{f}	5.7^{d}	3^{b}
C-3	90^{a}	332^{d}	8.1^{e}	84^{e}	6.0^{cd}	3^{b}
C-4	96^{a}	434^{ab}	10.9^{bc}	103^{c}	6.9^{b}	4^{a}
V1-1	94^{a}	388^{c}	11.0^{bc}	104^{c}	5.5^{d}	3^{b}
V1-2	98^{a}	446^{ab}	11.1^{abc}	119^{a}	6.0^{cd}	3^{b}
V1-3	97^{a}	454^{a}	10.9^{bc}	114^{ab}	6.4^{bc}	4^{a}
V1-4	97^{a}	415^{b}	10.1^{d}	109^{bc}	6.6^{bc}	4^{a}
V2-1	96^{a}	394^{c}	10.4^{cd}	117^{ab}	6.4^{bc}	3^{b}
V2-2	100^{a}	420^{b}	11.3^{ab}	97^{d}	6.0^{cd}	3^{b}
V2-3	99^{a}	386^{c}	10.7^{bcd}	87^{e}	6.4^{bc}	3^{b}
V2-4	98^{a}	441^{ab}	11.4^{a}	113^{ab}	6.5^{bc}	3^{b}
Control	100^{a}	392^{c}	10.7^{bcd}	115^{ab}	7.7^{a}	4^{a}
p[3]	***	***	***	***	***	***
Lavandula angustifolia 'Munstead'						
C-1	15^{c}	154^{j}	6.7^{g}	29^{f}	6.0^{e}	1^{d}
C-2	68^{b}	204^{i}	8.5^{f}	56^{d}	6.8^{d}	2^{c}
C-3	97^{a}	228^{h}	9.6^{e}	47^{e}	9.6^{c}	2^{c}
C-4	100^{a}	320^{e}	13.8^{c}	82^{b}	10.6^{bc}	3^{b}
V1-1	100^{a}	459^{b}	16.6^{a}	80^{b}	9.9^{c}	3^{b}
V1-2	100^{a}	422^{c}	13.9^{c}	86^{b}	10.0^{c}	3^{b}
V1-3	99^{a}	355^{d}	14.4^{bc}	68^{c}	10.2^{c}	3^{b}
V1-4	100^{a}	287^{fg}	10.8^{d}	71^{c}	10.6^{bc}	3^{b}
V2-1	100^{a}	491^{a}	16.1^{a}	85^{b}	10.1^{c}	3^{b}
V2-2	100^{a}	302^{ef}	14.9^{b}	100^{a}	10.4^{bc}	3^{b}
V2-3	100^{a}	271^{g}	14.4^{bc}	66^{c}	11.4^{b}	3^{b}
V2-4	100^{a}	231^{h}	14.5^{bc}	87^{b}	10.6^{bc}	3^{b}
Control	100^{a}	340^{d}	10.8^{d}	90^{b}	12.1^{a}	5^{a}
p	***	***	***	***	***	***

[1] See Table 1 [2] VR: visual rating. [3] *** Indicate significant at $p \leq 0.001$. Values with different letters in columns differ at $p \leq 0.05$ (Student-Newman-Keuls test).

terials with CF did not generally cause significant effects. Phosphate content in shoots was similar for all materials and mixes with the exception of V1, V2 and the 25%:75% V1:CF mix. Potassium content was higher in shoots of plants grown in C, V1 and V2 than in CF and it decreased for the three materials when they were mixed with CF. Calcium shoot content was higher in V1 than in V2 and C, and similar to CF. It decreased for C and V1 when mixed with a high proportion (75%) of CF and increased for V2 when mixed with a small proportion (25%) of CF. The content of Mg^{2+} was highest in shoots of plants grown in V1 followed by those in C, CF and finally in V2. The concentration of this element decreased in shoots growing on C and V1 mixes and increased in shoots growing on V2 mixes as the proportion of CF in the mix increased. Iron content was largest in pure C and decreased with dilution. It was lower in V1 and V2 than in control and whilst it remained constant in V1 it increased in V2 with dilution.

Discussion

Composting and vermicomposting are two aerobic bio-oxidative processes which differ in some relevant aspects affecting the rate at which the organic matter

Table 3. Main effects of the substrates (material: C, V1 and V2; and mix: with coconut fiber) on rooting and growth of *Euonymus japonicus* 'Microphylla' and *Lavandula angustifolia* 'Munstead'

	Euonymus japonicus						***Lavandula angustifolia***					
		Shoot		**Root**				**Shoot**		**Root**		
	Rooted cuttings (%)	**Dry weight (mg/cutting)**	**Length (cm)**	**Dry weight (mg/cutting)**	**Legth (cm)**	**Root size-VR[1] score**	**Rooted cuttings**	**Dry weight (mg/cutting)**	**Length (cm)**	**Dry weight (mg/cutting)**	**Length (cm)**	**Root size-VR score**
Material[2]												
C	70^{b}	280^{c}	7.7^{c}	73^{c}	5.6^{b}	3	70^{b}	227^{c}	9.7^{c}	54^{c}	8.3^{c}	2^{b}
V1	97^{a}	427^{a}	10.8^{b}	111^{a}	6.1^{a}	3	100^{a}	381^{a}	13.9^{b}	76^{b}	10.1^{b}	3^{a}
V2	98^{a}	411^{b}	11.1^{a}	103^{b}	6.3^{a}	3	100^{a}	328^{b}	15.0^{a}	85^{a}	10.6^{a}	3^{a}
p[3]	***	***	***	***	***	ns	***	***	***	***	***	***
Mix[4]												
1	74^{c}	316^{d}	8.8^{c}	87^{c}	5.2^{d}	2^{c}	71^{c}	368^{a}	13.1^{a}	65^{b}	8.6^{c}	3
2	86^{b}	352^{c}	9.8^{b}	93^{b}	5.9^{c}	3^{b}	89^{b}	309^{b}	12.4^{b}	81^{a}	9.1^{b}	3
3	95^{a}	394^{b}	9.9^{b}	95^{b}	6.3^{b}	3^{b}	99^{a}	285^{c}	12.8^{ab}	61^{b}	10.4^{a}	3
4	97^{a}	430^{a}	10.9^{a}	108^{a}	6.7^{a}	4^{a}	100^{a}	279^{c}	13.0^{a}	80^{a}	10.7^{a}	3
p	***	***	***	***	***	***	***	***	**	***	***	ns
Interaction A ×B												
p	***	***	***	***	***	**	***	***	***	***	***	**

[1] VR: visual rating. [2] C: composted material; V1: vermicompost produced on pre-composted material; V2: straight vermicomposted material. [3] ns, ** and *** indicate significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively . Values with different letters in columns differ at $p \leq 0.05$ (Student-Newman-Keuls test). [4] Proportion (v/v) of compost or vermicompost to coconut fibre in the mix: 1 = 100/0; 2 = 75/25; 3 = 50/50; 4 = 25/75; Control = 0/100.

is transformed, the quality of the final products obtained, compost and vermicompost and their potential uses (Fornes *et al.*, 2012).

For cutting propagation the rooting medium is of paramount importance. Apart from holding the cutting in place the medium has to provide the correct degree of moisture to the cutting base whilst permitting aeration (Hartmann *et al.*, 2010). Some physical adequate ranges (AR) have been suggested for rooting media: bulk density (D_B) between 300 and 800 kg m^{-3}, air volume between 15 and 40% (ideally 20-25%) and water holding capacity between 20-60% (Maronek *et al.*, 1985). Our results showed that most of the substrates assayed did not fulfil these AR (Table 1). For compost C and vermicomposts V1 and V2 D_B falls within range but for coir fibre (CF) D_B was markedly low and all the mixes prepared from C, V1 and V2 with CF fell short of range. Aeration was adequate only for the pure compost and vermicomposts and it was too high for the C and V1 mixes, and especially for CF. According to these AR, CF showed the worst physical properties for cutting rooting purposes. Nevertheless, coir fibre has been proposed as a good component for rooting media (Matysiak & Nowak, 2008) and our experiments showed maximum (100%) rooting percentage in the CF substrate (Table 2). Moreover, when we studied the dependence of the rooting percentage on the physical properties of the substrate we did not find any significant correlation (data not shown).

Since adventitious root formation and growth is a prerequisite to successful cutting propagation the physicochemical and chemical environment surrounding the cutting base is also relevant. For these characteristics some AR for good quality rooting media have also been suggested: pH should be between 4.5 and 6.5 and soluble salt content between 400 and 1000 mg L^{-1} in a 1:2 (v:v) medium: water extract (Maronek *et al.*, 1985). The suggested AR values for salt content are equivalent to EC values of 5 to 20 mS m^{-1} for the 1:5 (v:v) extract (adapted from Ansorena, 1994) carried out in this study. Our results showed that all the assayed substrates were markedly alkaline and saline —mainly those produced with C (pH = 8.5-8.9; EC = 116-285 mS m^{-1}) compared to the control of CF (pH = 6.8; EC = 21 mS m^{-1})—. Nevertheless, high EC seems to be the only responsible for the reduction in rooting percentage observed in the compost-based substrates as suggested by the strong correlation between EC or the main ions contributing to EC, and rooting (Fig. 1) and by the lack of correlation between pH and rooting (data not shown) for the two species studied. Similar results were found by Iglesias-Díaz *et al.* (2009) in relation to the use of gorse composts as rooting media for the propagation of *Thuja plicata*. From the regression curves (Fig. 1) it seems that *E. japonicus* and *L. angustifolia* were relatively tolerant to salinity since the EC value from which growth started to decline was 100 mS m^{-1}.

After adventitious root initiation, root and shoot growth must follow to assure cutting survival. At this stage of the propagation process substrate physical and chemical requirements might be different from those at the rooting stage. When compared to the recommended range for the use as soilless growing media for containerized plant production (Bunt, 1988; Carmona & Abad, 2007), both bulk density (AR < 400 kg m^{-3}) and particle density (AR = 1,450-2,650 kg m^{-3}) of all the materials and mixes were acceptable, though CF was markedly lighter than C, V1 and V2 (Table 1). The lightness of CF is an advantage for it facilitates the transport of the rooting trays in the nurseries. Total porosity was below adequate range (> 85%) in C, V1 and V2 whilst it was within range in CF. While air volume and water volume of both vermicomposts were close to the lower limit of the AR (20-30%) or within AR (52-68%), respectively, aeration of C and CF were excessive and water-holding capacity was too low for C and close to AR for CF. All the materials and mixes showed shrinkage values within adequate range (< 35%), C being the one with the lowest value. Nevertheless, independently of the suggested AR our results indicate that plant performance (root and shoot growth) did not correlate with the physical properties of the substrate (data not shown). The factors negatively affecting plant growth were EC and K^+, SO_4^{2-} and Na^+ concentrations in the substrate. However, a highly significant correlation between these parameters and plant growth was only found for *E. japonicus* 'Microphylla' (Fig. 2).

Plant growth is supported by the available nutrients in the medium and plant nutritional status reflects this availability. In our experiments no mineral fertilizer was added and plant nutrition relied on the nutrients supplied by the materials constituting the substrates. Of these materials V1, V2 and particularly C had large content of K^+, Ca^{2+} and Mg^{2+} but not of N_{min} and $H_2PO_4^{2-}$ whilst CF was poor in all the elements. According to this and based on the sufficiency range (SR) for plant nutrient content (Mills & Jones, 1996) nitrogen and phophorous contents fell below range (N-SR = 1-6%; P-SR = 0.2-0.5%) in the two shrubs. The SR for potassium is 1.5-4%, thus, the rooted cuttings of *Lavandula* were within range in all mixes whereas the *Euonymus*' ones were below SR in 50%:50% C:CF, 25%:75% C:CF and 100%:0% V1:CF mixes. With respect to calcium the SR ranges from 0.5 to 1.5% and its content was above range for all mixes and species in the experiment. Magnesium content was within or above SR (0.15-0.4%) in all cases. These results suggest that an exogenous addition of nitrogen and phosphorous is needed to improve plant growth. Nevertheless, at least for the initial stages of plant growth once the cuttings had rooted, we did not find any significant correlation between root and shoot biomass and the initial nutrient content in substrates (data not shown). Moreover, a sensible practice in the case of the compost would be to leach the excess K^+, SO_4^{2-} and Na^+ before fertilizing with nitrogen or phosphorous in order to decrease its EC, as previously indicated by Fornes *et al.* (2010).

Thus, as a summary, the presented data indicated the following: (i) for rooting cuttings of *Eounymus* and *Lavandula* the physico-chemical characteristics (EC and ion contents) of the substrates were much more relevant than their physical properties; (ii) the initial growth of roots and shoots of cuttings was also more affected by the EC and the salinizing ions in the substrates than by their physical properties; (iii) vermicomposts were adequate materials for rooting cuttings and could be present at large proportions in the rooting media whilst compost had too high an EC to be considered adequate for this purpose and it could exclusively be considered for rooting media at low proportions.

Acknowledgements

Authors are deeply grateful to Dr. María José López and Dr. Raquel Melgar for supervising the composting and vermicomposting procedures. This study was funded by the Instituto Nacional de Investigación y Tecnología Agraria (INIA) of the Spanish Ministerio de Ciencia e Innovación (Project Reference RTA2006-00008-C02-02).

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