Urban Forestry & Urban Greening 34 (2018) 175–180

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Morpho-physiological plant quality when biochar and vermicompost are used as growing media replacement in urban horticulture

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ARTICLE INFO

Keywords:
Bedding plants
Carbon storage
Peat substitution
Pelargonium
Petunia

ABSTRACT

Peat moss is the most used soilless substrate in the production of container plants in floriculture. Nevertheless, the drainage of peat bogs due to the peat extraction has increased the necessity of seeking products that could replace the peat that is used in plant production. Therefore, a comparative study was conducted to evaluate the effect of a biochar *(B)* - vermicompost *(V)* mixture, as a partial substitute for peat-based substrates, on the morpho-physiological characteristics of ornamental plants. Different blends containing *B* and *V* were compared to a baseline peat-based substrate (*S*) as control in the cultivation of two ornamental bedding plant species that are widely used in urban areas: geranium (*Pelargonium peltatum*) and petunia (*Petunia hybrida*). Plant growth and physiological parameters were assessed. Results showed that it is possible to grow container plants of these two species with commercial quality, using a peat-based substrate mixed with biochar and/or vermicompost (up to 30% *V* and 12% *B*). Plants in these substrates showed a similar or enhanced physiological response to those grown in the control using commercial peat-based substrate.

1. Introduction

Container nursery plants are primarily produced by using peat moss as a soilless substrate. Worldwide, 11 million tons of peat moss are used per year (DOI-USGS, 2013) because of its consistent and favorable physical characteristics and high nutrient exchange capacity. However, there is a growing environmental concern of using peat moss because of the numerous environmental services generated by peatlands (Ostos et al., 2008). Consequently, peat is widely considered a non-removable resource because it takes thousands of years to produce (Keddy, 2010). Therefore, there is a growing interest in replacing peat with other soilless substrates. As a consequence, a number of studies have been undertaken to establish the potential substitution of peat with different organic materials such as bark (Bilderback et al., 2005), wood fiber (Gruda and Schnitzler, 2004), coconut coir (Abad et al., 2005), and compost (Carlile et al., 2015). But it is noteworthy that commercial compost (Garcia-Gomez et al., 2002) and vermicompost (Sardoei, 2014), have received special attention from researchers. Compost and vermicompost are products derived from the biological degradation of organic wastes. They were used in studies as the most referenced range of substitution of approximately 20 to 40% in volume, enhancing plant's rooting and growth and having no negative side effects (Prasad and Maher, 2001; Alvarez et al., 2001; Arancon and Edwards, 2005; Belda et al., 2013). However, vermicompost usually has a better quality than urban compost or solid waste management compost (vermicompost has less heavy metal and other content of contaminants) and green compost (vermicompost has a higher N content in the available form of nitrates) (Arancon and Edwards, 2005; Atiyeh et al., 2000).

On the other hand, biochar is a solid byproduct that is obtained from the thermochemical conversion of biomass in an oxygen-limited environment with the aim of producing energy from organic materials (Lehmann, 2007). Biochar, as opposed to charcoal, is not usually incinerated for power generation, but it is employed as organic soil amendment in order to enhance water holding capacity and to retain nutrients (such as nitrates and ammonia) while avoiding the leaching of these nutrients, to decrease the bulk density and to ameliorate the pH (Laird, 2008; Alburquerque et al., 2013; Lal, 2015). There are strengths and weaknesses of using biochar as a soil amendment (Lal, 2015) as its properties vary widely and its effects on soil organic carbon dynamics depend on feed-stock, pyrolysis production systems and site properties

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https://doi.org/10.1016/j.ufug.2018.06.021
Received 6 March 2018; Received in revised form 25 June 2018; Accepted 26 June 2018

(Lorenz and Lal, 2014). Nevertheless, high-temperature biochars can bind carbon in soil and other nutrients over the long term (Mukherjee and Lal, 2013).

Even if the use of biochar may have strengths and weaknesses, some researchers have found that a good combination of biochar and compost is an acceptable growing media (Schmidt et al., 2014) because of the improvement of soil fertility over the short-, medium-, and long-term (Fisher and Glaser, 2012). Several residues have been used as sources of biochar included in growing media, such as biosolids (Méndez et al., 2017), urban wastes (M.L. Alvarez et al., 2017; Nieto et al., 2016) and deinking sludge (Méndez et al., 2015), among others.

Currently, biotic strategies of carbon sequestration in soil (Lal, 2008) are broadly considered. Biochar and vermicompost may play an innovative role in the container production of ornamental plants to decrease the C footprint by replacing peat-based substrates (Christopher Marble et al., 2012). Vermicompost (from dairy manure) and biochar (from pine species) can be commonly found all around the world and their combination may play an interesting role in partially replacing peat as growing media (J.M. Alvarez et al., 2017). Notwithstanding, to our knowledge, research on the effects of biochar mixed with compost or vermicompost on substrates that are utilized in floriculture is scant or not available.

Moreover, it must be taken into account that commercialization of ornamental plants involves not only morphological characteristics of plant quality (i.e. adequate size, dense foliage, leaf color, and number and color of flowers) but also enough vigor and capacity to maintain growth and withstand environmental stresses after leaving the nursery (Ferrante et al., 2015). Among traditional indicators of commercial plant quality parameters are those related to water stress resistance or low temperature tolerance, as well as the ability to continue growing after transplant (Landis et al., 2010; Santagostini et al., 2014), that are usually assessed at the end of the nursery growth period. Nevertheless, to our knowledge, there are few if any studies on the physiological responses of plants grown in a substrate composed of a peat-based growing medium and partially substituted by biochar and vermicompost.

Therefore, the main focus of the present study was to analyze 1) the usual morphological growth parameters such as Shoot Dry Weight (SDW) and number of flowers, 2) some physiological traits related to plant response to environmental stresses, such as cuticular transpiration (i.e. the loss of water through the leaf epidermis when stomata are closed), 3) whole plant transpiration, 4) frost tolerance and 5) root growth capacity. The latter two parameters are indicators of the general vigor of plants and their capacity to withstand several types of stress. The experiment was designed to test that there is no loss of physiological properties of two bedding plants when using a growing medium, whereby a non-renewable peat-based substrate is partially replaced by biochar and vermicompost.

2. Materials and methods

2.1. Experimental design and plant material

A commercial peat-based growing mix (Farfard 3B mixture by SunGro® Horticulture Distribution Inc., Bellevue, WA, USA) was used as the control (*S*). Further, this commercial peat-based growing mix was partially replaced by biochar (*B*) and vermicompost (*V*) to make up the rest of substrate treatments. The peat-based substrate was comprised of Canadian *Sphagnum* peat moss, pine bark, perlite, vermiculite, dolomitic limestone, and a wetting agent, at 6:4:2:1 Peat:Bark:Perlite:Vermiculite volume ratio, and received a slow release fertilizer (Scotts Osmocote plus 15-3.9-10 N-P_2O_5-K_2O at 5.9 g/L). The biochar and the vermicompost were also commercial products: Soil Reef Pure 02 (Biochar Solutions Inc., Carbondale, CO, USA) produced by pyrolysis of *Pinus monticola* wood at high temperature (600–800 °C) in a downdraft gasifier-type reactor with 1 min residence time, and Black Diamond Vermicompost prepared by vermicomposting of dairy manure solids (which had been pre-composted for two weeks in an aerated composting system) for 70–80 days. More details of properties of substrate components are shown in J.M. Alvarez et al. (2017). Since *V* could increase substrate salinity, the two ornamental species used in this assay, *Petunia x hybrida* cv. Dreams Neon and *Pelargonium peltatum* cv. Summer Showers, were selected because they are bedding plants that are widely used in urban areas (Ignatieva and Stewart, 2009; Sendo et al., 2010). They also have different salt tolerance. *Petunia* is more tolerant than *Pelargonium* (Mionk and Iebe, 1958; Do and Scherer, 2013).

Table 1
Volume fraction (%) of peat-based substrate (*S*), vermicompost (*V*) and biochar (*B*) used as substrate treatments (*S*:*V*:*B*). Control treatment was 100:00:00.

Treatment	Petunia	Pelargonium
1	100:00:00	100:00:00
2	86:10:04	86:10:04
3	68:20:12	68:20:12
4	82:10:08	88:00:12
5	78:10:12	70:30:00
6	58:30:12	66:30:04

The control with the peat-based substrate (*S*) and six treatments per species containing different mixtures of *B* and *V* with the commercial peat-based substrate were selected. These treatments were chosen based on the plant size and flower production obtained in a previous experiment including an extended range of mixtures J.M. Alvarez et al. (2017), which suggested to replace *S* with *V* at a rate less than 30%. As detailed in Table 1, at least three treatments were identical for petunia and geranium in this experiment (the control, and treatments 2 and 3 containing a slight and a moderate substrate replacement, respectively). The other three treatments had a slight difference in the *B* and *V* ratios.

Two hundred young seedlings were germinated in plastic plug trays (21.8 cm^3) in a glasshouse at 54% average relative humidity and 24 °C average air temperature with a micro sprinkler irrigation system. Two sets of sixty seedlings were randomly selected from the plug tray and transplanted to 800 cm^3 plastic containers located on 8 m^2 surface benches in a greenhouse at 20 °C average air temperature and 29% average relative humidity (2 sets × 2 species × 6 treatments × 5 plants = 120 plants). Containers were watered manually as needed, based on environmental conditions and plant size under usual commercial conditions, and moisture content was kept to field capacity. The growing period was 20 weeks for *Petunia* and 24 weeks for *Pelargonium*. Plants were periodically moved to minimize deviations in microclimatic conditions.

2.2. Plant growth and physiological parameters

Due to the major commercial importance of these two species, plant size (evaluated through the shoot dry weight, SDW) and flower production were taken into account as morphological parameters in this assessment. SDW and number of flowers were evaluated at the end of the growth period, the number of flowers of *Pelargonium* plants being the open inflorescences plus inflorescence-buds. SDW was measured after oven-drying at 55 °C for 72 h.

As physiological parameters to be evaluated at the end of the nursery growth period, parameters related to mineral composition, to water conservation or consumption (cuticular transpiration −CT− and water transpiration by the whole plant −WT−, respectively), to root growth capacity (RGC) and to frost tolerance were chosen (Carevic et al., 2010; Landis et al., 2010).

Plant dry samples were crushed to pass through a 0.5 mm sieve, and digested by wet oxidation with high purity concentrated HNO_3 under pressure in a microwaveoven (Miller, 1998). Nutrients (P, K, Ca, Mg. S), and trace elements (Fe, Mn, B, Cu, Zn, Na, Al), were determined by ICP-

OES and expressed on a dry mass basis (Dahlquist and Knoll, 1978). After Kjeldahl digestion, spectrophotometry in a flow autoanalyzer was employed to determine total N concentration.

CT was assessed on one leaf per plant, five plants per treatment and species, using the method of Quisenberry et al. (1982) and Carevic et al. (2010). Hence, descending transpiration curves were constructed and used to calculate the CT (mmol/(m^2s) of H_2O) by analyzing the rectilinear part of the curve of fresh weight *vs.* time. In addition, leaf area and leaf dry weight were measured in order to calculate specific leaf area (SLA, m^2/kg). RGC was assessed according to Ritchie (1985). Five plants per treatment were transplanted with the root ball intact into larger containers (28.3 cm diameter, 1260 cm^3 volume) filled with horticultural perlite of grade 2. Containers were placed on benches in a greenhouse with 22 °C average air temperature, 50% average relative humidity and natural photoperiod (~12 h), and watered manually as needed. Eight weeks later, the perlite was carefully separated from the roots and the amount of new root growth was evaluated (i.e. new white roots emerged from the root ball). New roots were collected, cleaned, dried at 70 °C until constant weight and weighed.

Frost tolerance was evaluated with a freeze-induced electrolyte leakage (FIEL) test. This test is based on the fact that freeze-damaged cell membranes leak electrolytes that can be measured with an electrical conductivity meter (Burr et al., 2001). Several freezing temperatures were tested in advance and the freezing temperature that caused 50% of leaf damage (i.e. −6.7 °C) was selected for the test. This was assessed using the method described by Royo et al. (2003) on one fully developed leaf per plant. Therefore, the damage index (DI) was calculated at −6.7 °C as: $DI_{6.7}$ (%) = 100 (RC - RCc)/(100 - RCc), with RC and RCc (relative conductivities) being calculated as follows: $RC = 100*(EC_1\text{-}B1)/(EC_2\text{-}B2)$, $RCc = 100*(EC_{1c}\text{-}B1)/(EC_{2c}\text{-}B2)$, where EC_1 and EC_2 were the initial and final, respectively, sample EC, and EC_{1c} and EC_{2c} were, respectively, the initial and final EC of the control (i.e. a sample which did not suffer the frost event). B1 and B2 were the EC of blanks included in the test. This damage index was an estimation of the amount of frost injury.

In addition, the water transpiration rate by the whole plant (WT, mmol/(m^2s)) was measured in well-watered plants, taking into account the transpiring water during a full day, and calculated as follows: $WT = (W1 - W2)/(LA \cdot T)$, where W1 is the overall weight on the first day of the container, the substrate, and the plant (g), W2 is the overall weight on the following day (g), and both were measured just after dawn; then, the transpired water was calculated as W1 - W2 (g); *LA* was the leaf area of the whole plant (m^2); and *T* was the time elapsed between W1 and W2 (s). This was undertaken on three different days for every plant, in order to determine an average value per plant. To prevent water evaporation from the container surface to the air, the containers were wrapped with a white plastic bag.

2.3. Data analysis

One-way analysis of variance (ANOVA, SPSS Statistics 17.0) was carried out for each species to determine statistically significant differences between treatments (at $\alpha = 0.05$), with the treatment being a fixed effect. The Tukey-Honest Significant Difference (HSD) or the Dunnett T3 tests were used to evaluate comparisons among the treatments and to differentiate within homogeneous groups.

For plant transpiration (WT), an analysis of covariance (ANCOVA) was used with two covariates for *Pelargonium* (leaf area, initial substrate humidity) and one covariate for *Petunia* (leaf area). The models were chosen for their accurate and lower goodness-of-fit indicator values of consistent Akaike information criterion (CAIC) (Table 2). As there was a liner relationship between substrate moisture content and daily water transpiration for *Pelargonium* ($R^2 = 0.314$, $p = 0.001$), it was decided to include the moisture content as a covariate for this species even though the CAIC was slightly lower for one covariate (leaf area) than for two covariates. In addition, correlation analysis between morphophysiological parameters of plants was carried out.

Table 2
Model comparisons for daily plant transpiration (WT), being the full model performed by a fixed effect (substrate treatment [*Treat*]) and two covariates (leaf area [*LA*], and initial substrate moisture content [*IM*]). CAIC: consistent Akaike's information criterion. *p*: significant level for the fixed effect. The models selected are typed in bold.

Model effects	Petunia		Pelargonium	
	CAIC	p (Treat)	CAIC	p (Treat)
Treat (LA)(IM)	387.2	0.005	**328.8**	< **0.001**
Treat (LA)	**383.7**	**0.001**	326.1	< 0.001
Treat (IM)	400.0	0.275	342.2	< 0.001
Treat	395.6	0.250	340.6	< 0.001

3. Results and discussion

3.1. Plant size and flower production

The biomass accumulated by the plants and the number of flowers per plant for the two ornamental crops grown in the different substrate treatments are shown in Fig. 1. It can be highlighted that *Petunia* SDW and flower production were significantly lower in the control treatment compared with the other treatments ($p < 0.001$), except for flowers in 78:10:12 and 58:30:12. For instance, plant weight in treatment 86:10:04 was 115% greater and produced 320% more flowers than plant weight using the standard peat-based substrate.

The improvement of *Petunia* SDW and *Petunia* and *Pelargonium* flowering are interesting results that should allow growers to substitute peat-based substrate by using *V* and *B*. These favorable results were obtained when $B \le 12\%$ and $V \le 30\%$ volume fraction were used. To our knowledge, no similar results have been found in container production of ornamental plants. There are studies in which peat-based substrates were partially replaced by biochar in horticulture for the production of vegetables (Mulcahy et al., 2013) or ornamentals (Tian et al., 2012) with good results, but without incorporating both materials *V* and *B* combined as partial substitution of a peat-based substrate. *B* and *V* can complement each other since *V* provides nutrients, and *B* increases cation-exchange capacity and C fixation in the long-term (Fisher and Glaser, 2012; Alburquerque et al., 2013; Mukherjee and Lal, 2013).

3.2. Physiological parameters

Plant transpiration rate (WT) in *Petunia* was significantly ($p = 0.001$) lower in the control treatment than in the other treatments for well-watered plants (Fig. 2). However, *Pelargonium* control plants significantly ($p < 0.001$) transpired less than mixtures 86:10:04, 70:30:00, 66:30:04 and 68:20:12 (Fig. 2). Hence, the *Petunia* plants in the control treatment, under well-watered conditions, saved more water than in mixtures containing *B* and *V*, but at the same time growth and flower production decreased. Only substrates containing less than 14% of the organic amendments ($B + V$) in *Pelargonium* showed a lower water loss. Therefore, although the addition of *V* and *B* led the plants to consume more water than the control plants, the greater physiological activity could have boosted growth and flower production. This fact was highly evident for *Petunia*.

Differences in cuticular transpiration (CT) among the control treatment and the mixes were not significant, hence this physiological response due to the inclusion of *V* and *B* in the substrate mixture was not detrimental to plants, and the water loss when the stoma are closed (i.e. leaf permeability) varied minimally (Villar-Salvador et al., 1999). In other words, in the event that the plants suffer from a short period of water stress, plants grown on the new substrates will not decrease their

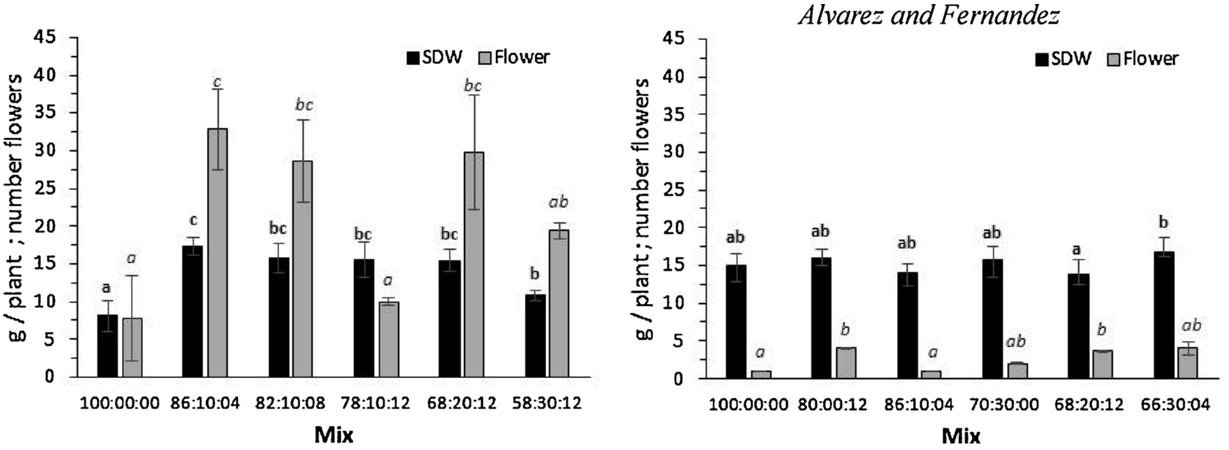

Fig. 1. Shoot dry weight (SDW, g) and number of flowers of petunia (left) and geranium (right) grown in mixtures with different proportions of peat-based substrate (*S*), biochar (*B*) and vermicompost (*V*). Different letters show significant differences between substrates ($0.001 \leq p < \leq 0.0465$) (Tukey-HSD test for SDW both species, and Flowers in *Petunia*; Dunnett T3 test for Flowers in *Pelargonium*).

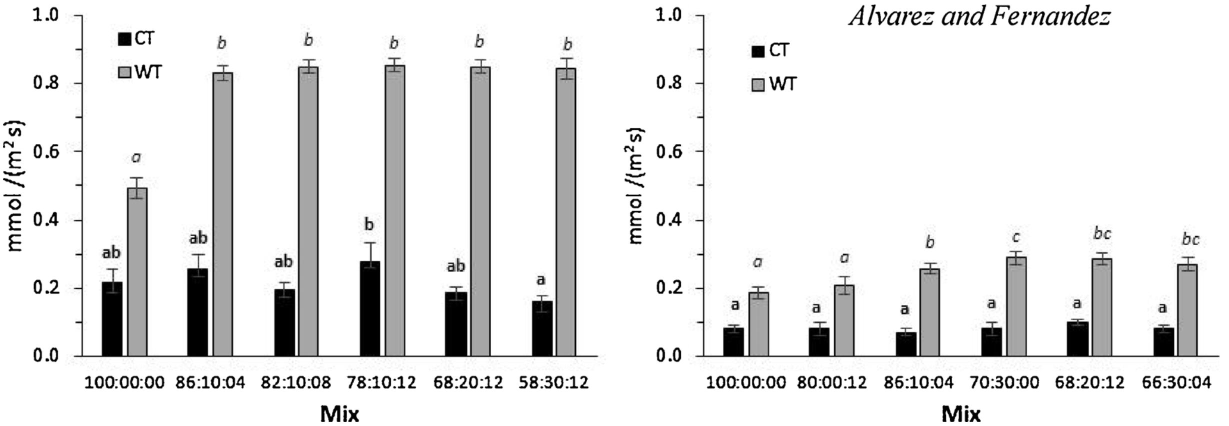

Fig. 2. Cuticular transpiration (CT, mmol/(m^{2}s)) and plant transpiration rate (WT, mmol/(m^{2}s)) for well-watered plants of petunia (left) and geranium (right) grown in mixtures with different proportions of peat-based substrate (*S*), biochar (*B*) and vermicompost (*V*). Letters show significant differences between substrates ($0.001 \leq p < 0.0225$) (Tukey-HSD test for CT both species, and WT in *Pelargonium*; Dunnett T3 test for WT in *Petunia*). CT in *Pelargonium* was not significantly different among substrates ($p = 0.703$).

Table 3
Root Growth Capacity (RGC) of petunia and geranium grown in mixtures with different proportions of peat-based substrate (*S*), biochar (*B*) and vermicompost (*V*). Different letters within the same column show significant differences between substrates (Tukey-HSD test).

Petunia		*Pelargonium*	
Treatment	RGC	Treatment	RGC
S:V:B	(g)	*S:V:B*	(g)
100:00:00	0.15 ± 0.02 a	100:00:00	0.67 ± 0.03 ab
86:10:04	0.20 ± 0.01 ab	86:10:04	0.59 ± 0.05 ab
68:20:12	0.22 ± 0.03 ab	68:20:12	0.60 ± 0.01 ab
82:10:08	0.18 ± 0.04 ab	88:00:12	0.82 ± 0.12 b
78:10:12	0.26 ± 0.03 b	70:30:00	0.50 ± 0.05 a
58:30:12	0.19 ± 0.03 ab	66:30:04	0.52 ± 0.01 a
Average ± SE	0.2 0 ± 0.01	Average ± SE	0.63 ± 0.04
p	0.025		0.031

capacity to conserve water.

With respect to *Petunia* RGC, the results were slightly better in every treatment than the results in the control, but no significate differences were observed except for the mixture 78:10:12 (Table 3). *Pelargonium* control plants did not differ in RGC from other mixtures. Consequently, after transplanting, root growth is expected to be similar in plants cultivated in a peat-based substrate than in plants where *V* and *B* were incorporated into the substrate in different proportions. Hence, the general physiological plant state has not been altered. To our knowledge, there are no related results in the ornamental horticultural production in container in the existing body of literature.

Regarding the freeze damage index ($DI_{6.7}$), mean values were 56.0 ± 7.5% for petunia and 83.3 ± 6.2% for geranium, without significant differences among treatments ($p > 0.05$). This means that plants showed a similar response in any treatment, as in the research results of Birchler et al. (2001) with Douglas-Fir seedlings. Therefore, the addition of *V* and *B* maintained plant frost resistance in spite of increasing plant size and inflorescence production (i.e. increasing growth and metabolic activity).

Overall, nutrient concentrations in leaves were within the normal ranges suggested for these species (Mills and Jones, 1996), and did not manifest clear deficiency symptoms (Tables 4 and 5), although slightly lower N and Fe concentrations were obtained for both species. Nutrient concentrations were not correlated with CT, RGC, $DI_{6.7}$ and WT ($r < 0.25, p > 0.65, n = 6$), and mean values of SLA (42.2 ± 1.5 m^2/kg for petunia and 13.0 ± 0.6 m^2/kg for geranium) were not significantly different among treatments ($p > 0.05$), hence it is not necessary to deepen the discussion with respect to these parameters. In summary, commercial quality *Petunia* and *Pelargonium* plants can be grown in a substrate containing *S, V,* and *B*, with related or improved appearance over those grown in a peat-based control substrate (*S*). Plants grown with limited ratios of *B* and *V* in the mixtures, when

Table 4
Leaf mineral concentrations (dry weight basis) of *Petunia* grown on different substrate mixtures.

Treatment	N	P	K	Ca	Mg	S	Na	Fe	Mn	B	Cu	Zn
S:V:B[1]				(%)						(μg g^{-1})		
100:00:00	2.13	0.43	3.85	1.76	0.44	0.44	0.43	85.73	68.8	14.9	9.81	62.8
86:10:04	2.06	0.45	3.44	1.63	0.53	0.51	0.59	97.36	46.0	14.1	10.84	73.4
68:20:12	1.92	0.48	3.34	1.67	0.50	0.47	0.52	74.39	48.9	14.7	8.15	70.5
82:10:08	1.93	0.49	3.46	1.60	0.46	0.47	0.55	79.54	56.7	13.0	9.45	75.1
78:10:12	2.06	0.45	3.34	1.66	0.49	0.47	0.52	64.56	57.2	14.7	8.11	66.8
58:30:12	1.98	0.53	3.86	1.69	0.53	0.47	0.50	76.08	44.1	15.5	11.23	82.9
Average	2.01	0.47	3.55	1.67	0.49	0.47	0.52	79.61	53.6	14.5	9.60	71.8
(SE)	(0.04)	(0.04)	(0.42)	(0.14)	(0.05)	(0.04)	(0.09)	(16.90)	(10.7)	(1.9)	(2.32)	(8.4)
Sug. Range[2]	3.85	0.47	3.13	1.20	0.36	0.33	0.31	84	44	18	3	33
	7.60	0.93	6.68	2.81	1.37	0.80	1.09	168	177	43	19	85

[1] *S:V:B*, Volume fraction of peat-based substrate (*S*), vermicompost (*V*) and biochar (*B*). Control, 100:00:00.

[2] Suggested ranges (Mills and Jones, 1996).

Table 5
Leaf mineral concentrations (dry weight basis) of *Pelargonium* grown on different substrate mixtures.

Treatment	N	P	K	Ca	Mg	S	Na	Fe	Mn	B	Cu	Zn
S:V:B[1]				(%)						(μg g^{-1})		
100:00:00	1.48	0.25	2.39	1.57	0.67	0.17	0.40	77.7	252.2	27.3	4.96	43.8
86:10:04	1.52	0.36	2.62	1.62	0.61	0.18	0.41	80.2	162.8	29.8	4.84	48.6
68:20:12	1.55	0.41	3.07	1.51	0.56	0.17	0.49	72.5	89.2	31.7	4.50	38.2
88:00:12	1.49	0.26	2.59	1.60	0.68	0.18	0.37	78.0	266.2	27.4	4.06	36.0
70:30:00	1.54	0.42	3.03	1.53	0.58	0.18	0.48	64.8	86.0	32.9	4.90	41.2
66:30:04	1.39	0.44	3.35	1.60	0.56	0.17	0.53	80.4	92.5	32.4	5.01	46.9
Average	1.49	0.35	2.84	1.58	0.61	0.18	0.45	75.5	158.1	30.2	4.71	42.4
(SE)	(0.04)	(0.01)	(0.07)	(0.02)	(0.01)	(0.01)	(0.01)	(7.21)	(15.4)	(3.7)	(1.00)	(1.3)
Sug. Range[2]	3.3	0.30	2.50	0.80	0.20	0.25	–	100	40	30	5	7
	4.8	1.24	6.26	2.40	0.51	0.70		580	325	75	25	100

[1] *S:V:B*, Volume fraction of peat-based substrate (*S*), vermicompost (*V*) and biochar (*B*). Control, 100:00:00.

[2] Suggested ranges (Mills and Jones, 1996).

transplanted or exposed to abiotic stress, also showed a similar or occasionally enhanced physiological status to plants grown in a peat-based control substrate. This statement is based on the fact that: the addition of *V* and *B* to the substrate enhanced SDW and flower production; RGC did not vary significantly except for 78:10:12 in *Petunia*, which was 73% higher than the control; and DI_{67} and CT did not show significand differences among substrate treatments for both species.

On the other hand, when vermicompost and biochar partially replace peat-based substrates, there is a Carbon storage potential per pot transplanted into the bedding area in the garden. A 800 ml container may store up to 88.74 g of CO_{2e} for long periods of time (J.M. Alvarez et al., 2017) probably for centuries (Kuzyakov et al., 2009).

4. Conclusions

Plant size and flower production improved when peat-based substrate was substituted by vermicompost and biochar at rates of $B \leq 12\%$ and $V \leq 30\%$ volume fraction. No similar results have been found to date in container production of ornamental plants. Growers of *Petunia* and *Pelargonium* as well as other container plants may benefit from these findings. The changes in the considered physiological parameters, showed that plants grown in these new substrates will be able to adapt themselves, at least similarly well as the plants grown in peat-based growing media, to the new environment after transplanting to garden soil. These outcomes are pertinent to reduce peat usage in container production of ornamental plants and store carbon (C) for long time-periods in urban areas after bedding plants were transplanted to gardens. These facts are also relevant to lowering inorganic fertilization, as vermicompost can provide the required plant nutrients. As biochar is a highly variable product, depending on the feedstock material and pyrolysis conditions, the present results advocate for its use as a component of growing media, but more extensive research should be carried out to maximize both its environmental and agronomical benefits.

Acknowledgements

This work was partially supported by the projects CTQ2013-46804-C2-1-R and CGL2016-76498-R of the Spanish Ministry of Economy and Competitiveness and the European Regional Development Funds (ERDF). The authors wish to thank the Horticultural Department and Carbon Sequestration and Management Center of Ohio State University for providing materials and facilities for this investigation. Similarly, the authors are deeply grateful to the following people: Mrs. Loewe and Dr. J. Altland from Application Technology Research Unit at Wooster OSU campus for their laboratory assistance in determining the physical properties substrate mixtures. Miss S. Stieve and Dr P. Jourdan from the Ornamental Germoplam Center at Columbus OSU campus are also thanked for their laboratory assistance in the accurate and precise weighing of leaves.

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