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Compost and vermicompost as nursery pot components: effects on tomato plant growth and morphology

C. Lazcano[1]*, J. Arnold[2,3], A. Tato[1], J. G. Zaller[2,4] and J. Domínguez[1]

[1] *Departamento de Ecología y Biología Animal. Universidad de Vigo. 36310 Vigo. Spain*
[2] *Institute of Organic Agriculture. University of Bonn. 53115 Bonn. Germany*
[3] *Present address: Institute of Soil Science and Forest Nutrition. University of Göttingen. 37077 Göttingen. Germany*
[4] *Present address: Institute of Zoology. University of Natural Resources and Applied Life Sciences. 1180 Vienna. Austria*

Abstract

Post transplant success after nursery stage is strongly influenced by plant morphology. Cultural practices strongly shape plant morphology, and substrate choice is one of the most determining factors. Peat is the most often used amendment in commercial potting substrates, involving the exploitation of non-renewable resources and the degradation of highly valuable peatland ecosystems and therefore alternative substrates are required. Here the feasibility of replacing peat by compost or vermicompost for the production of tomato plants in nurseries was investigated through the study of the effect of increasing proportions of these substrates (0%, 10%, 20%, 50%, 75% and 100%) in target plant growth and morphological features, indicators of adequate post-transplant growth and yield. Compost and vermicompost showed to be adequate substrates for tomato plant growth. Total replacement of peat by vermicompost was possible while doses of compost higher than 50% caused plant mortality. Low doses of compost (10 and 20%) and high doses of vermicompost produced significant increases in aerial and root biomass of the tomato plants. In addition these treatments improved significantly plant morphology (higher number of leaves and leaf area, and increased root volume and branching). The use of compost and vermicompost constitute an attractive alternative to the use of peat in plant nurseries due to the environmental benefits involved but also due to the observed improvement in plant quality.

Additional key words: peat moss, plant nursery, soil-less substrate, *Solanum lycopersicum* L.

Resumen

Compost y vermicompost como componentes de sustratos artificiales de cultivo en viveros: efectos en el crecimiento y morfología del tomate

Tanto las prácticas de cultivo en los viveros como la elección del tipo de sustrato tienen una gran influencia sobre la morfología de las plántulas y por lo tanto en su adaptación post transplante. Aunque la turba es uno de los sustratos más utilizados en viveros, su uso conlleva la explotación de un recurso no renovable y la degradación de las turberas, por lo que se hace necesaria la búsqueda de sustratos alternativos que puedan reemplazarla total o parcialmente. En este trabajo se investigó la posibilidad de reemplazar la turba por compost o vermicompost en la producción de plántulas de tomate, mediante el estudio de los efectos de proporciones crecientes de estos sustratos (0%, 10%, 20%, 50%, 75% y 100%) en parámetros morfológicos y de crecimiento claves para la adaptación post transplante. Compost y vermicompost mostraron ser sustratos adecuados para el crecimiento de las plántulas. La sustitución total de la turba sólo fue posible con vermicompost mientras que las dosis de compost mayores que el 50% produjeron la mortalidad de las plántulas. Las dosis bajas de compost (10 y 20%) y altas de vermicompost, produjeron incrementos significativos en la biomasa aérea y radicular de las plantas. Además estas dosis mejoraron de forma significativa su morfología (número de hojas, superficie foliar, volumen y ramificación de las raíces). Compost y vermicompost constituyen alternativas atractivas al uso de turba en la producción de plántulas de tomate no sólo por sus beneficios medioambientales sino también por la mejora significativa de la calidad de las plántulas.

Palabras clave adicionales: *Solanum lycopersicum* L., sustrato artificial de cultivo, turba, vivero.

* Corresponding author: cristina@uvigo.es
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Introduction

The main goal of horticultural nurseries is to produce quality seedlings with target morphological and physiological features that guarantee crop success after transplanting. Development of an altered above- and belowground plant morphology during this stage can have consequences for plant growth and health in the field. Survival of newly-planted seedlings is largely dependent on the rapid extension of roots, which re-establish root-soil contact and absorb water to replenish water loss due to transpiration (Burdett *et al.,* 1983). Root system morphology determines the amount of soil that can be exploited by the plants and will therefore influence the uptake of nutrients and water. Similarly, an adequate development of the aerial parts of the plant will determine an efficient photosynthesis and gas exchange as well as the plant susceptibility to attacks by sucking or chewing insects (*e.g.* leaf thickness).

Increasingly, nursery stock is produced in containers due to market demands and numerous production advantages including greater production per surface unit, faster plant growth, higher plant quality, and lack of dependence on arable land. Nursery potting media usually contain substantial amounts of peat moss (*Sphagnum* spp.) since it provides adequate aeration, moisture retention and support for the seedlings (Raviv *et al.*, 1986). However the use of peat involves the exploitation of non-renewable resources and the degradation of highly valuable ecosystems like peatlands (Robertson, 1993). In many countries several restrictions have been established for the use of this material due to environmental concerns and, as a consequence, peat has become a rather scarce and expensive potting substrate. Therefore, in order to reduce costs and adopt more environmentally-friendly practices, research on alternative substrates is of great interest, and several alternatives have been proposed. The parallel increasing concern in waste recycling has lead to the proposal of some organic materials such compost-like substrates (Ostos *et al.*, 2008), as partial substitutes of peat. Compost, as a product of thermophilic processes of organic waste degradation, and vermicompost, as a mesophilic biodegradation product resulting from interactions between earthworms and microorganisms are humus-like materials which could act as suitable substitutes of peat. In addition, the higher nutrient content of compost and vermicompost as compared to peat could allow the reduction of the mineral fertilizers used reducing the expenses of the nursery operations.

Due to their different production processes, compost and vermicompost might exhibit different physical and chemical features which might influence plant growth and morphology in diverse ways. Generally, after vermicomposting the organic material is ground up to a more uniform size which gives the final substrate a characteristic earthy appearance while the resulting material after composting has normally a more heterogeneous appearance (Ndegwa and Thompson, 2001; Tognetti *et al.*, 2005). The use of compost in horticulture has shown to be occasionally limited by the high electrical conductivity and the excessively high amount of certain ions causing phytotoxicity (García-Gómez *et al.*, 2002) as a consequence of the chemical properties of the initial waste and/or inadequate operation processes. These adverse effects, although possible, are less likely to occur when vermicompost is used as potting amendment (Chaoui *et al.*, 2003). Nevertheless the most remarkable differences among compost and vermicompost are related to their biological properties. Composting and vermicomposting are two rather different biological processes which strongly condition the biological properties of the final substrate resulting in important differences among compost and vermicompost both in the bacterial community composition (Vivas *et al.*, 2009) and fungal abundance (Lazcano *et al.*, 2008) even when the same organic waste is used as a feedstock material. Considering that most of the beneficial effects of compost and vermicompost have been related to their biological properties (De Brito *et al.*, 1995; Atiyeh *et al.,* 1999; Canellas *et al.*, 2002), these differences could determine rather different effects in plant growth and morphology that need to be investigated.

In spite that several studies have addressed the effect of different types of compost (García-Gómez *et al.*, 2002; Grigatti *et al.*, 2007; Herrera *et al.*, 2008) and/or vermicompost (Edwards *et al.*, 2004; Hashemimajd *et al.*, 2004; Tognetti *et al.*, 2005) as potting or soil amendments on plant growth and yield, there are no studies concerning the effects of these two substrates in plant morphology when they are incorporated as potting substrates.

In this study the feasibility of replacing peat by compost and vermicompost for the production of tomato plants in nurseries was investigated through the study of the effect of increasing proportions of these substrates in target tomato plant growth and morphological features, good indicators of adequate post-transplant growth and yield.

Material and methods

The experiment was carried out at the University of Vigo, Spain. The growth of tomato plants in a commercial peat-based substrate (Compo Sana®Universal) composed of black peat amended with perlite, lime, slow release fertilizer and Agrosil® (a mixture of phosphates that stimulate plant rooting), was compared with the growth in the peat-based media substituted with different proportions of either compost or vermicompost. The compost was commercially produced from cow manure (Energía Viva S.A., León, Spain) and the vermicompost was produced from pig manure in continuous flow reactors with the earthworm *Eisenia fetida* (Savigny, 1826) in the facilities of the University of Vigo. The physicochemical properties of the commercial substrate, compost and vermicompost are presented in Table 1.

Tomato seeds, *Solanum lycopersicum* L. Miller cv. 'Marlglobe', were sown in cell plug trays within a cultivation chamber at 24°C. At the two-leaf stage, tomato seedlings were transplanted into pots (Ø 14 cm) that contained a mixture of commercial peat substrate and different substitutions (0%, 10%, 20%, 50%, 75% and 100% w/w) of either compost or vermicompost. Each mixture was replicated five times. Pots were kept in the cultivation chamber at 21°C, 85% humidity and a light period of 16 hours a day following a complete randomized design. In order to avoid nutrient limitations, all plants were fertilized twice a week with 50 mL of a liquid suspension containing commercial fertilizer (Compo Fertilizante Universal®), with a total content of 525 ppm of N, 375 ppm of P_2O_5 and 450 ppm of K_2O, following commercial recommendations. Tomato plants were watered with tap water when needed. All plants in the potting media containing 75% or 100% compost died within the first three days of the trial and therefore they were not included in the analyses.

Table 1. Physicochemical and biochemical characteristics of the peat-based substrate, the compost and the vermicompost used as potting media

	Peat-based substrate	Compost	Vermi-compost
Organic matter content (%)	89	61	61
pH	7.0	9.3	6.5
Conductivity (mS cm^{-1})	0.4	3.7	1.3
NH_4^+-N (µg g^{-1} dw)	270	248	297
NO_3^--N (µg g^{-1} dw)	111	48	104
P (mg L^{-1})	91	107	310
K (mg L^{-1})	305	8277	1020
Na (µg g^{-1} dw)	352	2391	484
Mg (µg g^{-1} dw)	1438	8413	5950
Cl (µg g^{-1} dw)	287	7207	723
Ca (µg g^{-1} dw)	23470	20245	25467
Fe (µg g^{-1} dw)	1599	1446	3830
Zn (µg g^{-1} dw)	24	115	688

dw: dry weight.

Before blooming, at the end of the nursery stage (10 weeks after emergence), tomato plants were harvested and their growth and biomass production assessed. The aboveground parts were clipped off at the soil surface and roots were washed carefully from the attached soil. The number of leaves per plant was counted and leaf area was determined on scanned leaves using image analysis software (WinRhizo, Régent Instruments, Toronto, Canada). Likewise, some of the main parameters describing root morphology (root volume, number of tips and forks) were determined on scanned roots of the whole radical system of each plant using the above-mentioned image analysis software. Plant biomass was determined after drying for 24 h at 60°C.

Organic matter of the initial substrates was calculated after ashing in a muffle oven for 4 h at 550°C. The pH and electrical conductivity were determined by using water diluted samples (1:20). Inorganic nitrogen (NH_4^+-N and NO_3-N) was determined in 0.5M K_2SO_4 extracts (1:10 w:v) using the modified indophenol blue technique (Sims *et al.,* 1995), with a Bio-Rad Microplate Reader 550. Available P and K were analyzed in a solution of oven dried (60°C) and ball milled subsamples with amonium bicarbonate-diethylen triaminepentaacetic acid (AB-DTPA) (1:6 w:v), using induced coupled plasma optical emission spectrometry (Soltanpour and Schwab, 1977). The content of Na, Mg, P, Cl, Ca, Fe, and Zn was determined through X-Ray fluorescence on dried and ground samples using a Siemens SRS 3000 analyzer.

The effects of the type of substrate (compost and vermicompost) and the dose within type of substrate (0, 10, 20, 50, 75, and 100%) were analyzed through ANOVA with general linear models using the software package Statistica 7.0. Significant differences were further analyzed with Fisher LSD post-hoc test. Transformations using square root (root biomass), logarithm (shoot: root ratio, root volume, root tips and root forks) and Ln(x+1) (aerial biomass) were enough to meet normality and homocedascitycty. Statistical analyses were carried out using the absolute parameter values;

nevertheless the changes in each of the measured parameters as compared to the peat based media, indicating plant response to the different amendments, are represented in the figures for a clearer graphical layout. Plant response was calculated as follows:

Plant response = (Parameter measured in the amended plant – Parameter in the peat-based media) / Parameter in the peat-based media

Results

Substitution of peat by compost or vermicompost increased the aerial biomass of the tomato plants as compared to the pure peat-based substrate. The observed increases in plant aerial biomass were different in each substrate depending on the dose (Fig. 1, ANOVA results for the effect of the dose within each substrate: $P<0.01$). Substitution of the peat-based substrate by 10 and 20% compost produced significant increases in aerial biomass, while 50% substitution did not produce any significant difference as compared to peat. Substitution of the peat-based substrate with 10, 50, 75 and 100% vermicompost resulted in significantly higher aerial biomass.

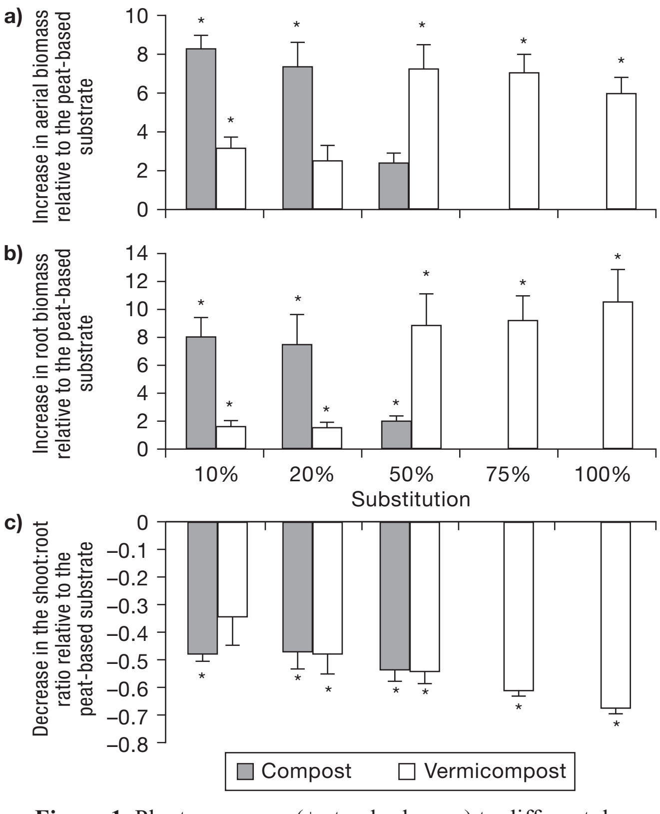

Figure 1. Plant responses (± standard error) to different doses of compost and vermicompost in aerial (a) and root (b) dry weights and shoot:root ratio (c) as compared to the commercial peat-based substrate. Asterisks indicate significant differences with the pure peat-based substrate at $P<0.05$ (Fisher LSD test). *Note:* seedlings died in substrates with 75% or 100% compost.

Addition of compost or vermicompost to the potting media of tomatoes produced significant increases in the root biomass of the plants. The effects of the doses were different depending on the substrate (Fig. 1, ANOVA results for the effect of the dose within each substrate: $P<0.01$). The highest increases in root biomass due to compost addition were observed with 10 and 20% substitution, while for vermicompost the proportions that resulted in highest root growth were 50, 75 and 100%.

Shoot:root ratio of the tomato plants was slightly decreased after substitution of the peat-based substrate by compost and vermicompost, and the observed decreases in this parameter depended on the dose of compost and vermicompost (Fig. 1, ANOVA results for the effect of the dose within each substrate: $P<0.01$). All the assayed compost substitutions produced significant decreases in shoot: root ratio, while only 20, 50, 75 and 100% vermicompost substitution reduced this parameter. For both substrates, increasing percentages lowered the shoot: root ratio of the plants, resulting in the lowest value with 100% vermicompost.

The number of leaves in each plant was significantly increased by compost and vermicompost substitution as compared to pure peat-based substrate, although increases in this parameter depended on the dose applied (Fig. 2a, ANOVA results for the effect of the dose within each substrate: $P<0.01$). Substitution of peat by the lowest proportions of compost (10, and 20%) produced the highest number of leaves per plant as compared to 50% substitution. All the proportions of vermicompost increased the number of leaves per plant as compared the pure peat-based substrate, although the highest values in this parameter were observed with 50% substitution.

The use of different doses of compost and vermicompost in the growing media, influenced significantly the leaf area of the tomato plants (Fig. 2b, ANOVA results for the effect of the dose within each substrate: $P<0.01$). Substitution of peat by low doses of compost (10 and 20%) produced significant increases in the leaf area of the plants as compared to the pure peat-based substrate, and a slight decrease in this parameter was observed with the highest dose of compost (50%) although this was not significant. Substitution of peat

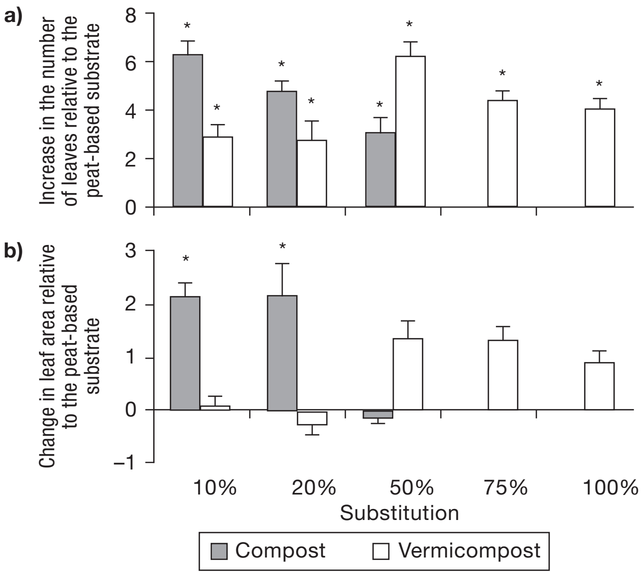

Figure 2. Plant responses (± standard error) to different doses of compost and vermicompost in the number of leaves (a), and leaf area (b) as compared to the commercial peat-based substrate. Asterisks indicate significant differences with the pure peat-based substrate at $P<0.05$ (Fisher LSD test). *Note:* seedlings died in substrates with 75% or 100% compost.

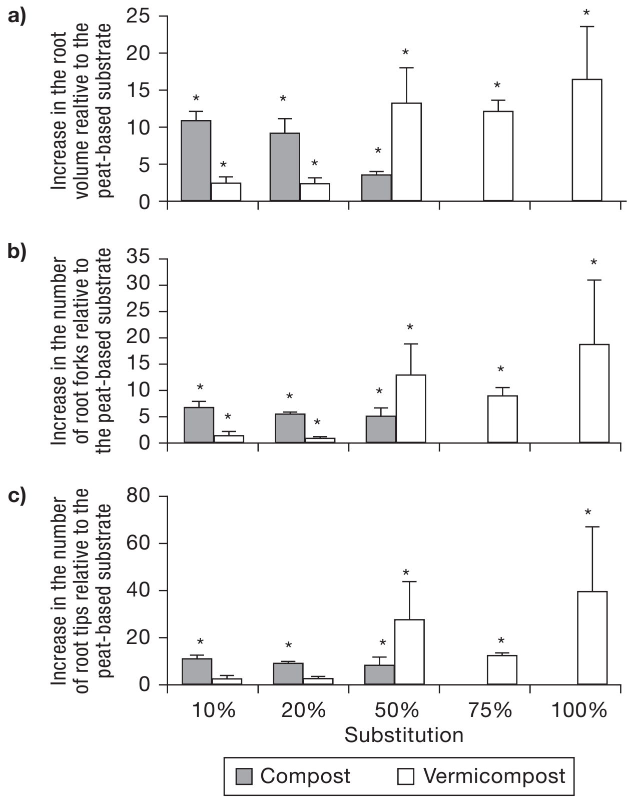

Figure 3. Plant responses (± standard error) to different doses of compost and vermicompost in the root volume (a), number of root forks (b), and number of root tips (c), as compared to the commercial peat-based substrate. Asterisks indicate significant differences with the pure peat-based substrate at $P<0.05$ (Fisher LSD test). *Note:* seedlings died in substrates with 75% or 100% compost.

by vermicompost resulted in increased leaf area with 10, 50, 75 and 100% substitution, while 20% substitution slightly decreased the leaf area of the tomato plants as compared to pure peat; however the effect of the vermicompost proportions were not statistically different from the peat-based substrate in any case.

The root volume of the tomato plants was increased in all the assayed treatments including peat substitution by compost or vermicompost with differences depending on the dose (ANOVA results for the effect of the dose within each substrate: $P<0.01$). Substitution of peat by compost produced increases in root volume in all the doses assayed, although the highest values were observed with 10 and 20% substitution. Substitution of peat by vermicompost also increased significantly the root volume of the plants as compared to peat, with the highest doses (50, 75, 100%) producing the highest volumes (Fig. 3a).

The number of root forks was increased after substitution of peat by compost and vermicompost although these increases depended on the dose in each substrate (ANOVA results for the effect of the dose within each substrate: $P<0.01$). Compost addition to the potting media produced similar increases in the number of root forks with all the doses assayed as compared to the pure peat-based media, while higher doses of vermicompost (50, 75, and 100%) produced the highest number of forks as compared to 10 and 20% (Fig. 3b).

Substitution of the peat-based substrate with compost and vermicompost produced significant increases in the number of root tips which were different depending on the doses (ANOVA results for the effect of the dose within each substrate: $P<0.01$). Peat replacement by 10, 20 and 50% compost produced significant increases in the number of root tips of the tomato plants as compared to the pure peat-based media, while with vermicompost significant increases were only observed with 50, 75 and 100% substitution (Fig. 3c).

Discussion

The results of this experiment show that it is possible to substitute peat by compost or vermicompost for the production of tomato plants in nurseries although substantially different effects were observed between these substrates in plant morphology and growth depending on the dose used. Total replacement of peat was only possible when vermicompost was used, while doses of compost higher than 50% caused prompt plant mortality. Plant mortality after compost introduction in the potting media has already been reported in previous studies and it has been attributed to the change in the physical properties of the substrate (*i.e.* increase in bulk density and decrease in pore and readily available water) (Papafotiou *et al.*, 2005), to the increase in substrate salinity particularly in the case of tomato plants (García-Gómez *et al.*, 2002; Castillo *et al.*, 2004; Herrera *et al.*, 2008) and to the presence of excessively high concentrations of certain ions (Hashemimajd *et al.*, 2004). The compost used here was characterized by an excessively high pH and electrical conductivity as well as by high concentrations of Cl^- as compared to the peat-based substrate and the vermicompost, and most likely, these three factors interacted synergistically to cause plant damage at the root level and subsequent plant mortality with 75 and 100% peat substitution.

Consequently, substitution of peat by cow manure compost could only be accomplished at low doses, but total substitution was feasible with pig slurry vermicompost. Further, upon application of the adequate dosage, significant improvements in plant growth were observed as compared to the pure peat-based substrate. Root morphology was also significantly improved through the increase in root volume and branching as compared to the peat-based substrate containing a root promoting mixture of phosphates. These improvements in plant growth and morphology involve an enhancement of post-transplant success, since they determine a higher capacity to exploit soil resources (López-Bucio *et al.*, 2003) and a higher photosynthetic capacity through the increase of the available surface for gas exchange and light interception, all of these features resulting in a potentially higher yield of the plants.

Opposite to Atiyeh *et al.* (2000) and Hashemimajd *et al.* (2004) where tomato plant growth was significantly increased after the addition of small doses of vermicompost to the potting media (up to 30%), in this study best results on plant growth and morphology were observed with the highest doses assayed (50, 75 and 100%). Most likely, such large substitution doses were possible because of the adequate pH and salt content of the pig slurry vermicompost and the persistence of favourable physical conditions for plant growth in the potting media with the increasing doses of vermicompost. Also the use of different varieties could be a reason for the high variability observed in the response of the tomato plants to the different doses of vermicompost among the existing studies.

Compost and vermicompost have shown to enhance plant growth in several occasions and these growth enhancements have been attributed to an improvement of the physical, chemical and biological properties of the growing substrate. Generally, replacement of peat with moderate amounts of compost or vermicompost produces beneficial effects on plant growth due to the increase on the bulk density of the growing media, and to the decrease on total porosity and amount of readily available water in the pots (Papafotiou *et al.*, 2005; Bachman and Metzger, 2007; Grigatti *et al.*, 2007). Such changes in the physical properties of the substrates might be responsible for the better plant growth with the lower doses of compost and vermicompost as compared to the peat-based substrate.

In spite that the amount of nutrients in these amendments varies depending on the parent material from where they are originated, both compost and vermicompost constitute a slow release source of nutrients that supply the plants with the nutrients when they are needed (Chaoui *et al.*, 2003; Nevens and Reheul, 2003). Further, several examples in the literature show that compost and vermicompost are able to enhance the growth of a wide range of plant species further what can be expected because of the supply of nutrients (Edwards *et al.*, 2004; Grigatti *et al.*, 2007). Mycorrhizal colonization (Cavender *et al.*, 2003), microbial activity (Domínguez, 2004) and suppressiveness of soilborne plant pathogens (Hoitink and Boehm, 1999; Szczech, 1999; Szcech and Smolinska, 2001; Scheuerell *et al.*, 2005; Noble and Coventry, 2005; Termorshuizen *et al.*, 2006) have shown to be enhanced through the addition of compost and vermicompost to a potting media or as a soil amendment. Furthermore, biologically active metabolites such as plant growth regulators (Tomati and Galli, 1995; El Harti *et al.*, 2001) and humates (Atiyeh *et al.*, 2002; Canellas *et al.,* 2002) have been discovered in vermicomposted materials.

Root morphology is known to be influenced by water and nutrient availability as well by external applications of hormones (López-Bucio *et al.*, 2003). Root growth and branching is favoured in nutrient-rich environments and in the presence of hormones like auxins; this enables the plant to optimize the exploitation of the available resources which are in turn transformed into photoassimilates and transported again to the root consequently influencing plant growth and morphology in a systemic manner (Forde and Lorenzo, 2001). It is evident that development of such morphology in the tomato plants was favoured after the application of nutrient-rich and biologically-active substrates like compost and vermicompost as compared to peat.

Replacement of the peat based-substrate for the production of tomato plants in nurseries by compost and vermicompost was possible and, in addition, with the adequate doses for each substrate, significant improvements in plant growth and morphology were observed as compared with the pure peat-based substrate. Although the effects of compost and vermicompost might vary depending on the parent waste and production process, and therefore they cannot be generalized, these results constitute a new proof of the viability of sustainable culture practices in horticulture, which entail both environmental and economic benefits.

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