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Benefits of Vermicompost as a Constituent of Growing Substrates Used in the Production of Organic Greenhouse Tomatoes

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***Abstract*. Six individual growing substrate components were selected. From the individual components, 35 growing substrates were constructed. Preliminary analyses, which included pH, electrical conductivity, and macro- and micronutrient concentrations, combined with environmental and cost implications were conducted to identify which substrates had the appropriate properties for growing tomatoes. From the 35 combinations, four growing substrates were chosen as having preferred properties required for organic greenhouse tomato production. A 22-week growth experiment was performed to determine if any of the selected substrates could improve the marketable yield of tomatoes when compared with rockwool (RW) under greenhouse conditions. The greenhouse crop used for this experiment was *Lycopersicon esculentum* 'beefsteak' tomato, cultivar Matrix F1 Hybrid. Within the experiment, Forterra Royal GRO 1 (GRO 1; coconut coir/vermicompost) and Forterra Royal GRO 2 (GRO 2; aged pine bark/coconut coir/vermicompost) attained significantly higher marketable yields per plant compared with the plants grown in RW. A similar trend was seen in the incidence of Blossom End Rot (BER) with GRO 1 and GRO 2 having reduced numbers of BER incidences per plant when compared with RW. In conclusion, the addition of vermicompost to organic growing substrates is beneficial for tomato growth and yield.**

Organic production has seen an exponential rise in popularity in recent years with international sales doubling since 2000 and reaching a market value of $38.6 billion U.S. in 2006 (Willer et al., 2008). However, protocols for organic horticultural production systems are still in their infancy. Limited information is available when compared with the vast amount of knowledge accumulated for conventional practices (Martin, 2001). Greenhouse vegetable growers are particularly in need of more research focusing on organic production because there is little technical information available for this sector (Peet et al., 2004; Rippy et al., 2004). An optimum quality growing substrate is one of the most important components involved in successful production, because it directly affects the availability of water and nutrients to the plant. Materials such as aged pine bark, coconut coir, compost, peatmoss, perlite, sand, vermiculite, and wood byproducts (e.g., sawdust, composted pine bark) can potentially be used as growing medium components for organic horticultural production systems. These materials all have beneficial properties for plant growth, but none are suitable as a sole constituent. Research has been conducted on organic horticultural production systems; however, the vast majority has focused on the effects of organic fertilizers (Hadas and Kautsky, 1994; Heeb et al., 2005). There has been research conducted on growing substrates for organic production; however, the volume of research is limited. Peet et al. (2004) conducted an experiment using an organic substrate (70% sphagnum peatmoss/30% perlite) and three organic fertilizers. They concluded that nutrient availability, pH, and electrical conductivity (EC) were important parameters that needed to be monitored regularly and that organic fertilizer concentrations could be based on conventional nutrient solution concentrations. To optimize organic production methods, Rippy et al. (2004) conducted research using two organic fertilizers and two organic substrates: 1) 85% Fafard's Special Organic Mix (Fafard, Anderson, SC)/15% Vermicycle worm compost (Vermicycle Organics, Charlotte, NC) composed by volume (v/v); and 2) 63% Scott's 366 coconut coir (Scotts, Marysville, OH)/22% composted pine bark/15% Vermicycle worm compost (v/v). They concluded that greenhouse tomatoes produced organically were comparable to those produced conventionally in regard to nutritional status, plant development, and harvest yields.

Marketable yields of organic horticultural crops are frequently below conventional crop yields (Martin, 2006) and this is restricting widespread adoption of organic production. More research is needed to provide a base of information that will lead to the expansion of the organic sector, especially in the greenhouse industry, to meet consumer demands and preferences. The objective of this research was to study the growth and yield responses of greenhouse tomatoes grown in four organic substrates as compared with rockwool.

Materials and Methods

Growing substrate design. Six individual growing substrate components were selected. From the individual components, 35 growing substrates were constructed. Preliminary analyses were conducted on the 35 growing substrates to identify which substrates had the appropriate properties for growing tomatoes. The evaluation criteria used were pH, EC, and macro- and micronutrient concentrations, which were combined with environmental and cost implications. The preferred pH range for greenhouse crops grown in soilless media is 5.5 to 6.5 (Ministry of Agriculture and Food, 1999). From the 35 growing substrates, substrates with initial values for pH ranging between 6.0 and 7.0 were chosen; however, the substrates needed to have a fairly low pH as many growing substrates (i.e., composts) tend to have a very high pH making them too alkaline for successful nutrient uptake for plant growth. The pH values were therefore lowered with the addition of elemental sulfur. EC needed to be ≈1 to 2 $mS\cdot cm^{-1}$, reducing the need for additional granular fertilizers. The use of peatmoss within the growing substrates has environmental implications because peatmoss is a finite resource; therefore, mixtures containing peatmoss were not used. In Canada, peatmoss (containing no synthetic wetting agents) can be used in organic horticultural production systems.

It was decided that the previously mentioned parameters enabled a quick and informative analysis that would aid in the identification of suitable growing substrates. From the 35 preliminary substrates, four substrates with promising characteristics were selected and used in this study to evaluate the effects on the growth and marketable yield of organically grown greenhouse tomatoes. The four growing substrate combinations (v/v) were: 1) Substrate 1: Forterra Royal GRO 1 (GRO 1), coconut coir (Coarse grade; Millenniumsoils Coir Inc., St. Catharines, Ontario, Canada)/vermicompost (Forterra Inc., Puslinch, Ontario, Canada); 2) Substrate 2: 70% coconut coir/30% composted manure (Pig/Horse Manure; Dingo Farms, Bradford, Ontario, Canada); 3) Substrate 3: 40% coconut coir/30% composted manure/15% perlite (US Grade No. 3; Canadian Hydro-Gardens Ltd., Ancaster, Ontario, Canada)/15% vermiculite (US Grade No. 3; Plant Products Co. Ltd., Brampton, Ontario, Canada); and 4)

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Substrate 4: Forterra Royal GRO 2 (GRO 2), aged pine bark (15 mm or less; Gro-Bark Ltd., Milton, Ontario, Canada)/coconut coir/vermicompost. The percentages of the components for GRO 1 and GRO 2 are confidential because the recipes have been licensed to Forterra Inc. (Puslinch, Ontario, Canada). The control used rockwool (RW) as the growing substrate and conventional inorganic soluble fertilizers, RW being a common substrate used in soilless culture (Heuvelink, 2005). Over half of the vegetable growers in Ontario, Canada, use RW for greenhouse vegetable production [Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2009].

Previous research has shown that the incorporation of large amounts of granular fertilizer into a growing substrate resulted in an initial high EC and pH, both of which subsequently declined rapidly (Peet et al., 2004). Within this experiment, granular fertilizers were used to adjust the total nitrogen (N), phosphorus (P), and potassium (K) values to a ratio of 1–0.4–1.6. The four organic growing substrates had a total N concentration of 165 mg·L^{-1}. Lower rates of K were added to the growing substrates as K is easily leached out. Additional K was supplied by fertigation. Granular fertilizer additions to the organic growing substrates included: Spanish River Carbonatite ™ and Rock Phosphate (Chatham-Kent Organic Epicentre, Dresden, Ontario, Canada), Basalt (rock dust; Les Engrais Naturels McINNES Inc., Stanstead, Quebec, Canada), and Acti-sol (hen manure; Acti-Sol Inc., St-Wenceslas, Quebec, Canada). Elemental sulfur (fine powder, 99.9%; Canadian HydroGardens Ltd., Ancaster, Ontario, Canada) was used to lower the pH to ≈5.7 based on information obtained for modifying the pH of various types of media (University of Missouri Extension, 2008).

Physical and chemical analyses. European Committee for Standardization (CEN) standards were used to establish the pH (EN 13037 Annex A) and EC (EN 13038) of the various individual growing substrate components and the four growing substrates [International Society of Horticultural Science (ISHS), 2003]. A portable Oakton pH/Con 300 Meter (Oakton Instruments, Vernon Hills, IL) was used to measure pH and EC. The bulk density was measured using the CEN standard, EN 13040 Annex A (ISHS, 2003). A 1:2 extraction ratio was used to analyze the readily available nutrient content of the individual growing substrate components (Handreck and Black, 2002). Analyses were conducted using ion chromatography (DX-120; Dionex Canada Ltd., Oakville, Ontario, Canada). Total porosity (TP), container capacity (CC), and air-filled porosity (AFP) of the four growing substrates were measured using the North Carolina State University porometer (Fonteno and Bilderback, 1993). Physical and chemical characteristics of the individual growing substrate components and the four growing substrates are shown in Tables 1 and 2.

Growth experiment. The experiment was initiated on 20 Apr. 2008 and ended on 26 Sept. 2008. The research was conducted in a glass greenhouse (7.62 × 6.10 m) at the University of Guelph, Guelph, Ontario, Canada.

On 20 Apr. 2008, tomato (*Lycopersicon esculentum* 'beefsteak' tomato, cultivar Matrix F1 Hybrid, untreated; De Ruiter Seeds Inc., Lakewood, CO) seeds were germinated.

On 13 May 2008, the seedlings were transplanted into 90 × 102 × 75-mm (height × upper diameter × lower diameter) containers containing a customized organic transplant growing substrate designed at the University of Guelph. The transplant growing substrate was comprised of Canadian sphagnum peat (less than 4 mm), composted manure (less than 4 mm), perlite (US Grade No.3), and vermiculite (US Grade No.3). For the control transplants, the seedlings were transplanted into 100 × 100-mm RW cubes (Grodan Inc., Milton, Ontario, Canada).

On 9 June 2008, the organic transplants were repotted into 14-L cylindrical containers (280 × 270 × 240 mm, height × upper diameter × lower diameter) containing the four organic growing substrates. The control transplants were placed onto RW slabs (460 mm × 150 mm × 100 mm). One plant per experimental unit was used. Replicates of six were used for both the organic growing substrates and the control substrate, RW. In total, 30 experimental units were used for this experiment. The experimental units were arranged in a completely randomized design across four wooden frames (333 × 64 × 40 cm, length × width × height). The 14-L cylindrical containers were held in the frames. The RW slabs were situated on a stand and placed within the wooden frames.

The experimental setup consisted of four wooden frames that accommodated eight experimental units per frame in a 2 × 4–cell array giving a density of ≈2 plants/m^2. Experimental units were arranged in twin-growing rows 0.6 m apart with a 0.9-m walkway separating the four wooden frames in accordance with the standards for greenhouse tomato production produced by OMAFRA (OMAFRA, 2005).

All organic substrate plants were irrigated with the same liquid organic fertilizer using drip emitters (4 L·h^{-1}) with one emitter per plant. Organic Gem® Liquid Fish fertilizer (Fish; Advanced Marine Technologies; New Bedford, MA), Evergreen Liquid Carbon (Liquid Carbon; Black Earth Humates Ltd., Edmonton, Alberta, Canada), Liquid Seaweed Extract (Acadian Agri-tech, Nova Scotia, Canada), and MetaNaturals Organic Calcium (6% calcium; Planet Natural; Bozeman, MT) were the organic fertilizers used for fertigation. The nutrient concentrations of the organic fertilizers are shown in Table 3. The N–P–K ratio for the liquid organic fertilizer concentrations (fish + liquid carbon) were based on OMAFRA (2005) recommendations for greenhouse tomato production. The concentrations of nutrients were increased by a factor of 0.5, because organic fertilizers have been found to only release 25% to 60% of their N content (Prasad et al., 2004). The pH of the fertigation solution was adjusted using 6% acetic acid (Apple cider vinegar; Bio-Ag Consultants & Distributors Inc., Wellesley,

Table 1. Physical and chemical characteristics of the individual growing substrate components and the organic growing substrates: Forterra Royal GRO 1 (GRO 1), Substrate 2, Substrate 3, and Forterra Royal GRO 2 (GRO 2).

Growing substrate	pH*	Electrical conductivity^z (μS·cm^{-1})	Bulk density^z (g·L^{-1})	Total N	Phosphorus	Potassium	Magnesium	Calcium	Chlorine	Sulfur	Sodium
GRO 1	6.71 ± 0.05	1343 ± 7.2	432 ± 4.1	127.3	5.3	230.1	79.4	81.2	394.5	15.2	106.2
Substrate 2	6.57 ± 0.05	2043 ± 47.9	427 ± 8.9	29.5	27.4	208.1	78.8	79.0	390.6	26.1	104.7
Substrate 3	6.50 ± 0.01	2113 ± 95.9	437 ± 6.4	39.4	33.7	199.9	57.0	58.1	353.0	32.1	80.2
GRO 2	6.67 ± 0.01	1100 ± 47.0	473 ± 5.5	84.9	3.7	159.9	55.5	59.0	272.1	10.3	76.4
Aged pine bark^z	6.36 ± 0.06	67 ± 3.2	468 ± 2.3	0.0	0.0	7.7 ± 0.0	0.0	7.7 ± 0.0	0.71 ± 0.04	0.0	7.9 ± 0.02
Coconut coir^z	6.76 ± 0.01	189 ± 4.6	232 ± 3. 9	0.0	4.3 ± 0.13	124.3 ± 0.68	77.7 ± 0.02	77.7 ± 0.07	265.5 ± 3.1	4.6 ± 0.32	97.7 ± 0.50
Composted manure^z	7.83 ± 0.02	3227 ± 40.2	674 ± 5.1	98.0 ± 3.6	81.1 ± 1.4	403.4 ± 9.1	81.3 ± 0.17	82.1 ± 0.29	682.2 ± 29.3	76.3 ± 1.9	120.9 ± 1.5
Perlite^z	7.54 ± 0.04	24 ± 5.3	118 ± 1.8	0.04 ± 0.0	0.0	0.0	0.0	5.1 ± 3.1	0.67 ± 0.03	0.21 ± 0.02	8.1 ± 0.03
Vermicompost^z	8.70 ± 0.02	1087 ± 13.5	604 ± 1.8	424.4 ± 5.5	7.7 ± 0.42	476.9 ± 5.8	83.5 ± 0.15	89.4 ± 0.26	695.4 ± 10.6	40.1 ± 0.64	125.9 ± 0.78
Vermiculite^z	8.66 ± 0.22	37 ± 2.7	100 ± 3.5	0.44 ± 0.12	0.0	8 ± 0.04	7.7 ± 0.00	7.7 ± 0.01	2.2 ± 1.3	1.2 ± 0.47	9.0 ± 0.48

^{z}The means ± SES were obtained from three replicates. The nutrient concentration (mg·L^{-1}) of the four organic growing substrates were calculated from the readily available nutrient contents of the individual growing substrate components by summing the percentage of each single element obtained from each individual component of the substrate. These values were used to calculate the granular fertilizer additions.

Ontario, Canada) or 1 M $NaHCO_3$. On 5 Aug. 2008, the concentration of the organic fertilizer solution was increased to support the increased fruit load (Stage 2, Table 3). On alternate weeks, plants were supplemented with calcium or micronutrients using drip irrigation; the nutrients' concentrations are shown in Table 3. Control plants were fertigated using 2-L·h^{-1} drip emitters with one emitter per plant. Inorganic soluble fertilizers were used for the fertigation of the control plants. The pH of the fertigation solution was adjusted using 1 M HNO_3 or 1 M KOH. Guidelines for conventional greenhouse tomato fertigation produced by OMAFRA (OMAFRA, 2005) were used throughout the experiment (Table 3).

The pH and EC of the nutrient solutions were monitored daily for both the conventional and organic production. After pH adjustment, the organic fertilizer solution had an average pH of 5.77 ± 0.025. The average adjusted pH for the conventional fertilizer solution was 5.82 ± 0.007. The EC was modified according to the growth and development of the crop. Irrigation scheduling was computer-controlled (Argus Control Systems Ltd., White Rock, British Columbia, Canada) and based on accumulated solar radiation for both the conventional and organic substrates. Plants in the organic growing substrates were fertigated with 500 mL of fertilizer solution for every accumulated 1 to 2 KW·m^{-2} of global solar radiation depending on the growth stage of the plants and the environmental conditions. After each fertigation, the irrigation lines were flushed for 1 min with ≈100 mL of deionized water. The RW plants were fertigated with 100 mL of conventional fertilizer solution for every accumulated 0.3 to 0.6 KW·m^{-2} of global solar radiation depending on the growth stage of the plants and environmental conditions.

The greenhouse environment was set as recommended by OMAFRA (2005). To reduce the temperature at the top of the canopy, roof shade curtains were used when a threshold of greater than1 KW·m^{-2} of total incoming radiation was reached.

Pollination was undertaken manually between 1000 and 1300 HR (Heuvelink, 2005). Weekly maintenance included plant maintenance (deleafing, lowering, cluster clipping) and scouting for greenhouse pest insects. Biological control agents were applied biweekly to suppress pest insects. *Orius insidiosus* (predatory bug) was used to suppress western flower thrip (*Frankliniella occidentalis)*, *Encarsia Formosa* (parasitic wasp) was used to control greenhouse whitefly (*Trialeurodes vaporariorum*), and *Phytoseilus persimilis* (predatory mite) was used to suppress two-spotted spider mite (*Tetranychus urticae*). The perimeter of the growing area contained tomato plants to protect the experimental units; in addition, two guard tomato plants occupied the unused bench cells within the 2 × 4 bench array.

Harvest. Fruit was graded into the following categories: Canada No. 1 Grade (73 mm or greater diameter), Canada Commercial Grade (63 mm or greater diameter), and Canada No. 2 Grade (38 mm or greater diameter; Government of Canada, 1990). Fruits were harvested at a ripeness classification described as "turning" or beyond. Harvesting was conducted three times per week until the termination of the experiment on 26 Sept. 2008 (Weeks 13 to 22). Defective fruit were also recorded throughout the duration of the experiment. Leaf number, stem diameter, and stem length were recorded at the termination of the experiment.

Substrate and leachate chemical analyses. Pour-through extraction (Reed, 1996) was undertaken in Week 20. Leachate was also collected throughout the experiment to monitor the growing substrates pH, EC, nutrient concentrations, and the percentage of leachate. The leachate nutrient content was analyzed using ion chromatography (DX-120).

Statistical analysis. Statistical analyses were conducted using SAS, Version 9.1 (SAS Institute Inc., Cary, NC). Substrate effects were subjected to an analysis of variance using PROC GLM after analyzing the residuals to confirm the variance analysis assumptions; in addition, Lund's test using Studentized residuals was conducted to determine if any of the observations could be declared as outliers (Lund, 1975). Differences among means were tested by Tukey's multiple means comparison test. Fisher's protected least significant difference was used to clarify the least squares means if the *P* value was significant, but Tukey's multiple means comparison was unable to show the difference. A significance level of ≤ 0.05 was used for all statistical tests.

Results and Discussion

Physical characteristics of the organic growing substrates. Significant differences in CC were observed (Table 2). Growing substrates with higher CC are able to attain higher volumetric water contents, which could potentially increase the amount of water readily available to the plants. Growing substrates with increased volumetric water contents have been shown to increase tomato yields. Ismail et al. (2008) showed that increased soil water contents resulting from multiple water applications produced a higher tomato yield. Marouelli and Silva (2007) demonstrated that the number of marketable tomato fruit was linearly increased as the soil water tension decreased. Similar trends of higher tomato yields attained from plants irrigated more frequently were observed by Aroiee et al. (2006) and Tüzel et al. (2001).

Table 2. Physical properties (% vol.) of the organic growing substrates: Forterra Royal GRO 1 (GRO 1), Substrate 2, Substrate 3, and Forterra Royal GRO 2 (GRO 2).

Growing substrate	Total porosity	Container capacity	Air-filled porosity
GRO 1	86.9 b	65.8 a	21.1
Substrate 2	87.1 b	60.5 bc	26.6
Substrate 3	80.1 c	56.8 b	23.3
GRO 2	89.8 a	64.4 ac	25.4
SE	0.58	0.86	1.2
P	<0.0001	0.0003	0.0543

Means were obtained from three replicates. Means followed by the same letter are not significant at $P \leq 0.05$.

Table 3. Fertigation (drip irrigation) schedules and nutrient concentrations (mg·L^{-1}) for the organic and inorganic soluble fertilizers.

Stages of production	Total nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Iron	Manganese	Zinc	Boron	Copper	Molybdenum
Inorganic soluble fertilizers											
Stage A[y]—used to saturate the RW cubes (100 × 100 mm) and for fertigation	210	50	353	247	75	0.8	0.55	0.33	0.5	0.05	0.05
Stage B[y]—used to saturate the RW slabs (460 mm × 150 mm × 100 mm) and for fertigation	190	50	400	190	75	0.8	0.55	0.33	0.5	0.05	0.05
Stage C[y]—normal feed	212	50	400	190	65	0.8	0.55	0.33	0.5	0.05	0.05
Stage D[y]—heavy fruit load	232	50	420	190	75	0.8	0.55	0.33	0.5	0.05	0.05
Organic fertilizers											
Stage 1[z]	300	131	644	178	20	74					
Stage 2[z]	400	171	855	405	26	95					
Liquid seaweed concentrate	38	19	383	6	6	0.42	0.05	0.14	0.27	0.02	
MetaNaturals Organic Calcium				180							

[z]Stages 1 and 2 contained Organic Gem® Liquid Fish fertilizer and Evergreen Liquid Carbon.
[y]Stock solutions containing calcium nitrate, potassium nitrate, ammonium nitrate, monopotassium phosphate, potassium sulphate, potassium chloride, magnesium sulphate, manganese sulphate, zinc sulphate, borax, copper sulphate, sodium molybdate, and iron chelate 13% were used to produce the inorganic fertilizer solution.
RW = rockwool.

All experimental plants were watered with a fixed fertigation volume. GRO 1 and GRO 2 had higher CC and were able to produce higher marketable yields when compared with Substrates 2 and 3. There were significant differences in TP with GRO 2 having a significantly higher value when compared with GRO 1 and Substrates 2 and 3. GRO 2 was the only growing substrate to contain aged pine bark (15 mm or less), which was the largest particle size used in the formulation of the growing substrates. AFP measurements were not significantly different among substrates. The organic substrates had AFP measurements ranging from 21% to 27%, which were within the range of 10% to 30% (Raviv and Heinrich Leith, 2008).

Table 4. Stem diameter, stem length, and leaf number for tomato plants grown using organic and rockwool (RW) growing substrates.[z]

Growing substrate	Stem diam. (mm)	Stem length (cm)	Leaf number
RW	14.71 a	436	53
GRO 1	11.86 b	482	53
Substrate 2	12.36 b	469	53
Substrate 3	11.65 b	447	53
GRO 2	11.53 b	443	49
SE	0.43	12	1
P	<0.0001	0.0658	0.1142

[z]Forterra Royal GRO 1 (GRO 1), Substrate 2, Substrate 3, and Forterra Royal GRO 2 (GRO 2) were organic growing substrates fertigated with organic fertilizers. The control used RW fertigated with inorganic soluble fertilizers. Means were obtained from six replicates. Means followed by the same letter are not significant at $P \leq 0.05$.

Plant growth. The total amount of nutrients added by drip irrigation varied between the RW-grown plants and the plants grown in organic growing substrates (Table 3). The nutrient concentrations of the organic fertigation solution were increased by a factor of 0.5, because organic fertilizers have been found to only release 25% to 60% of their N content (Prasad et al., 2004). As shown in Table 3, this did increase the total N concentrations to levels above the recommendations of OMAFRA (2005); however, excessive amounts of N are known to induce vigorous vegetative growth to the detriment of fruit production (OMAFRA, 2005). This observation was not observed in this experiment. Analysis of the growth parameters (Table 4) showed no significant differences when comparing the stem length or leaf number of RW-grown plants with plants grown in organic substrates. There were significant differences in stem diameter with RW having a significantly larger stem diameter when compared with the plants grown in organic substrates.

Yield. There were no significant differences between No. 1 and No. 2 Grade tomato yields obtained from plants grown in organic growing substrates compared with RW (Fig. 1; P = 0.1203 and 0.1813, respectively); however, there were significant differences in both the marketable and commercial yields obtained from the organic substrates compared with the RW (P = 0.0072 and 0.0007, respectively). GRO 1 and GRO 2 had significantly higher marketable yields per plant when compared with RW. The marketable yields obtained for the numbers of fruits per plant were the highest for GRO 2 (Fig. 1), but when calculated by gram per plant, the marketable yield was the highest for GRO 1 (Table 5). There were no statistical differences between GRO 1 and GRO 2 for either analysis.

The result may be explained by individual components (vermicompost, or composted

Table 5. Marketable yields (g/plant) and number of Blossom End Rot (BER) occurrences per plant obtained from plants grown in organic growing substrates as compared with rockwool (RW).[z]

Growing substrate	Mean marketable yield (g/plant)	Number of BER per plant (no. of BER/plant)
RW	1515 b	25 ab
GRO 1	2787 a	9 c
Substrate 2	2263 ab	30 a
Substrate 3	2065 ab	28 b
GRO 2	2549 a	15 bc
SE	246	3
P	0.0130	0.0004

[z]Forterra Royal GRO 1 (GRO 1), Substrate 2, Substrate 3, and Forterra Royal GRO 2 (GRO 2) were organic growing substrate fertigated with organic fertilizers. The control was RW fertigated with inorganic soluble fertilizers. Means ± SES were obtained from six replicates. Means followed by the same letter are not significantly different at $P \leq 0.05$.

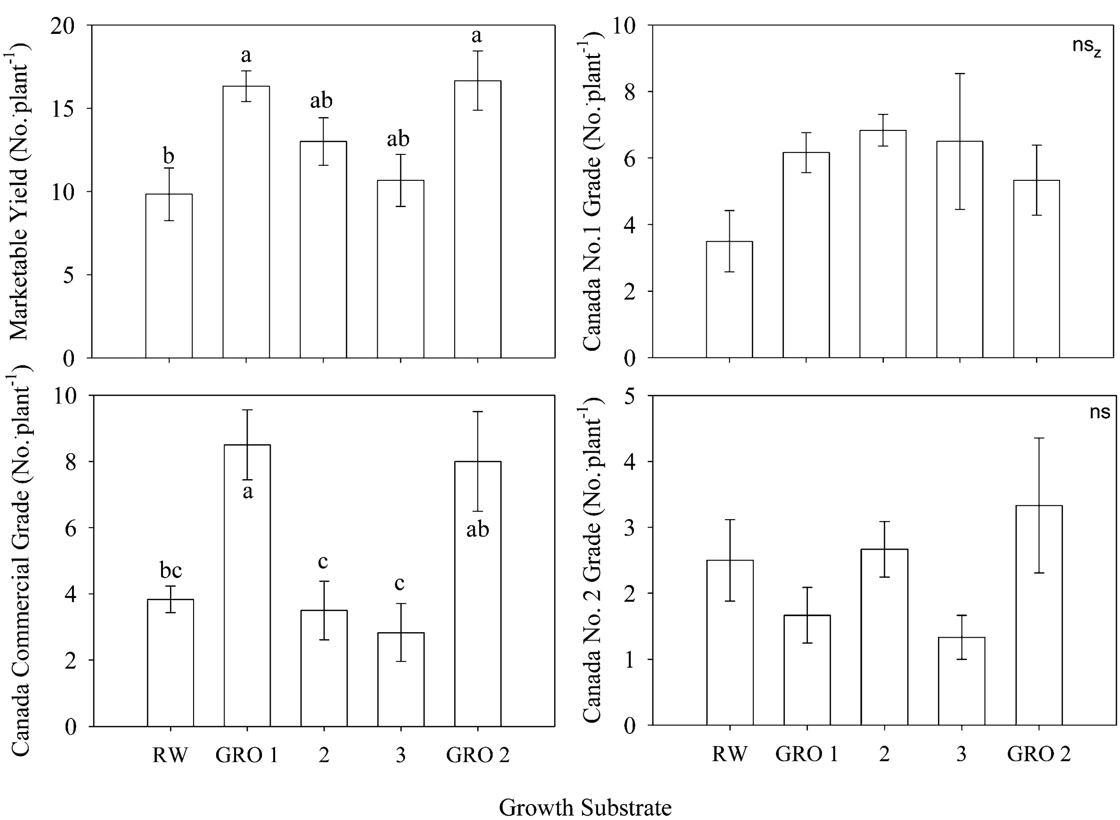

Fig. 1. Greenhouse tomato yields (number of fruit/plant) obtained from plants grown in organic growing substrates compared with plants grown in rockwool (RW). Forterra Royal GRO 1 (GRO 1), Substrate 2 (2), Substrate 3 (3), and Forterra Royal GRO 2 (GRO 2) were organic growing substrates fertigated with organic fertilizers. The control was RW fertigated with inorganic soluble fertilizers. Means ± SES were obtained from six replicates. Means followed by the same letter are not significant at $P \leq 0.05$. [ns] represents non-significant data analysis. [z]Multiple means comparison was analyzed using Fisher's protected least significant difference.

Table 6. Nutrient content (mg·L^{-1}) of the four organic growing substrates.[z]

Growing substrate	Total nitrogen[y]	Phosphorus	Potassium	Magnesium	Calcium	Chlorine	Sulfur	Sodium
GRO 1	211 a	397	697	69	262 a	74[x]	222	488
Substrate 2	122 b	787	644	71	90 b	53	55	357
Substrate 3	124 b	6866	668	94	100 b	50	137	343
GRO 2	110 b	566	502	35	184 ab	67	147	295
SE	18.5	213.8	136.4	9.2	24.2	7.7 (9.5[x])	57.7	184.5
P	0.0165	0.6231	0.7564	0.2592	0.0032	0.2340	0.3199	0.8937

[z]Forterra Royal GRO 1 (GRO 1), Substrate 2, Substrate 3, and Forterra Royal GRO 2 (GRO 2) obtained by pour-through analysis. Means were obtained from three replicates. Means followed by the same letter are not significant at $P \leq 0.05$.
[y]Multiple means comparison was analyzed using Fisher's protected least significant difference.
[x]Outlier removed from data analysis.

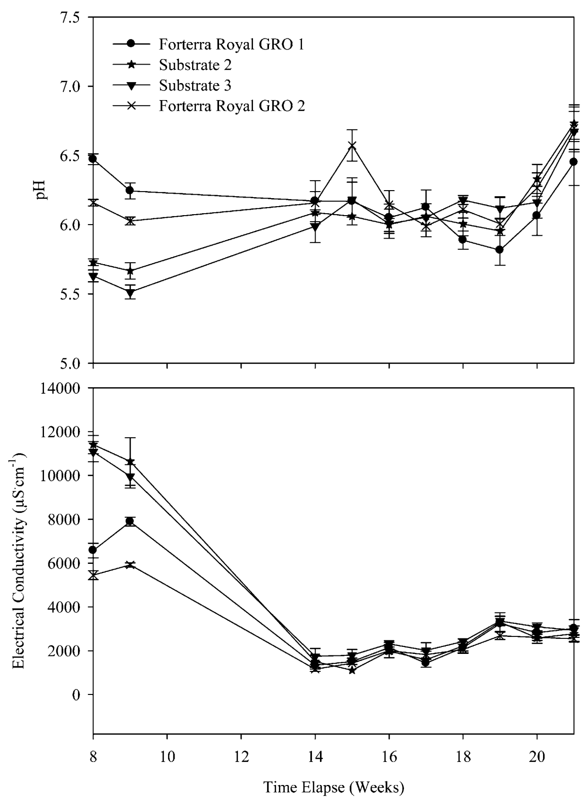

Fig. 2. Leachate pH and electrical conductivity (EC) measurements taken during Weeks 8 to 21. Forterra Royal GRO 1, Substrate 2, Substrate 3, and Forterra Royal GRO 2 were organic growing substrates fertigated with organic fertilizers. Means ± SEs were obtained from six replicates.

manure) of the growing substrates. Both GRO 1 and GRO 2 contained varying proportions of vermicompost. Numerous researchers have found increased yields from the use of vermicomposts (Arancon et al., 2004; Atiyeh et al., 2000; Gutiérrez-Miceli et al., 2007; Zaller, 2007). Arancon et al. (2004) speculated that increased plant growth and yield was an indirect effect of increased microbial populations resulting from the earthworm activities during the vermicomposting process, leading to the production of growth hormones or humates in the vermicompost, which can promote plant growth. Similar findings were observed by Atiyeh et al. (2002) and Tomati et al. (1988). Within Substrates 2 and 3, composted manure was added instead of vermicompost. Many researchers have also found increased yields from the addition of composted waste materials (Pronk, 1995; Ribeiro et al., 2000). There were no statistical differences in marketable yield (on either number or weight per plant basis) among the four organic growing substrates.

Similar results were also observed in the occurrence of blossom end rot (BER) per plant (Table 5). GRO 1 had a significantly lower number of BER fruits per plant when compared with Substrates 2 and 3 and RW-grown plants. The difference in the number of BER fruit per plant between GRO 1 and GRO 2 was not statistically different. Similar findings were reported by Roberts et al. (2007), in which the addition of vermicompost improved the marketability of the fruit by lowering the incidence of physiological disorders, e.g., BER and cracking. Roberts et al. (2007) speculated that structural changes in the growing media resulting from the addition of vermicompost may have induced changes in water availability. Researchers have found increased water-holding capacities of growing substrates as a result of the addition of vermicompost (Gutiérrez-Miceli et al., 2007), therefore potentially increasing water availability to the plant and allowing increased movement of nutrients into the plant. Researchers have also stated that vermicomposts have a favorable cation exchange capacity (Atiyeh et al., 2000), providing a buffer against nutrient changes in the root zone, which decreases fluctuations in nutrient availability.

BER was the principal cause of defective fruit. The four organic growing substrates and RW all exhibited some degree of BER, perhaps as a result of the greenhouse environment (Heuvelink, 2005).

Substrate chemical analyses. Analysis of variance of the pH and EC of the substrates, using the pour-through extraction method, indicated a significant difference in pH obtained for the four organic growing substrates ($P = 0.0376$). Substrate 2 had a significantly higher pH when compared with GRO 2; however, all four organic growth substrates had a pH within the preferred range of 5.5 to 6.5 for most greenhouse crops grown in soilless media (Ministry of Agriculture and Food, 1999). Reed (1996) also stated that a pH of 5.5 to 6.5 was optimum for pour-through measurements. There was no statistical difference in EC among the four organic growing substrates ($P = 0.9601$) with EC ranging from 3240 to 3570 µS·cm^{-1}. Pour-through EC for established plants ranging from 2600 to 4600 µS·cm^{-1} is an indication of a healthy root zone environment (Cavins et al., 2000).

Within the organic growing substrates, there were no statistical differences in P, K, magnesium, chlorine, sulfur, or sodium concentrations obtained from the pour-through analysis (Table 6); however, GRO 1 had a significantly higher total N concentration when compared with Substrates 2 and 3 and GRO 2. The total N concentrations were within or just above the optimum range for greenhouse potting media nitrate concentration (Reed, 1996). Calcium concentration was also significantly higher in GRO 1 when compared with Substrates 2 and 3. The calcium (Ca) concentration in GRO 1 was not statistically different from GRO 2. GRO 1 and GRO 2 had Ca concentrations within or just above the optimum range for greenhouse potting media (Reed, 1996); however, Substrates 2 and 3 were below the optimum range. Many researchers have stated the significance of Ca availability when explaining the occurrence of BER (Banuelos et al., 1985; Heuvelink, 2005; Papadopoulos, 1991).

The percentage of leachate for each substrate was recorded throughout the experiment. There were no significant differences between substrates with the average leachate percentages being 21% ± 4.67, 17% ± 5.01, 19% ± 4.74, and 29% ± 3.40 for GRO 1, Substrate 2, Substrate 3, and GRO 2, respectively. Leachate pH remained fairly constant for the duration of experiment, being within the preferred range of 5.5 to 6.5 (Ministry of Agriculture and Food, 1999) with the exception of Week 21, when there was a slight increase in Substrates 2 and 3 and GRO 2 to pH 6.73, 6.67, and 6.70, respectively (Fig. 2). EC was initially high when compared with conventional tomato growing standards, but usual symptoms from high EC or salinity were not observed in this experiment. The EC then fell when the fertilizer additions that were initially added to the substrates were leached out. A similar trend was observed by Peet et al. (2004).

In conclusion, the addition of vermicompost to growing substrates suitable for organic production was beneficial for tomato growth. The marketable yields obtained from GRO 1 and GRO 2, which contained vermicompost, were significantly higher than the RW-grown tomato plants. Also, the incidence of defective fruit was significantly lower in substrates containing vermicompost when compared with RW-grown tomato plants. Furthermore, it was observed that GRO 1 and GRO 2 had higher CC and were able to produce higher marketable yields.

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