Effect of Composts in Substrates on the Growth of Tomato Transplants

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ADDITIONAL INDEX WORDS. peat, growing media, seedbed, solid urban waste, vegetable, vine pomace

SUMMARY. In this work, we studied the effect of different substrate mixes composed of blond peat and compost produced from solid urban waste, vegetable waste, and vine pomace on the quality of tomato seedlings (*Solanum lycopersicum* cv. Dakapo). Each compost was mixed with blond peat at different ratios such that the initial electric conductivity (EC) of the final mixes was 2.5, 3.5, and 4.5 dS·m⁻¹. The following control substrates were used: blond peat and blond peat + black peat + standard coconut fiber used in commercial nurseries on experimental basis. Emergence and several seedling quality variables were monitored. Results showed that peat in nursery substrates can be partially substituted by these composts to grow tomato seedlings. The quantity of vegetable waste and vine pomace compost used should not allow the initial EC to exceed 2.5 dS·m⁻¹.

Efficient production of horticultural seedlings in nurseries requires plants that can develop rapidly and uniformly until they are well established. To that end, the role played by substrates is critical (Sterrett, 2001). Many materials, alone or mixed, can be used to produce substrates with the appropriate physical, chemical, and biological characteristics to grow different crops under diverse cultural conditions (Burés, 1997). Currently, sphagnum peat provides the base material for the majority of commercial substrates used in nurseries; its excellent physical, chemical, and biological properties make it ideal for growing horticultural seedlings (Abad et al., 2001; Burés, 1997). Peat is collected from bogs, marshes, and wetlands, which are often fragile ecosystems of great ecological and archaeological value (Bustamante et al., 2008). Unfortunately, the high demand for peat in horticulture has led to constant exploitation of peatlands, the consequent depletion of this resource, and the ecosystem degradation (Raviv, 1998; Sterrett, 2001). Since the late 1970s, alternatives to peat have been sought worldwide (Raviv et al., 1986).

Many authors have indicated the viability of vegetable waste composts (VW), solid urban wastes (UW), and the residues of the wine industry [vine

pomace (VP)] as seedbed substrates for the production of horticultural seedlings in nurseries (Castillo et al., 2004; García-Gómez et al., 2002; Herrera et al., 2008; Kostow et al., 1996; Pérez-Murcia et al., 2006). The use of these composts also helps solving a major environmental problem: their disposal. Every year, Europe alone produces more than 1.8 billion megagrams of total waste—3.5 Mg of waste per person (Bernal and Gondar, 2008).

Immaturity and instability are common problems of composts when used as seedbed substrates for horticultural seedlings (Carmona and Abad, 2008). Even well-stabilized compost can have properties considered to be limiting factors for horticultural use, such as the presence of heavy metals, low water-holding capacity, aeration problems, or excessive content of salt and nutrients (Carmona and Abad, 2008; García-Gómez et al., 2002). The use of very

saline substrates to grow tomato seedlings can lead to physiological, morphological, and biochemical abnormalities. Effects of salinity on tomato seed germination are closely linked to the substrate's concentration, the species, and the cultivar used (Cuartero and Fernández-Muñoz, 1999; Foolad and Lin, 1997; Srinivas, 2001), as well as plant height, leaf number, stomatal density, leaf area (Al-Karaki, 2000; Romero-Aranda et al., 2001), and root development. When the damage caused is severe, chlorosis and necrosis appear, especially at the leaf edges (Al-Karaki, 2000; Romero-Aranda et al., 2001). Combining peat with compost can attenuate some of the physical and chemical problems that composts present when used alone (Bustamante et al., 2008; Raviv et al., 1986).

Several authors have shown the viability of UW, VW, and VP as components of substrate mixes for tomato seedlings (Castillo et al., 2004; Herrera et al., 2008; Kostow et al., 1996). Herrera et al. (2008) reported that a mixture of 30% UW, 65% peat, and 5% perlite (v/v) allowed the production of tomato plants with development properties similar to those produced using the common nursery substrate mix of blond peat, black peat, and coconut fiber. In addition, these authors also noted that to reduce the negative effects of the high electrical conductivity (EC; 11.4–19.8 dS·m⁻¹) and pH (8.1–8.8) of their compost, the ratio of the compost component should not exceed 30% (v/v). Ribeiro et al. (2007) evaluated a compost obtained from forestry waste and solid swine manure (EC = 0.27 mS·cm⁻¹, pH 6.88) as a substrate for the production of tomato seedlings. The greatest

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
0.2276	inch ² /oz	cm ² ·g ⁻¹	4.3942
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵
1.0012	oz/ft ³	kg·m ⁻³	0.9988
0.001	ppm	g·L ⁻¹	1000
1	ppm	mg·L ⁻¹	1
0.9072	ton(s)	Mg	1.1023
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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growth was achieved with 100% composted substrate, while the least growth was achieved with peat alone. Castillo et al. (2004) reported that pH, salinity, and organic matter content of UW have great influence on the quality of tomato seedlings. In addition, they reported that EC values of more than 9 dS·m⁻¹ were associated with plants of poorer quality.

The above-mentioned studies suggest that the partial substitution of peat by composts for tomato seedlings production is feasible. However, they failed to define the optimal ratios with respect to the physical and chemical properties of such composts. The aim of the present work was to examine the effect of seedbed substrates with several EC values on the growth of tomato seedlings, based on different peat, UW, VW, and VP compost ratios.

Materials and methods

These experiments were performed in a multitunnel greenhouse at a specialized nursery in Almería, Spain. UW, VW, and VP composts used were obtained from commercial composting plants. All composts were sieved to eliminate particles larger than 5 mm in diameter. They were then individually mixed with blond peat, perlite, and vermiculite at different ratios until substrates with an EC of 2.5, 3.5, and 4.5 dS·m⁻¹ were produced (Tables 1 and 2). Two control substrates were also prepared: one with blond peat, black peat, and coconut fiber (the standard substrate used at the experimental station), and

another substrate based on blond peat. Final substrate ratios are shown in Table 1, while the chemical characteristics of the treatments are shown in Table 2.

EC of the saturated extracts obtained from these substrates was determined using the method of Richards (1954) and Scofield (1940). EC values of the compost mixtures were established taking into account an optimum salinity of 3 to 5 dS·m⁻¹ for the substrate solution, as described for horticultural plants by Abad et al. (2004), and the <3.5 dS·m⁻¹ maximum value of the saturated extract for seedbed substrates described by Lemaire et al. (1985) and Wright (1986).

Seedlings were grown in expanded polystyrene trays with 150 wells lined with single-use polypropylene sleeves. The wells were manually filled with substrate; in contrast, seeds were sown mechanically with one 'Dakapo' tomato seed per well. Seeds were sown on 19 Aug. 2007 (Expt. 1) or 6 Sept. 2008 (Expt. 2). The sowing depth was 2 mm. All the wells were then covered with an insulating and evaporation-reducing layer of vermiculite (no. 3 granules between 1 and 4 mm size with density between 60 and 90 kg·m⁻³).

Water was then added to saturate the substrate and the trays were placed in a pre-germination chamber at 27 °C and 98% relative humidity for 5 d. They were then removed and placed on greenhouse benches (height 60 cm). In both experiments, 0.5 L of water with 1.3 dS·m⁻¹ EC was applied through sprinkle irrigation

during the first 10 d after sowing (DAS). From 11 DAS, fertigation was applied every day evenly (with microsprinklers) for all treatments. Fertilization was provided with 0.5 g·L⁻¹ potassium nitrate (13N-0P-38.2K) + 0.3 g·L⁻¹ potassium dihydrogen phosphate (0N-22.7P-27.4K) + 0.2 g·L⁻¹ ammonium nitrate (33.5N-0P-0K). The volume of water and fertilizers applied at the beginning was 0.5 L/tray. At 20 DAS, the volume was increased to 0.8 L/tray. Finally, on day 28 (DAS), the volume of water was increased to 1 L/tray, remaining at such a level until the end of the crop season.

Both experiments had a randomized block design with 11 treatments (Table 1) and four blocks (four trays consisting of 150 cells each); effects of the variable experiment were taken into account in the analysis of variance (ANOVA). Thus, in each experiment, 6600 seeds were sown. Trays were arranged in the central area of the greenhouse to avoid border effects.

To determine the chemical variation of each substrate over the two experiments, EC and pH were recorded before sowing and after the growth of the seedlings using a conductivity meter and a pH meter with a precision of 0.1 units (HI-9811; Hanna Instruments, Eibar, Spain).

In both experiments, percentage emergence (both cotyledons extended above the substrate) was assessed at 5, 7, 9, 11, and 13 DAS. The emergence rate was also calculated using the modified version of the Timson index: $\Sigma G/t$, where G is the number of seeds that emerge in

Table 1. Composition of the substrate treatments used for production of tomato transplant in Almería, Spain in 2007 and 2008.

Treatments ^a	Composition of the substrates (% v/v)					
	Blond peat	Black peat	Coconut fiber	Compost	Perlite A-13	Vermiculite
P	90	0	0	0	5	5
HNS	45	10	35	0	5	5
VW2.5	81	0	0	9	5	5
VW3.5	76	0	0	14	5	5
VW4.5	72	0	0	18	5	5
VP2.5	54	0	0	36	5	5
VP3.5	36	0	0	54	5	5
VP4.5	0	0	0	90	5	5
UW2.5	76	0	0	14	5	5
UW3.5	69	0	0	21	5	5
UW4.5	66	0	0	24	5	5

^aP = peat, HNS = habitual nursery substrate, VW = vegetable waste compost, VP = vine pomace compost, UW = solid urban waste compost; numbers (2.5, 3.5, and 4.5) following VW, VP, and UW indicate the initial electrical conductivity (EC_i) of the saturated extract in dS·m⁻¹ (1 dS·m⁻¹ = 1 mmho/cm).

Table 2. Chemical characteristics of the substrate treatments used for production of tomato transplants in Almería, Spain in 2007 and 2008.

Treatments ^z	EC (dS·m ⁻¹) ^z	Nitrates (mg·L ⁻¹) ^y	Sulfates (mg·L ⁻¹)	Chlorides (mg·L ⁻¹)	Phosphorus (mg·L ⁻¹)	Sodium (mg·L ⁻¹)	Potassium (mg·L ⁻¹)	Calcium (mg·L ⁻¹)	Magnesium (mg·L ⁻¹)
P	0.62	20	296	23	29	29	79	111	15
HNS	0.72	15	196	86	33	71	164	45	11
VW2.5	2.5	19	516	831	27	172	557	181	75
VW3.5	3.5	18	638	1280	26	251	823	221	108
VW4.5	4.5	17	735	1639	25	314	1035	252	134
VP2.5	2.5	1446	1385	431	17	108	1291	235	51
VP3.5	3.5	2160	1930	635	12	147	1897	296	69
VP4.5	4.5	3587	3020	1042	0	226	3110	420	105
UW2.5	2.5	63	1603	1161	24	611	545	557	86
UW3.5	3.5	85	2257	1729	22	902	778	780	121
UW4.5	4.5	94	2537	1973	21	1026	878	875	136

^zP = peat, HNS = habitual nursery substrate, VW = vegetable waste compost, VP = vine pomace compost, UW = solid urban waste compost; numbers (2.5, 3.5, and 4.5) following VW, VP, and UW indicate the initial electrical conductivity (EC_i) of the saturated extract in dS·m⁻¹ (1 dS·m⁻¹ = 1 mmho/cm).

^y1 mg·L⁻¹ = 1 ppm.

intervals of 2 d and t is the total time over which emergence was recorded (Khan and Ungar, 1998). At the end of the growth period (34 d), 16 seedlings per tray were randomly selected and the following variables were recorded: plant height (from the soil surface to the tip of the seedling), stem diameter measured just under the cotyledons using a digital caliper (sensitivity = 0.1 mm, model CDE300; Medid Precision, Barcelona, Spain), etiolating ratio (height/diameter), number of leaves per seedling (excluding the cotyledons), total leaf area per seedling measured using Photoshop CS3 Extended software (Adobe Systems, San Jose, CA), and total dry weight, root dry weight, stem dry weight, and leaf dry weight using a balance (sensitivity = 0.0001 g, model AB54-S; Mettler-Toledo International, Basel, Switzerland) after drying the plants in an oven at 80 °C for 48 h. The distribution of weight between the different parts of the plant was calculated, as well as the specific leaf area [SLA (the leaf surface area per unit of dry leaf weight)] and the leaf area/total dry weight ratio (LADMR). Both ratios can be used to assess resistance to transplantation stress; smaller values indicate greater stress vulnerability (Herrera et al., 2008).

Data collected in both experiments were subjected to two types of ANOVA. In the first experiment, 11 treatments were analyzed according to the linear model $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \epsilon_{ijk}$ where Y_{ijk} is the ijk -th observation, μ is the overall mean of the variable in question, α_i

is the effect of the i -th treatment, β_j is the effect of j -th experiment, $(\alpha\beta)_{ij}$ is the effect of the interaction treatment $\times$ experiment, τ_k is the effect of the k -th block, and ϵ_{ijk} is the experimental error. The second type of ANOVA experiment assessed the effect of the interaction compost type $\times$ EC_i. Therefore, the control treatments P and HNS (see Table 1) were not taken into account. The linear model for this analysis was $Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \gamma_l + \epsilon_{ijkl}$ where Y_{ijkl} is the $ijkl$ -th observation, μ is the overall mean of the variable in question, α_i is the effect of the i -th compost, β_j is the effect of the j -th EC, $(\alpha\beta)_{ij}$ is the effect of the interaction compost type $\times$ EC_i, τ_k is the effect of the k -th block, γ_l is the effect of l -th experiment, and ϵ_{ijkl} is the experimental error. The analysis of variance was carried out using the data of both experiments. Comparison between mean results for each treatment was undertaken using the multiple range tests (least significant difference method) (Gómez and Gómez, 1984). All calculations were made using Statgraphics software (version 4.0; Statpoint Technologies, Warrenton, VA).

Results and discussion

CHEMICAL PROPERTIES (pH AND EC) OF THE SUBSTRATES. Significant differences were found between the substrates in terms of initial (pH_i) and final (pH_f) pH (Table 3).

pH_i varied from 6.08 to 7.58, and pH_f from 6.3 to 7.4 (Table 3). These values are slightly higher than the 5.3 to 6.5 considered to be the

optimum level for seedbed substrates (Abad et al., 2001). Other authors indicate that most greenhouse crops grow better in substrates with a pH of 5.2 to 7.0 (Raviv et al., 1986). The final EC values of the saturated extract (EC_f) and their increase with respect to EC_i was determined (Table 3). No significant differences were found between the EC_f values for any of the substrates investigated, which ranged between 4.6 and 6.6 dS·m⁻¹ (Table 3). These values are higher than the 3.5 dS·m⁻¹ recommended by Lemaire et al. (1985) and Wright (1986) as the limit for optimum growth and development of seedlings in nurseries, but below the limit of 8 dS·m⁻¹ proposed by Cuartero and Fernández-Muñoz (1999) for tomato crops. A greater change in EC was observed for substrates having a lower EC_i (Table 3). These results show that salts added in fertilization that are not absorbed by the plant accumulate and remain in the substrate until a certain concentration value is reached and the excess is eliminated by leaching.

EFFECT OF SUBSTRATES ON PLANT EMERGENCE AND THE EMERGENCE RATE. Seedling emergence was significantly affected by the substrate (Fig. 1). Increase of EC_i in the substrate mix delayed the emergence, thus reducing the emergence rate in tomato seeds (Table 4, Fig. 1). The emergence rate and the germination percentage were strongly related to the EC_i of the substrate (Cuartero and Fernández-Muñoz, 1999). At 13 DAS, the emergence percentage was >95% in all substrates except for those

Table 3. pH and electrical conductivity (EC) of the different substrate mixtures used for production of tomato transplants before and after the growth period. Mean EC at the end of the seedling growth period (EC_f) and increase in EC ($\Delta EC = EC_f - EC_i$) with respect to the initial (EC_i) of the different treatments. Mean pH at the start and the end of the seedling growth period (pH_f) and increase in pH ($\Delta pH = pH_f - pH_i$) with respect to the initial (pH_i) of the different treatments. ($n = 8$).

Treatments ^z	EC_f ($dS \cdot m^{-1}$) ^z	ΔEC ($dS \cdot m^{-1}$)	pH_i	pH_f	ΔpH
P	6.4 a	5.8 a	6.83 cd	6.55 bcd	-0.28 bc
HNS	6.2 a	5.5 a	6.54 de	6.46 bcd	-0.09 b
VW2.5	6.3 a	3.8 bc	6.08 f	6.31 d	0.23 a
VW3.5	6.1 a	2.6 cde	6.09 f	6.35 cd	0.26 a
VW4.5	6.2 a	1.7 ef	6.14 ef	6.43 bcd	0.29 a
VP2.5	5.8 a	3.3 bcd	7.06 bc	6.66 b	-0.40 c
VP3.5	5.7 a	2.2 def	6.82 cd	6.58 bc	-0.24 bc
VP4.5	4.6 a	0.1 g	6.83 cd	6.54 bcd	-0.29 bc
UW2.5	6.6 a	4.1 b	7.58 a	7.17 a	-0.41 c
UW3.5	6.3 a	2.8 cde	7.50 ab	7.36 a	-0.14 bc
UW4.5	5.5 a	1.0 fg	7.56 a	7.39 a	-0.17 bc
Significance ^y	NS	***	***	***	**

^zP = peat, HNS = habitual nursery substrate, VW = vegetable waste compost, VP = vine pomace compost, UW = solid urban waste compost; numbers (2.5, 3.5, and 4.5) following VW, VP, and UW indicate the initial electrical conductivity (EC_i) of the saturated extract in $dS \cdot m^{-1}$ ($1 dS \cdot m^{-1} = 1 mmho/cm$).

^yANOVA taking into account the 11 treatments according to the model $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \epsilon_{ijk}$. NS = not significant; *, **, *** $P \leq 0.05, 0.01$, and 0.001 , respectively.

Fig. 1. (A) Emergence of the tomato seedling in the different treatments ($n = 4$); P = peat, HNS = habitual nursery substrate, VW = vegetable waste compost, VP = vine pomace compost, and UW = solid urban waste compost; VW, VP, and VW followed by 2.5, 3.5, and 4.5 indicate the initial electrical conductivity (EC_i) of the saturated extract in $dS \cdot m^{-1}$. (B) Effect of substrate on tomato emergence ($n = 12$). (C) Effect of substrate EC_i (2.5, 3.5, and 4.5 $dS \cdot m^{-1}$) on tomato emergence ($n = 12$); $1 dS \cdot m^{-1} = 1 mmho/cm$.

containing UW (3.5 and 4.5), all of which had significantly smaller values (even compared with the controls). The final germination percentage was smaller in the UW3.5 and UW4.5 mixtures (Table 4, Fig. 1). Differences were found between the EC_i values of the UW compost and the other two composts, VW and VP, as well as between 2.5 and 4.5 $dS \cdot m^{-1}$. Besides, significant interaction between compost type $\times EC_i$ was shown, leading to a differential effect only between compost UW and EC_i (Tables 4 and 5). Nitrogen compounds dissolved in the substrate promote

seed germination (Bethke et al., 2006; Hendricks and Taylorson, 1974). However, this was not the case in our experiments because there were no germination differences between the treatment with the highest nitrate concentration (VP4.5) and the treatment with the lowest nitrate concentration (HNS). The fact that at similar EC_i values (2.5, 3.5, or 4.5) VW and VP composts showed different emergence rates than the UW compost might have been caused by a higher presence of sodium and chlorine in the mix, just as it happened with the UW compost (Table 2).

EFFECT OF SUBSTRATES ON SEEDLING MORPHOLOGY. pH and EC_i of the compost mixtures have a direct impact on seedlings' morphology and may affect their height, diameter, and the height/diameter ratios (Tables 4 and 5). In both experiments, taller plants were produced with treatments VW3.5 (13.6 cm), VW4.5 (14 cm), and VP2.5 (13.9 cm), while the shortest plants were produced with treatment UW4.5 (9.3 cm). Plants of treatments VW4.5 and VP2.5 were significantly taller than those in the blank control (treatment P), while those of treatments UW3.5 and UW4.5 were significantly smaller (Table 4). Seedlings of HNS, UW3.5, and UW4.5 treatments had smaller diameters, while those of P, VW2.5, VW3.5, VW4.5, VP2.5, VP3.5, VP4.5, and UW2.5 treatments were significantly thicker (Table 4).

The type of compost and the EC_i significantly affected the height and diameter of the stem; besides, a significant interaction was observed in the two variables among the three EC_i levels of the three different types of compost. The height and diameter of plants decreased as EC_i increased, as previously reported by Romero-Aranda et al. (2001). In the second ANOVA test, it was shown that the VW-containing substrates produced significantly taller and thicker diameter seedlings than other compost-containing substrates. UW-containing substrates produced the shortest and thinnest seedlings (Table 5).

Table 4. Effect of different mixtures of substrate—with different electrical conductivity (EC_i) values—on seedling emergence and the emergence rate (13 d after sowing, $n = 8$), seedling morphology, plant dry weight production, and leaf indices (34 d after sowing, $n = 64$).

Treatments ^a	Emergence		Seedling morphology			Dry matter production				Leaf indices			
	(%)	rate	Plant ht (cm) ^y	Stem thickness (mm) ^y	Ht/diam	Root dry wt (mg/plant) ^y	Stem dry wt (mg/plant)	Leaf dry wt (mg/plant) ^y	Total dry wt (mg/plant)	Leaves (no.)	Leaf area (cm ²) ^y	SLA (cm ² ·g ⁻¹) ^y	LADMR (cm ² ·g ⁻¹) ^y
P	94.9 ab	7.3 ab	12.7 cde	2.9 a	43.8 e	64 de	112 de	157 e	334 g	4.1 def	56.4 d	361 b	171 bcd
HNS	97.4 a	7.5 a	11.5 g	2.4 f	47.3 d	54.0 g	82.0 f	121 f	257 i	3.9 f	36.2 f	294 f	137 c
VW2.5	97.4 a	7.5 a	13.1 bcd	2.8 abc	47.8 cd	77.0 a	144 a	228 a	449 a	4.5 ab	75.9 a	344 bc	174 b
VW3.5	96.9 a	7.5 a	13.6 abc	2.7 cd	50.5 ab	71 bc	132 b	217 ab	421 bc	4.5 ab	66.4 b	319 de	164 cd
VW4.5	96.9 a	7.5 a	14.0 a	2.8 bc	50.7 a	69 cd	120 cd	200 c	387 de	4.4 bc	60.8 c	314 e	162 d
VP2.5	95.3 ab	7.3 ab	13.9 ab	2.8 abc	50.3 abc	74 ab	144 a	223 a	438 ab	4.4 abc	73.3 a	337 cd	170 bcd
VP3.5	96.7 a	7.4 a	13.0 cd	2.8 ab	46.8 de	70 bc	128 bc	208 bc	404 cd	4.6 a	67.4 b	337 cd	173 bc
VP4.5	94.8 ab	7.3 ab	12.2 ef	2.6 de	46.1 de	59 f	107 e	184 d	349 fg	4.4 bc	60.9 c	353 bc	187 a
UW2.5	91.8 b	7.1 b	12.4 def	2.6 e	48 bcd	69 bc	108 e	186 d	363 ef	4.3 cd	61.5 c	350 bc	175 b
UW3.5	86.9 c	6.7 c	11.7 fg	2.5 f	47.2 d	60 ef	80 f	151 e	291 h	4.2 de	53.9 d	387 a	195 a
UW4.5	83.6 c	6.4 c	9.3 h	2.4 f	38.9 f	53 g	62 g	127 f	243 i	4.1 ef	43.9 e	360 b	189 a
Significance ^y	***	***	***	***	***	***	***	***	***	***	***	***	***

^aP = peat, HNS = habitual nursery substrate, VW = vegetable waste compost, VP = vine pomace compost, UW = solid urban waste compost; numbers (2.5, 3.5, and 4.5) following VW, VP, and UW indicate the initial EC_i of the saturated extract in $dS\cdot m^{-1}$ ($1\ dS\cdot m^{-1} = 1\ mmho/cm$).

^y1 cm = 0.3937 inch, 1 mm = 0.0394 inch, 1 mg = 3.5274×10^{-5} oz, $1\ cm^2 = 0.1550\ inch^2$, $cm^2\cdot g^{-1} = 4.3942\ inch^2/oz$.

^zANOVA taking into account the 11 treatments according to the model $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \epsilon_{ijk}$; *, **, *** $P \leq 0.05$, 0.01, and 0.001, respectively.

As indicated by Herrera et al. (2008), the growth of seedlings was clearly influenced by the EC_i of the substrate. Furthermore, differences found between the composts and their interaction with the EC_i (Table 5) show that differences in nutrient concentration of the initial mixes (Table 2) have an impact on the height and diameter of plants. The same effect is produced by the presence of more toxic salts at the same EC_i value, for instance, the high sodium and chlorine levels found in UW compost mixes.

SUBSTRATES IMPACT ON SEEDLING DRY WEIGHT. The effect of different substrates and the interaction compost type $\times$ EC_i on seedling dry weight were analyzed (Tables 4 and 5). Leaf, root, and total dry weights of the plants in the regular nursery substrate (HNS) and in UW4.5 were significantly smaller than in all other treatments.

UW4.5 treatment produced seedlings with the lowest stem dry weight. Treatments VW2.5 and VP2.5 produced plants with stem dry weight significantly greater than those recorded for all other treatments. VW2.5 produced the greatest root and total dry weights, showing significant differences with other treatments except with VP2.5. VW2.5 produced the greatest leaf dry weight, although there were no differences with VP2.5 and VW3.5 (Table 4). The differences seen may be associated with the EC_i , the higher presence of sodium and chlorine for the same EC_i value, and the nutrients associated with each type of compost (Table 2).

The type of compost used as well as the EC_i value had an impact on the dry weight of seedlings, besides the interaction of compost type $\times$ EC_i with all dry weight variables. For an increasing EC_i (Tables 4 and 5), the UW compost had the highest impact on dry weight. Different composts with the same EC_i value had different effects; therefore, the differences may be linked to the presence of nutrients and the contents of sodium and chlorine in the original mixes (Table 2). The VW compost produced plants with the largest root, shoot, leaf, and total dry weights, followed by the treatments with the VP compost, and finally those with the UW compost. Within each compost type, all dry matter variables became smaller as EC_i increased. These findings had

Table 5. Effect of different compost and different electrical conductivity (EC_e) values on seedling emergence and the emergence rate (13 d after sowing, $n = 24$), seedling morphology, plant dry weight production, and leaf indices (34 d after sowing, $n = 64$).

Treatments	Emergence		Seedling morphology				Dry matter production				Leaf indices			
	(%)	rate	Plant ht (cm) ^y	Stem ht (mm) ^y	Stem thickness (mm) ^y	Ht/ diam	Root dry wt (mg/plant) ^y	Stem dry wt (mg/plant)	Leaf dry wt (mg/plant)	Total dry wt (mg/plant)	Leaves (no.)	Leaf area (cm ²) ^y	SLA (cm ² ·g ⁻¹) ^y	LADMR (cm ² ·g ⁻¹) ^y
Compost ^z														
VW	97.1 a	10.1 a	13.6 a	2.7 a	2.7 a	49.7 a	72 a	132 a	215 a	419 a	4.45 a	67.7 a	326 c	167 c
VP	95.6 a	10.4 a	13.0 b	2.6 b	2.6 b	47.7 b	67 b	126 b	205 b	397 b	4.46 a	67.2 a	342 b	177 b
UW	87.5 b	5.9 b	11.1 c	2.5 c	2.5 c	44.7 c	61 c	84 c	155 c	299 c	4.18 b	53.1 b	366 a	186 a
Significance ^x	***	***	***	***	***	***	***	***	***	***	***	***	***	***
EC_e (dS·m ⁻¹) ^w														
2.5	94.8 a	9.9 a	13.1 a	2.7 a	2.7 a	48.7 a	73 a	132 a	212 a	417 a	4.40 a	70.2 a	344 a	173 a
3.5	93.5 ab	8.8 ab	12.8 a	2.7 a	2.7 a	48.2 a	67 b	114 b	192 b	372 b	4.41 a	62.6 b	348 a	177 a
4.5	91.8 b	7.8 b	11.8 b	2.6 b	2.6 b	45.3 b	60 c	96 c	170 c	326 c	4.28 b	55.2 c	342 a	179 a
Significance ^x	*	*	***	***	***	***	***	***	***	***	*	***	ns	ns
Compost × EC_e ^x	*	*	***	***	***	***	*	*	**	**	NS	NS	***	***

^xVW = vegetable waste compost, VP = vine pomace compost, UW = solid urban waste compost.^y1 cm = 0.3937 inch, 1 mm = 0.0394 inch, 1 mg = 3.5274 × 10⁻⁵ oz, 1 cm² = 0.1550 inch², cm²·g⁻¹ = 4.3942 inch²/oz.^zANOVA without taking into account the controls according to the model $Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \tau_k + \gamma_l + \epsilon_{ijkl}$; NS = not significant; *, **, *** $P \leq 0.05$, 0.01, and 0.001, respectively.^w1 dS·m⁻¹ = 1 mmho/cm.

been reported before by Al-Karaki (2000), who studied the effects of sodium chloride on the roots of tomato, determining that the greater the salinity the poorer the root growth (expressed as dry matter).

EFFECT OF SUBSTRATES ON LEAF GROWTH RATE. Substrates had a significant impact on the number of leaves produced and the leaf area. Treatment VP3.5 produced plants with the greatest number of leaves, although there were no significant differences compared with VW2.5, VW3.5, and VP2.5. Treatments VW2.5 and VP2.5 produced plants with a significantly greater leaf area than the rest of treatments. On the other hand, HNS produced the fewest leaves, although no differences were found with UW4.5 and P. UW4.5 produced plants with significantly smaller leaf area than the rest of treatments, followed by HNS (Table 4).

The UW compost was significantly worse in terms of number of leaves produced and leaf area, probably because of high concentrations of sulfates, chlorides, and sodium (Table 2). The interaction compost type × EC_e had no significant effect on these variables (Table 5). Other authors (Al-Karaki, 2000; Romero-Aranda et al., 2001) have reported that the values of both variables decrease depending on the stress term, the plant species, and the cultivar involved.

Plants in HNS treatment had SLA and LADMR values significantly smaller than those grown under all other conditions, so their leaves were more compact and dense. As Herrera et al. (2008) reported, this finding suggests that these plants show greater resistance to transplantation stress despite their poorer morphology and their lower dry weight values (Table 4). The VW compost was associated with significantly lower SLA and LADMR values than VP and UW composts. In contrast, EC_e had no influence on SLA and LADMR values, although the interaction compost type × EC_e did have a significant influence. Each type of compost showed a different behavior when EC_e changed (Table 5).

Conclusions

The final germination percentage, emergence rate, plant morphology, and dry weight values were all

found to be strongly affected by the EC_i values of the substrates, as well as by their composition. Different compost-containing mixes with the same EC_i value had different effects on germination, emergence, and the quality of seedlings produced as a consequence of high sodium and chlorine levels found in the original mix.

Partial substitution of peat by compost in nursery tomato seedbed substrate is viable; however, the ratio depends upon the physical and chemical characteristics of the compost used.

When substrates are prepared, VW and VP compost ratio should not lead to a resulting mix with an EC_i higher than 2.5 dS·m⁻¹. Stronger concentration of nutrients in VP and VW composts will promote better plant growth; although such effect does not necessarily mean that the plant quality will be higher. Plants grown in regular nursery substrates had the lowest SLA and LADMR values. Indeed, if the substrate already has high nutrient concentration levels, growers would save money by not having to apply high fertilization rates. Furthermore, the resulting seedlings would be more compact and presumably more resistant to transplantation despite their poorer morphological characteristics and lower dry weight.

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