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Effects of vermicompost as a potting amendment of two commercially-grown ornamental plant species

C. Lazcano[1]* and J. Dominguez[2]

[1] *Centro Tecnológico del Mar-Fundación CETMAR. C/ Eduardo Cabello, s/n. 36208 Bouzas (Vigo). Spain*
[2] *Departamento de Ecología y Biología Animal. Universidad de Vigo. 36310 Vigo. Spain*

Abstract

We evaluated the feasibility of incorporating vermicompost as a potting amendment into a commercial ornamental production system. Pansies (*Viola × wittrockiana* subsp. Delta) and primulas (*Primula acaulis* subsp. Oriental) were grown in peat-based conventional greenhouse medium substituted with 5%, 15% and 25% (v/v) commercial and pig slurry vermicompost. Vegetative growth and flowering were evaluated and compared to plants grown with 0% vermicompost. We observed a general reduction of growth in both species with increasing concentrations of commercial and pig slurry vermicompost. The highest percentage of vermicompost (25%) showed 20% of plant mortality, high levels of stress and damage to the photosynthetic apparatus, as well as a significant reduction in the number and biomass of leaves and in flower production. Most likely, the increase in electrical conductivity and pH interacted synergistically with the decrease in air space produced after the application of vermicompost and were magnified under sub-irrigation, causing the observed effects on plant growth. Therefore the cultivation system must be taken into account when incorporating vermicompost as a growing media constituent in commercial conditions.

Additional key words: commercial cultivation; ornamental plants; soilless potting media; subirrigation.

Resumen

Efectos del vermicompost como enmienda en el sustrato de cultivo de dos especies de planta ornamental cultivadas en condiciones comerciales

En este trabajo, se evaluó la posible incorporación de vermicompost como enmienda de cultivo en un sistema comercial de producción de planta ornamental. Se cultivaron dos especies, pensamientos (*Viola × wittrockiana* subsp. Delta) y prímulas (*Primula acaulis* subsp. Oriental), empleando un sustrato de cultivo convencional a base de turba reemplazado con proporciones crecientes (5%, 15% y 25% v/v) de vermicompost comercial y vermicompost de purín de cerdo. Se compararon el crecimiento vegetativo y la floración de las plantas cultivadas con vermicompost con el de plantas cultivadas sin vermicompost. Se observó una reducción generalizada del crecimiento en ambas especies con la adición de proporciones crecientes de vermicompost. La dosis más alta (25%) produjo una mortalidad del 20%, elevados niveles de estrés y daño del aparato fotosintético así como una reducción significativa en el número y biomasa de las hojas y en la producción de flores en ambas especies. Posiblemente el incremento en la conductividad eléctrica, pH y disminución en el volumen de aire de las macetas tras la adición de vermicompost interaccionaron de forma sinérgica y se vieron magnificados por el sistema de subirrigación empleado, causando los efectos observados en las plantas. El sistema de cultivo debe ser por lo tanto tenido en cuenta a la hora de incorporar vermicompost a los sistemas convencionales de producción comercial, siendo necesaria su adaptación con el fin de obtener el máximo rendimiento de este tipo de enmienda orgánica.

Palabras clave adicionales: cultivo comercial; plantas ornamentales; subirrigación; sustrato artificial de cultivo.

Introduction

The increasing concern in environmental issues such as soil degradation and waste recycling, together with society's demands for more environmentally-friendly plant and food production systems, has led in recent years to a significant increase in the use of organic amendments in agriculture. This has contributed to a

* Corresponding author: clazcano@cetmar.org; cristina@uvigo.es
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Abbreviations used: EC (electrical conductivity), F_M (maximal fluorescence), Fv (variable fluorescence), PEA (plant efficiency analyzer).

parallel increase in scientific research about the impacts of these amendments both on the soil and the plant. Although most of this research has been focused on the impacts of some widely-known organic amendments such as animal manures, green manures and compost, research into other alternative organic amendments such as vermicompost is gaining importance (Edwards *et al.*, 2004).

Vermicompost is a nutrient-rich, microbiologically-active organic amendment which results from the interactions between earthworms and microorganisms in the breakdown of organic matter. It is a stabilized, finely divided peat-like material with a low C:N ratio and high porosity and water-holding capacity that contains most nutrients in forms that are readily taken up by plants (Domínguez, 2004). Incorporation of vermicompost has been shown to influence also the physical properties of plant growing substrates (Kahsnitz, 1992; Hidalgo and Harkess, 2002; Hidalgo *et al.*, 2006). Moreover, previous pot and field trials carried out with tomato (*Solanum lycopersicum*) and marigold (*Tagetes patula*) seedlings, showed that when enough mineral fertilizers were supplied, vermicompost produced significant positive effects on plant growth and yield at relatively low proportions (up to 20% of the growing media), therefore suggesting the existence of non-nutrient mediated mechanisms of plant growth promotion (see revision by Edwards *et al.*, 2004).

Mixing of the plant-growing media with this microbiologically active organic amendment could influence plant growth through the increase of enzymatic activity (*i.e.* dehydrogenase activity) (Arancon *et al.*, 2006), the inhibition or reduction of plant diseases (Szczech, 1999; Szcech and Smolinska, 2001) and the production of plant-growth regulating substances. In this sense several studies have reported some kind of hormone-like activity of vermicompost (Krishnamoorthy and Vajranabhiah, 1986; Tomati *et al.*, 1988; El Harti *et al.*, 2001; Atiyeh *et al.*, 2002). Canellas *et al.* (2002) and Quaggiotti *et al.* (2004) reported the presence of certain plant hormones such as indoleacetic acid adsorbed into the low- weight humic substances extracted from earthworm faeces.

Ornamental plant production constitutes an important part of the horticultural sector in Spain as well as in other southern European countries due to their special climatic conditions. Recently there has been an increasing pressure on horticultural producers to increase water and nutrient use efficiency due to environmental concerns, and organic amendments are starting to be considered in conventional horticultural practices (Marfá *et al.*, 2002). Atiyeh *et al.* (2002) and Arancon *et al.* (2008) studied the effects of vermicompost incorporation in the potting media of two ornamental plants, marigolds and petunias. They reported that vermicompost increased significantly the growth of both species and that vermicompost incorporation up to 40% produced significant increases in the number of flowers per plant, the most important feature in the production of ornamentals. Both authors suggested the existence of biologically mediated plant growth regulating mechanisms.

Therefore, it would appear that the addition of small amounts of vermicompost into the potting substrates, would allow the commercial ornamental growers to easily increase both the production and quality of their crops. However, most of the previously reported effects have been observed under laboratory conditions where the cultivation system is adapted specifically for vermicompost incorporation; the plant growth promoting effects of vermicompost have seldom been tested under commercial conditions.

Here, we tested the effects of vermicompost under real and specific conditions; we hypothesized that vermicompost could have a significant effect on ornamental plant production under commercial conditions, increasing plant growth and flower production. According to this, we evaluated the feasibility of incorporating vermicompost into the potting media of commercially-grown pansies (*Viola wittrockiana* Delta) and primulas (*Primula acaulis* Oriental). In addition, we hypothesized that the effects of vermicompost could vary depending on the parent waste material and production process, for this reason two types of vermicompost were studied.

Material and methods

Substrates assayed

Two types of vermicompost were assayed: (i) Commercial vermicompost produced by Ecocelta S.L. and obtained from a mixture of different agricultural wastes processed by the earthworm species *Eisenia* sp.; and (ii) a vermicompost obtained from pig slurry in continuous feed vermireactors with *Eisenia fetida* at the facilities of the University of Vigo as described in Aira *et al.* (2007). These vermicomposts were mixed with peat-based greenhouse growing medium, which

Table 1. Physicochemical characteristics of the pig slurry vermicompost, commercial vermicompost and peat-based greenhouse medium (means ± standard error, $n = 5$)

	Pig slurry vermicompost	Commercial vermicompost	Greenhouse medium
Organic matter (%)	57.65 ± 0.59	60.10 ± 0.96	49.22 ± 0.83
pH	5.64 ± 0.02	8.42 ± 0.05	6.87 ± 0.03
EC ($mS \cdot cm^{-1}$)	0.82 ± 0.06	0.94 ± 0.02	0.34 ± 0.01
$N\text{-}NH_4^+$ (μg gdw^{-1})	558 ± 60	82 ± 17	1,504 ± 48
$N\text{-}NO_3^-$ (μg gdw^{-1})	1,704 ± 225	1,294 ± 37	516 ± 22
Total N (%)	3.01 ± 0.02	2.14 ± 0.01	0.75 ± 0.03
P_2O_5 (%)	9.41 ± 0.14	5.54 ± 0.37	0.74 ± 0.05
K_2O (%)	1.18 ± 0.01	4.25 ± 0.34	2.67 ± 0.15
Fe_2O_3 (%)	0.95 ± 0.02	0.64 ± 0.06	3.01 ± 0.23
Cl^- (%)	0.41 ± 0.01	1.26 ± 0.11	0.12 ± 0.01

consisted of peat amended with vermiculite (1 L m^{-3}) and Osmoform® solid fertilizer (1 kg m^{-3}), to obtain the different proportions assayed: 0, 5, 15 and 25% of vermicompost (v/v). All the proportions were prepared in plastic containers and thoroughly mixed before their incorporation into the plastic pots. The main physicochemical features of the vermicomposts and the peat-based greenhouse media are summarized in Table 1.

Experimental setup

The experiment was carried out in the facilities of Agritomsa, a commercial greenhouse in Pontevedra (Galicia, Spain). Pre-germinated seedlings of pansy (*Viola* × *wittrockiana* subsp. Delta) and primula (*Primula acaulis* subsp. Oriental) were transferred into 500 mL pots containing peat-based greenhouse medium amended with a volume of 0, 5, 15 or 25% of either commercial or pig slurry vermicompost. There were 5 replicates for each proportion. Pots were arranged in subirrigated benches in the greenhouse following a complete randomized design for primulas and a randomized block design for pansies.

A continuous pesticide treatment was applied to the plants from their sowing, when they were watered with a solution containing 0.53 mL L^{-1} of Proplant®, a systemic fungicide against *Pythium* and *Phytophtora* sp. After that, the plants were fumigated weekly with different pesticides (Switch® IPPON 55 SC®, Endosulfán®) in order to avoid the appearance of resistant strains. Fertilizers were also supplied to avoid nutrient limitations. All the treatments were regularly watered and fertilized twice a week with N:P:K 18:18:18 (8 g L^{-1}) until flowering, and 15:5:30 (40 g L^{-1}) from flowering until harvest, approximately one month before. Both solutions contained macro and micronutrients essential for plant growth. The electrical conductivity (EC) of the fertilizing solutions was regularly controlled and maintained between 1-1.5 mS cm^{-1}.

Plant analysis

Pansies and primulas were harvested and transported to the laboratory 56 and 117 days respectively after sowing, at their marketable stage. Chlorophyll fluorescence (*i.e.* F_V: variable fluorescence and F_M: maximal fluorescence) was measured *in vivo* using a Plant Efficiency Analyser (PEA) (Hansatech Instruments Ltd. Pentney, Norfolk, England). The plants were then removed from their pots and separated into root and shoot portions. The roots were separated from the substrate and carefully washed. The number of leaves and flowers per plant as well as the fresh weight of roots, shoots, leaves and flowers were recorded. Dry weigh was assessed after 8 days of oven drying at 60°C.

Substrate analysis

The EC and pH of the pure substrates and substrate mixtures were determined in water diluted samples (1:20). Inorganic nitrogen ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) was determined in 0.5 M K_2SO_4 extracts of the substrates (1:10 weight:volume) using the modified indophenol blue technique (Sims *et al.*, 1995), with a Bio-Rad Microplate Reader 550. Total N was determined on dried and ball milled subsamples by macro analysis on a CHNS-O EA-1108 analyzer; concentrations of P_2O_5,

K_2O, Fe_2O_3, Cl^-, and Na_2O were determined by X-ray fluorescence spectrometry on dried and ball milled subsamples. Bulk density, total air space per pot and water holding capacity were determined in the substrate mixtures according to the test methods for the examination of composting and compost (Thompson, 2002).

Statistical analysis

The data were analyzed using two-way ANOVA for primulas with dose and type of vermicompost as fixed factors. Data from the pansies were analyzed by a linear mixed model with dose and type of vermicompost as fixed factors and position (*x* and *y* coordinates) within blocks as subject factor. Significant differences were further analyzed with Sidak and HSD Tukey post-hoc tests for pansies and primulas respectively. The statistical analyses were carried out using the SPSS 14.0 software program.

Results

Effects of the vermicomposts on the physical and chemical properties of the potting media

The addition of the different doses of vermicompost affected significantly the pH of the potting media, but the effects were different depending on the type of vermicompost used (Table 2). Increasing amounts of commercial vermicompost produced higher pH values, while pH decreased with increasing amounts of pig slurry vermicompost (Table 3). The EC of the potting media increased significantly with vermicompost addition independently of the type of vermicompost considered (Table 2). Conductivity values were significantly higher with pig slurry vermicompost than with commercial vermicompost (Table 3).

The incorporation of vermicompost influenced also the bulk density of the substrates, independently of the source of vermicompost used (Table 2). Bulk density decreased with the addition of increasing proportions of vermicompost; however, there were no differences between different doses of the two vermicompost types (Table 3). The air space of the different potting mixtures was also significantly affected by the addition of vermicompost (Table 2), although the effects differed according to the two types of vermicompost used. The air space in the pots was significantly lower with commercial than with pig slurry vermicompost and this variable decreased proportionally with the incorporation of increasing amounts of commercial vermicompost (Table 3). On the contrary, with pig slurry vermicompost air space decreased only in pots with a proportion of 15% as compared with the control without vermicompost (Table 3).

The addition of vermicompost influenced the water-holding capacity of the potting substrates (Table 2) although this depended on the type of vermicompost considered. While commercial vermicompost significantly increased the water-holding capacity of the pots, the pig slurry vermicompost did not influence this variable significantly (Table 3).

Table 2. ANOVA results of the effect of the type of vermicompost and dose applied on the physichochemical properties of the potting media

	Type of vermicompost		Dose		Type of vermicompost × Dose	
	F	*p*	F	*p*	F	*p*
pH	1,318.00	<0.01	15.90	<0.01	186.50	<0.01
EC (mS cm^{-1})	22.34	<0.01	178.68	<0.01	2.60	<0.01
Bulk density (g cm^{-3})	4.94	<0.04	8.35	<0.01	0.62	0.64
Air space (mL pot^{-1})	66.58	<0.01	36.12	<0.01	23.58	<0.01
Water holding capacity (% w w^{-1})	44.94	<0.01	14.24	<0.01	18.98	<0.01
N-NH_4^+ (µg gdw^{-1})	0.10	0.75	55.59	<0.01	27.91	<0.01
N-NO_3^- (µg gdw^{-1})	107.61	<0.01	35.56	<0.01	12.02	<0.01
Total N (%)	35.11	<0.01	185.59	<0.01	6.79	<0.01
P_2O_5 (%)	135.87	<0.01	201.44	<0.01	17.49	<0.01
K_2O (%)	343.37	<0.01	2.70	0.04	51.58	<0.01
Fe_2O_3 (%)	0.90	0.34	57.72	<0.01	1.31	0.28
Cl (%)	960.95	<0.01	456.38	<0.01	168.08	<0.01
Na_2O (%)	1,191.24	<0.01	369.89	<0.01	226.50	<0.01

Table 3. Main physical and chemical characteristics of the peat-based greenhouse medium substituted with different proportions of commercial (CV) and pig slurry vermicompost (PSV). Different letters indicate significant differences at $p < 0.05$

	0%	5%		15%		25%	
		CV	PSV	CV	PSV	CV	PSV
pH	6.80 ± 0.03^{c}	6.80 ± 0.06^{c}	6.50 ± 0.02^{e}	7.20 ± 0.03^{b}	6.30 ± 0.00^{d}	7.50 ± 0.02^{a}	6.10 ± 0.02^{d}
EC (mS cm^{-1})	0.33 ± 0.01^{d}	0.43 ± 0.02^{c}	0.47 ± 0.01^{c}	0.53 ± 0.02^{b}	0.61 ± 0.01^{b}	0.61 ± 0.01^{a}	0.66 ± 0.03^{a}
Bulk density (g cm^{-3})	0.19 ± 0.00^{a}	0.16 ± 0.01^{b}	0.15 ± 0.01^{b}	0.17 ± 0.02^{b}	0.16 ± 0.00^{b}	0.16 ± 0.00^{cb}	0.15 ± 0.00^{b}
Air space (mL pot^{-1})	108.00 ± 4.83^{ab}	96.70 ± 8.90^{abc}	109.00 ± 4.25^{a}	78.35 ± 4.10^{c}	78.00 ± 3.81^{c}	55.50 ± 1.17^{c}	85.00 ± 3.00^{bc}
Water holding capacity (% w w^{-1})	57.77 ± 0.91^{c}	62.62 ± 1.94^{bc}	61.97 ± 1.34^{bc}	64.95 ± 2.32^{abc}	63.38 ± 1.12^{abc}	69.86 ± 0.09^{a}	63.59 ± 0.53^{abc}
N-NH_4^+ (µg gdw^{-1})	$1,505 \pm 48^{c}$	$2,405 \pm 143^{a}$	$2,059 \pm 24^{b}$	$2,151 \pm 107^{ab}$	$1,575 \pm 70^{c}$	$1,548 \pm 50^{c}$	$1,708 \pm 36^{c}$
N-NO_3^- (µg gdw^{-1})	516 ± 22^{e}	517 ± 76^{e}	982 ± 83^{cde}	521 ± 87^{e}	$1,437 \pm 238^{bc}$	796 ± 38^{de}	$2,208 \pm 134^{a}$
Total N (%)	0.75 ± 0.02^{e}	0.96 ± 0.03^{de}	0.99 ± 0.02^{d}	1.15 ± 0.02^{cd}	1.31 ± 0.03^{bc}	1.27 ± 0.02^{c}	1.51 ± 0.06^{ab}
P_2O_5 (%)	0.74 ± 0.05^{d}	0.96 ± 0.01^{cd}	1.36 ± 0.05^{bcd}	1.55 ± 0.04^{bc}	2.93 ± 0.17^{a}	1.80 ± 0.05^{b}	3.33 ± 0.20^{a}
K_2O (%)	2.67 ± 0.15^{b}	2.75 ± 0.03^{b}	2.16 ± 0.07^{c}	3.03 ± 0.03^{ab}	2.17 ± 0.04^{c}	3.18 ± 0.06^{a}	2.03 ± 0.06^{c}
Fe_2O_3 (%)	3.00 ± 0.21^{a}	2.51 ± 0.07^{b}	2.30 ± 0.09^{b}	2.06 ± 0.03^{bc}	2.23 ± 0.06^{bc}	1.75 ± 0.06^{c}	2.06 ± 0.09^{c}
Cl (%)	0.12 ± 0.01^{d}	0.23 ± 0.01^{c}	0.11 ± 0.00^{d}	0.45 ± 0.01^{b}	0.22 ± 0.01^{c}	0.60 ± 0.01^{a}	0.24 ± 0.01^{c}
Na_2O (%)	0.16 ± 0.01^{cd}	0.19 ± 0.01^{c}	0.14 ± 0.01^{d}	0.32 ± 0.01^{b}	0.17 ± 0.01^{cd}	0.41 ± 0.01^{a}	0.17 ± 0.00^{cd}

The N-NH_4^+ concentration of the different potting media differed significantly depending on the amount and type of vermicompost incorporated (Table 2). The addition of 5% and 15% of commercial vermicompost increased significantly the concentration of this nutrient as compared to the concentration of the control, which was similar to the values reached after 25% vermicompost incorporation (Table 3). The addition of 5% of pig slurry vermicompost produced a significant increase in this variable as compared to the control without vermicompost, and incorporation of 15% and 25% pig slurry vermicompost (Table 3).

The addition of vermicompost to the potting media produced a significant increase of N-NO_3^- especially when pig slurry vermicompost was incorporated (Table 2). Increasing doses of pig slurry increased the amount of this nutrient and the highest concentrations were observed with 25% of pig slurry vermicompost (Table 3). The increase produced by commercial vermicompost was lower and it was only observed with 25% incorporation (Table 3).

The total N content of the substrates was increased by both types of vermicompost (Table 3); however, the total N provided with the pig slurry vermicompost was higher and this resulted in higher increases than with commercial vermicompost. The same was observed for P, measured as P_2O_5 (Table 2). A different tendency was observed for K: the addition of 25% commercial vermicompost increased slightly the concentration of K in the potting media while pig slurry vermicompost produced a stable and significant decrease as compared with the control whatever the percentage of vermicompost added (Tables 2, 3). Increasing concentrations of both vermicomposts produced a significant decrease in Fe concentration in the potting media independently of the type of vermicompost used (Table 2). Concentration of Cl^- increased with increasing proportions of vermicompost particularly with commercial vermicompost (Tables 2, 3) and Na_2O increased significantly after the addition of commercial vermicompost to the potting media, while no changes were observed in this variable with pig slurry vermicompost (Tables 2, 3).

Effects of the vermicompost on plant growth

Increasing doses of vermicompost added to the potting media of pansies significantly influenced the aerial biomass of the plants independently of the type of vermicompost used (Fig. 1, Table 4). The addition of 15 and 25% of pig slurry and commercial vermicompost produced a significant reduction in plant aerial biomass as compared with 0 and 5% vermicompost. The aerial biomass of primulas was also significantly influenced by the different doses of vermicompost incorporated into the potting media and this was independent of the type of vermicompost used (Table 4). Primulas grown with 15 and 25% of vermicompost had significantly lower biomass than those with the control (0% of vermicompost) (Fig. 1).

Similarly, a reduction was found in the root biomass of pansies with increasing doses of vermicompost and

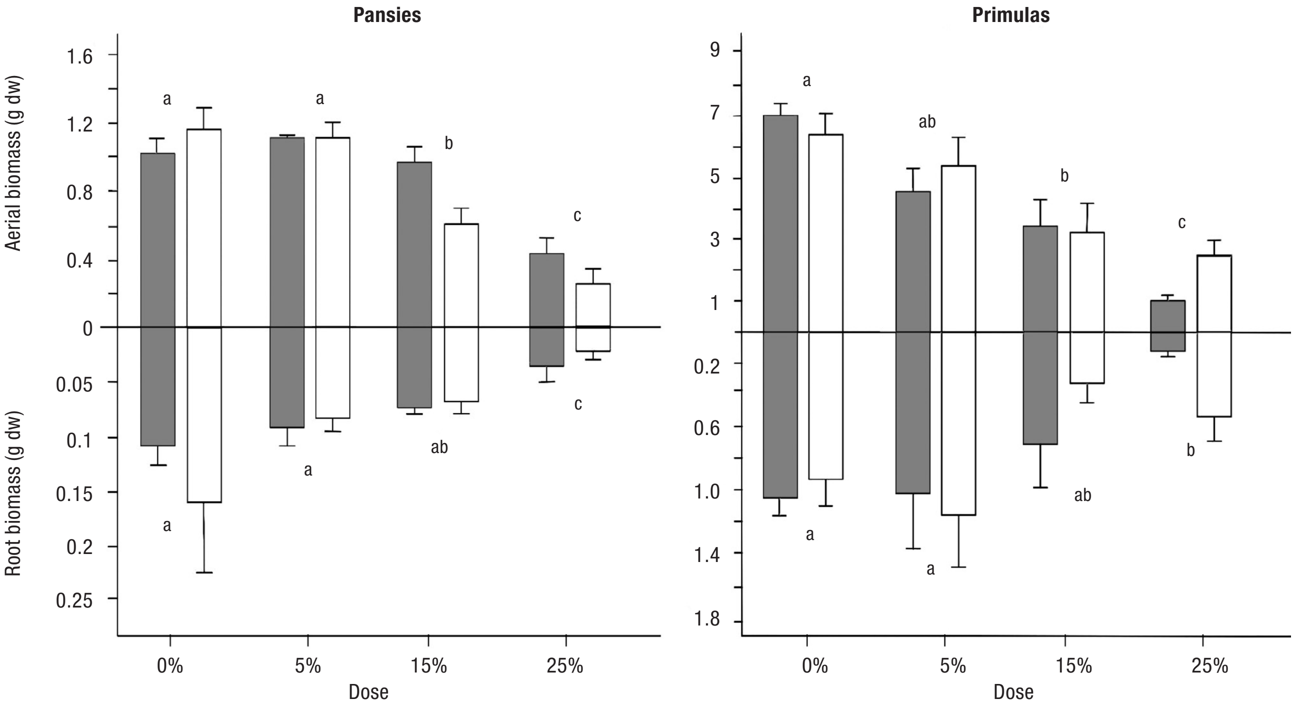

Figure 1. Aerial and root biomass (means ± standard error) of pansies and primulas amended with the different doses of pig slurry (grey bars) and commercial (white bars) vermicompost. Different letters indicate significant differences among vermicompost doses according to Sidak test at $p < 0.05$ for pansies and Tukey HSD test at $p < 0.05$ for primulas.

this was independent of the type of vermicompost employed (Table 4). The root biomass of pansies was significantly reduced by the addition of 25% of vermicompost as compared with 0% of vermicompost. In primulas, root biomass was reduced significantly by the dose of vermicompost applied independently of its type (Table 4). Significant differences were observed between 25% of vermicompost and the lowest doses (Fig. 1).

Table 4. Results of the linear mixed models and two-way ANOVA for the growth, physiological and flowering variables measured in pansies and primulas respectively

	Type of vermicompost		**Dose**		**Type of vermicompost × Dose**	
	F	***p***	**F**	***p***	**F**	***p***
Pansies						
Aerial biomass	2.12	0.15	32.30	< 0.01	2.52	0.10
Root biomass	0.06	0.81	9.19	0.01	0.30	0.82
Nº of leaves	0.52	0.48	9.40	0.02	0.28	0.83
F_V/F_M[1]	0.14	0.72	3.09	0.80	2.64	0.11
Nº flowers	0.52	0.48	5.18	0.02	1.08	0.39
Flower biomass	0.00	0.99	5.46	0.02	3.24	0.06
Primulas						
Aerial biomass	0.57	0.45	16.25	< 0.01	0.84	0.48
Root biomass	0.01	0.91	5.11	< 0.01	1.12	0.35
Nº of leaves	0.52	0.47	4.64	< 0.01	1.09	0.36
F_V/F_M[1]	1.26	0.27	4.06	0.01	2.78	0.05
Nº flowers	2.02	0.16	6.14	< 0.01	1.24	0.31
Flower biomass	1.26	0.27	5.88	< 0.01	1.21	0.32

[1] F_V/F_M: photosynthetic efficiency.

Table 5. Photosynthetic efficiency (F_V/F_M) and number of leaves of pansies grown with different doses of pig slurry vermicompost (PSV) and commercial vermicompost (CV). Means ± standard error, *n*= 5. Different letters indicate significant differences according to the Sidak test at $p < 0.05$

Dose	F_V/F_M		No. of leaves	
	PSV	CV	PSV	CV
0%	0.894 ± 0.00	0.906 ± 0.00	88.00 ± 15.40[a]	73.00 ± 8.30[a]
5%	0.903 ± 0.00	0.902 ± 0.00	81.20 ± 12.10[a]	84.60 ± 5.70[a]
15%	0.908 ± 0.00	0.906 ± 0.00	63.60 ± 5.10[a]	55.60 ± 9.10[ab]
25%	0.768 ± 0.13	0.683 ± 0.15	34.40 ± 8.40[b]	33.25 ± 12.40[b]

Parallel to the decrease in biomass, the dose of vermicompost applied affected significantly the number of leaves of pansies independently of the type of vermicompost employed (Tables 4, 5). In primulas there was also an effect of dose (Table 4) and the plants growing in 25% of vermicompost had significantly fewer leaves than the plants with 0%. Again the type of vermicompost did not influence the number of leaves and the dose-dependent change was the same for the pig slurry and the commercial vermicompost (Table 6).

Besides the observed effects on plant growth, the highest dose of vermicompost produced a decrease in the survival rate of the plants. Only 80% of the pansies growing in the potting media amended with 25% of commercial vermicompost survived and the same occurred with primulas growing in media with 25% of pig slurry vermicompost. Plant survival rate was 100% for the rest of the doses with both types of vermicompost.

Effects of the vermicomposts on plant physiology

The addition of vermicompost to the potting media did not affect the photosynthetic efficiency of pansies, expressed as the ratio between variable and maximal fluorescence (F_V/F_M) , and neither were any effects observed due to the type of vermicompost applied (Table 4). However, in the plants amended with 25% of commercial and pig slurry vermicompost F_V/F_M was below 0.832 ± 0.004, the range established as normal in plant functioning by Krause and Weis (1991) (Table 5). The photosynthetic efficiency of primulas was significantly reduced by the highest doses of vermicompost (Table 4). Plants with 25% of vermicompost showed a F_V/F_M ratio below normal, also significantly lower than in plants with 5% of vermicompost (Table 6). There was no effect of the type of vermicompost and therefore the reduction in the photosynthetic efficiency of primulas was the same for the pig slurry and commercial vermicompost (Table 4).

Effects of vermicompost on plant flowering

The addition of 25% vermicompost to the potting media of pansies reduced significantly the number of flowers produced (Fig. 2) independently of the type of vermicompost considered (Table 4). Similarly, flower biomass was also reduced by 25% vermicompost addition to pansies' potting media independently of the type of vermicompost (Table 4, Fig. 2).

Table 6. Photosynthetic efficiency (F_V/F_M) and number of leaves of primulas grown with different doses of pig slurry vermicompost (PSV) and commercial vermicompost (CV). Means ± standard error, n = 5. Different letters indicate significant differences according to the Tukey HSD test at $p < 0.05$

Dose	F_V/F_M		No. of leaves	
	PSV	CV	PSV	CV
0%	0.890 ± 0.00[ab]	0.878 ± 0.01[ab]	33.90 ± 2.50[a]	23.70 ± 3.10[a]
5%	0.891 ± 0.01[a]	0.891 ± 0.00[a]	20.90 ± 3.10[b]	21.30 ± 4.80[ab]
15%	0.862 ± 0.03[ab]	0.854 ± 0.01[ab]	13.30 ± 3.30[b]	12.20 ± 3.80[ab]
25%	0.806 ± 0.03[b]	0.876 ± 0.01[b]	16.70 ± 0.80[b]	10.50 ± 2.40[b]

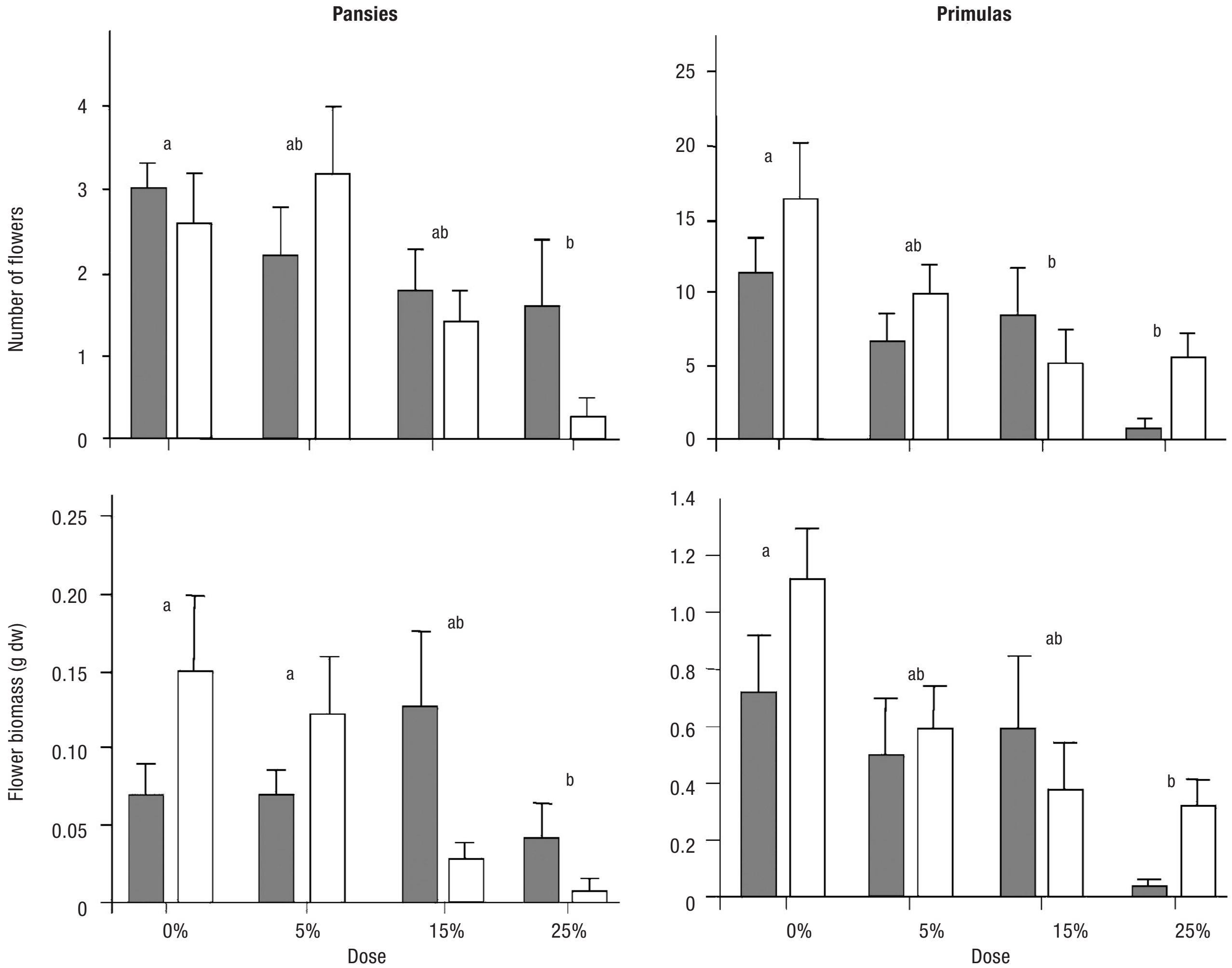

Figure 2. Number of flowers and flower biomass (means ± standard error) of pansies and primulas amended with the different doses of pig slurry (grey bars) and commercial (white bars) vermicompost. Different letters indicate significant differences among vermicompost doses according to Sidak test at $p < 0.05$ for pansies and Tukey HSD test at $p < 0.05$ for primulas.

In primulas, the dose of vermicompost had a strong effect on flower production independently of the type of vermicompost due to a significant reduction in plants amended with 25% vermicompost (Table 4, Fig. 2). Flower biomass was also significantly reduced with 25% vermicompost, and again, no effect of the type of vermicompost was found (Table 4, Fig. 2).

Discussion

Previous studies have shown that substitution of peat-based potting media by vermicompost could improve the growth and flowering of certain ornamental plants. Atiyeh *et al.* (2002) observed that vermicompost doses of 20% substitution were enough to produce a significant increase on the growth and number of flower buds of marigold plants as compared with the peat-based media and in the presence of full inorganic fertilization. Similar results were observed by Arancon *et al.* (2008) which signalled significant increases in biomass and flower production of petunias with vermicompost doses as low as 10% of the potting media. In our study, even though the plants tested were grown under optimal conditions following the recommendations for commercial production, vermicompost did not show beneficial effects on the growth of the two ornamentals assayed, either at low percentages, or at high. Furthermore, the only effects detected were negative, with 15 and 25% of vermicompost causing high damage and even mortality in the plants. The highest doses produced reductions in photosynthetic efficiency and thus, growth was significantly affected together with number and biomass of flowers, the most important plant feature in ornamental production.

The observed effects were similar for both kinds of vermicompost independently of their origin and production process suggesting some kind of general pattern in their performance. Both species of plants showed also fairly similar patterns in their response to increasing doses of vermicompost, evidencing the strength of the effect. However, a species-dependent effect was detected, since mortality was caused by different vermicompost for each plant species, which would seem to support the thesis that the effect of vermicompost on plant growth can vary greatly between plant species and even between varieties of the same species (Roberts *et al.*, 2007; Zaller, 2007).

In this study, given the fact that the plants were grown in a favorable environment regarding fertilization and phytosanitary conditions, after the addition of vermicompost we would expect either: (i) a positive effect of the vermicomposts on the growth of the two species due to enhanced microbial activity (Domínguez, 2004), together with the possible production of biologically active metabolites such as plant growth regulators (Tomati *et al.*, 1987; El Harti *et al.*, 2001) and humates (Atiyeh *et al.*, 2002; Canellas *et al.,* 2002) or (ii) an absence of effects. However, the appearance of negative effects was not expected, and it has been rarely reported in previous works.

In the absence of nutrient deficiencies and disease incidence, the main factors that could have determined a reduction in plant growth are EC, the presence of toxic ions, and changes in the physical properties of the substrates derived from vermicompost incorporation. EC is one of the most important factors affecting plant growth in soil-less media (Van Iersel, 1999) and it can be especially problematic when composted materials are incorporated (García-Gómez *et al.*, 2002). It is a critical issue in ornamental systems since it can significantly reduce flower production (Devitt and Morris, 1987). Decreased plant growth and flower production due to excess salinity in the growing media has also been reported in previous studies with vermicompost; however opposite to our study, these detrimental effects were only observed at the highest doses of vermicompost substitution [(above 60% in Atiyeh *et al*. (2002), or with 100% vermicompost in Atiyeh *et al*. (2001)] and it did not produce plant mortality in any of the cases. In our experiment, the EC of the substrates increased significantly with increasing incorporations of vermicompost even at the 5% dose and peaked at the 25% dose with both vermicomposts assayed. Even though the EC values were several orders of magnitude lower than those reported in Atiyeh *et al*. (2001), and lower than the tolerance thresholds established for this type of ornamentals (van Iersel, 1999), increases in EC were strongly correlated to decreases in plant biomass either in pansies ($r = -0.74$; $p < 0.0001$) or in primulas ($r = -0.72$; $p < 0.0001$). The cultivation system, sub-irrigation, presumably favoured an increase of the nutrients in the pots to a greater extent than the plants could assimilate, therefore increasing the EC of the pots to toxic levels, as well as the accumulation of certain toxic ions such as Na^+ and Cl. Differences in the plant sensitivity with previous studies could also be attributed to the different sensitivity to substrate salinity of the plant species assayed.

In addition, the observed reduction in the air space of the containers, especially after the application of commercial vermicompost, may have become more critical in sub-irrigation production system, since the medium at the root zone was at saturation for significant periods of time.

In summary, opposite to what we had initially predicted and to previous results shown in the literature, vermicompost did not exhibit beneficial effects on the growth and flowering of sub-irrigated pansies and primulas. Further, vermicompost produced chemically and physically-mediated negative effects which should be seriously considered by commercial growers before incorporating these substances into their productions systems. These effects were similar for the two type of vermicompost assayed differing in their production process and parent waste material, and also for the two ornamental plant species assayed. The appearance of beneficial effects of vermicompost on plant growth under commercial conditions seems to depend on the cultivation system. Under sub-irrigation, the action of factors such as increased EC and decrease in air space in the pots is magnified, causing a decrease in the number of leaves by salt accumulation, with a subsequent decrease in the production of photosynthates and growth and, at high doses, with the result of plant death (Munns, 2002). Consequently, in order to incorporate vermicompost, into sub-irrigated cultivation of pansies and primulas, fertirrigation and conventional operation processes should be revised. Further research is needed to determine whether vermicompost can have plant growth and flowering promoting effects under different commercial greenhouse cultivation systems.

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