Growth and yield of tomato cultivated on composted duck excreta enriched wood shavings and source-separated municipal solid waste

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Abstract

A greenhouse experiment was conducted to evaluate the use of growth substrates, made with duck excreta enriched wood shaving compost (DMC) and the organic fraction of source-separated municipal solid waste (MSW) compost, on the growth and yield of tomato (*Lycopersicum esculentum* Mill. cv. Campbell 1327). Substrate A consisted of 3:2 (W/W) proportion of DMC and MSW composts. Substrates B and C were the same as A but contained 15% (W/W ratio) of brick dust and shredded plastic, respectively. Three control substrates consisted of the commercially available peat-based substrate (Pr), an in-house sphagnum peat-based substrate (Gs), and black earth mixed with sandy loam soil (BE/S) in a 1:4 (W/W) ratio. Substrates (A, B, C) and controls received nitrogen (N), phosphate (P) and potassium (K) at equivalent rates of 780 mg/pot, 625 mg/pot, and 625 mg/pot, respectively, or were used without mineral fertilizers. Compared with the controls (Pr, Gs and BE/S), tomato plants grown on A, B, and C produced a greater total number and dry mass of fruits, with no significant differences among them. On average, total plant dry-matter biomass in substrate A, B, and C was 19% lower than that produced on Pr, but 28% greater than biomass obtained for plant grown, on Gs and BE/S. Plant height, stem diameter and chlorophyll concentrations indicate that substrates A, B, and C were particularly suitable for plant growth. Although the presence of excess N in composted substrates favoured vegetative rather than reproductive growth, the continuous supply of nutrients throughout the growing cycle, as well as the high water retention capacity that resulted in a reduced watering by 50%, suggest that substrates A, B, and C were suitable growing mixes, offering environmental and agronomic advantages.

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Introduction

In soilless horticulture, organic matter in combination with other growing media (perlite, vermiculite, sand, etc.) is greatly used for the production of growth substrates. Peat is the major source of organic matter for soil amendment and growth media (Papadopoulos, 1991; Gajdos, 1997). The main advantages of peat lie in its physical properties, which allow an adequate water/air ratio in the root zone, and a high cation exchange capacity able to adequately provide nutrient for plant growth and development (Raviv and Medina, 1997; Raviv *et al*., 1998). With increasing regulations to protect peatland ecosystems, the availability of peat is expected to decrease, resulting in an increase in price of organic materials to make growth media. At the same time, landfilling of organic residues is creating environmental concerns whereas the use of such residues for the production of artificial growth media may reduce peat and fertilizer use. Decomposable and non-hazardeous organic residues were considered as suitable substitutes for the production of growth substrates at a lower cost (Pinamonti *et al*., 1997; Garcia-Gomez *et al*., 2002).

The required physical and chemical characteristics of growth substrates vary notable with crop species and its management, and substrate choice can be influenced by environmental and economic considerations (Rouin *et al*., 1988). However, when defined in terms of its chemical and physical characteristics, any substrate must be able to provide anchorage, water, oxygen and essential nutrients for plant growth (Taha and de Boodt, 1985). The physical requirements for a good substrate are low bulk density, excellent aeration, and high water holding capacity of plant available water (Klougart, 1984; Verdonck *et al*., 1982). From a chemical standpoint, growing substrates must possess good buffering (pH) and nutrient exchange capacities, and supply essential nutrients for plant growth, thereby reducing the need for fertilizers (Verdonck, 1984; Waller and Wilson, 1984).

Composts have been widely used for vegetable, fruit, and field crop production, since compost amendments derive from mixes of different organic residues, and, if adequately processed, improve soil physical and chemical properties (Giusquiani *et al*., 1995; Preston *et al*., 1998;

Albiach *et al*., 2000), and might even suppress diseases (Hoitink *et al*., 1996). Compost produced from agricultural, industrial, and municipal waste is a valuable means of improving physical and chemical characteristics of soil organic matter, an effective sustainable method of recycling by-products in growing media, and reduces the cost of substrates. Composts, derived from waste materials such as bark, municipal waste, and sewage sludge, are a useful source of organic matter (Chen *et al*., 1988), providing essential nutrients, and having a positive influence on a wide variety of crops such as corn (*Zea mays* L.), potato (*Solanum tuberosum* L.), tobacco (*Nicotiana tabacum* L.) and tomato (*Lycopersicum esculentum*) (Preston *et al*., 1998; Hue *et al*., 1994; Gallardo-Lara and Nogales, 1987).

In a previous study, physical and chemical properties of composts indicate that such materials offer support and reservoir for plant nutrition, and have excellent characteristics for making growth substrates (Zoes *et al*., 2001). It was therefore hypothesized that composted animal manure and the organic fraction of source-separated municipal solid-waste can be engineered to provide suitable physical and chemical characteristics for plant growth. Hence, the objective of this study was to investigate the agronomic uses of growth substrates made from composted duck excreta, enriched wood shavings and organic fraction of source-separated municipal solid waste, as a peat substitute, and as an sustainable alternative to commercial substrates, for producing tomato cultivated in a greenhouse.

Materials and Methods

Growth substrates

Duck excreta enriched wood shavings (DMC) and the organic fraction of source-separated municipal solid wastes (MSW) were composted as reported by Zoes *et al*. (2001), until the materials were fully biostabilized according to the extractable lipids test described by Dinel *et al*. (1996a; 1996b). The composting process was done in an enclosed hall system as described by Paré *et al*. (1999). Chemical and physical properties of the composted materials are reported in Table 1. Briefly, the composted MSW was air-dried and sieved to obtain coarse (2 mm <F2<4 mm) and medium (1 mm<F3<2 mm) fractions (Paré *et al*., 1999; Zoes *et al*., 2001). Compost-made substrates were named A, B, and C. Substrate A consisted of 3:2 (M/M) proportion of DMC and MSW compost (same proportions of F2 and F3), respectively (Table 2). Substrates B and C were the same as A, but also contained 15% (M/M ratio) of brick dust and shredded plastic, respectively. The three substrates made with MSW fractions and DMC compost, and three other substrates used for comparison purposes: i) commercially available peat substrate (Pr) (Premier Tech., Riviere-du-Loup, Québec, Canada); ii) in-house-made peat based substrate (Gs); and iii) mixture of well-decomposed forest litter (black earth) and sandy loam soil (BE/S) in a 1:4 (W/W) ratio. All substrates are described in Table 2.

Greenhouse experiment

The greenhouse trial was carried out at the Central Experimental Farm of Agriculture Canada, Ottawa, Ontario. Thirty-four-day-old tomato (*Lycopersicum esculentum* cv. Campbell 1327) seedlings were transplanted individually into 5.2 L pots with a basal outlet utilized for the evaluation of water balance and nutrient drainage (plant density=3 plants m^{-2}). For each of the 6 substrates, 2 treatments were used: control and fertilization at rates corresponding to 780 mg/pot, 625 mg/pot, and 625 mg/pot of N (NH_4NO_3), P_2O_5 [$Ca(H_2PO_4)_2$], and K_2O (KCl), respectively, added in a granular form during preparation of the substrate mixes. Treatments were established in a randomized complete block design with 12 replications. Spacing was 1 m between and within rows. Day temperatures were 21±1°C and night temperature was maintained at 18°C. The plants were grown with a photoperiod of 16 h. Crops were watered manually three times a week with tap water. Once a week, a modified Hoagland solution containing only minor elements was applied. The watering schedule was sufficient to maintain adequate water supply during the full growth period since no plant showed signs of wilting. Pots were weighed before and after each watering for the estimation of plant water demand. Twice during the growing period, tomato plants grown in control Pr, Gs and BE/S were supplied with 900 mg/pot of N, P_2O_5, and K_2O (same as for compost substrates), respectively, by watering. This side-dressing was necessary to correct for nutrient shortage and ensure fruit production and maturity. Plant height (from media surface to the top of the canopy) and crossing stem diameter (at first internode) were recorded on 35, 54, and 70 days after transplanting. The chlorophyll concentration was non-destructively measured with a portable chlorophyll meter (Minolta SPAD 502, Minolta Corp., Ramsey, NJ, USA) on days 56 and 97 after transplanting. Chlorophyll concentrations were measured on 5 leaves of each plant. The unitless measurement of the chlorophyll meter is based on the difference in light attenuation at 430 and 750 nm. The greatest absorption of light by chlorophyll a and b occurs at wavelength of 430 nm and the least absorption at 750 nm where almost all the light is reflected or transmitted. The chlorophyll meter provides numbers ranging from 0 to 80, with higher numbers representing higher chlorophyll concentrations. Fruits were harvested as ripening progressed. At each harvest, fruits were classified and weighed. Fruits without superficial imperfections and heavier

Table 1. Chemical characteristics of compost and control substrates (air dry basis) used.

Substrates	pH ($CaCl_2$)	CEC (mmol kg^{-1})	C (mg kg^{-1})	N (mg kg^{-1})	C/N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg
A	7.3	379.6	319.4	15.2	21.0	635.6	118.7
B	7.4	322.7	271.5	12.9	17.8	540.3	100.9
C	7.5	312.8	262.0	12.8	17.2	521.2	98.0
Pr	5.9	326	36.6	1.9	19.2	11.7	99.2
Gs	4.9	1142	338.7	6.2	54.6	93.3	612.5
BE/S	5.4	410	142.1	5.5	25.8	40.85	99.4

A, duck excreta enriched wood shaving compost (DMC) + organic fraction of municipal solid waste (MSW) (3:2 M/M); B, 85% substrate A + 15% brick dust; C, 85% substrate A + 15% shredded plastic; Pr, commercially available peat-based substrate; Gs, in-house sphagnum peat-based substrat; BE/S, black earth + loam soil (BE/S) 1:4 (M/M).

Table 2. Compost and control substrates and fertilization treatments compared regimes for growing tomato.

Substrates	Fertilization*
Commercially available peat-based substrate (Pr)	None
Commercially available peat-based substrate (Pr)	N, P, K
In-house sphagnum peat-based substrate (Gs)	None
In-house sphagnum peat-based substrate (Gs)	N, P, K
Black earth + loam soil (BE/S) 1:4 (M/M)	None
Black earth + loam soil (BE/S) 1:4 (M/M)	N, P, K
A (F2°:F3#:DMC§) (2:2:6 (M/M))	None
A (F2°:F3#:DMC§) (2:2:6 (M/M))	N, P, K
B (F2:F3:DMC:Br^) (1.5:1.5:5.5:1.5 (M/M))	None
B (F2:F3:DMC:Br^) (1.5:1.5:5.5:1.5 (M/M))	N, P, K
C (F2:F3:DMC:Pl$) (1.5:1.5:5.5:1.5 (M/M))	None
C (F2:F3:DMC:Pl$) (1.5:1.5 :5.5:1.5 (M/M))	N, P, K

*All substrates received weekly minor essential nutrients; °MSW coarse fraction, 2 mm<F2<4 mm; #MSW medium fraction, 1 mm<F3<2 mm; §DMC, bulk duck excreta enriched wood shavings compost; ^Br: brick dus; $Pl, shredded plastic; A, duck excreta enriched wood shaving compost (DMC) + organic fraction of municipal solid waste (MSW) (3:2 M/M); B, 85% substrate A + 15% brick dust; C, 85% substrate A + 15% shredded plastic.

than 40 g were classified marketable. Fruits weighing less than 40 g and/or with the presence of superficial lesions were considered not-marketable, but all fruits were weighed to evaluate total fresh mass. Fruits were sliced and freeze-dried to assess total dry yields. At the end of fruit harvest, tomato shoots and roots were collected, weighed for fresh weight, and oven-dried at 60°C for three days and reweighed for dry matter yields. Plant water demand was estimated throughout the growing period and expressed as mL of water per 100 g of total dry matter mass and per day.

Statistical analyses

Analysis of variance was performed on all variables using the General linear Model of the Statistical Analysis System (SAS Inc., 1991). Means were separated by using the Duncan's multiple range test (Steel and Torrie, 1980).

Results and discussion

Tomato yield and growth

In all growth substrates, plants successfully produced tomato fruits (Table 3). For the unfertilized substrates, the greatest fruit number was obtained in substrates derived from composted organic fraction of source-separated municipal solid waste (MSW) and duck excreta enriched wood shavings (DMC) with no significant differences among composts, and control Pr (Table 3). Overall substrates A, B, and C yielded 23, 42, and 48% more tomato fruit than Pr, Gs, and BE/S used as control substrates, respectively (Table 3). However, fruits harvested from plants grown in substrates A, B, C were not solely composed of mature ones. The occurrence of a longer blooming period of plants grown in these substrates explains the presence of immature fruits, representing 25, 20 and 25% of the total fruit number in substrates A, B, and C, respectively, whereas the fruit harvested from plants in substrates Pr, Gs and BE/S were almost entirely composed of mature fruits. For example, only 5% of total fruits harvested from the substrate Gs were immature (Table 3).

Although in the control Pr, Gs, and BE/S treatments two side-dressings of N, P, and K were applied to reach fruit production and maturity, there were significant differences between corresponding fertilized and control substrates in the total fruit number, indicating that these substrates probably require more nutrients to sustain fructification than the others tested. There were also no significant differences between fertilized and not-supplementary fertilized (NFS) A, B, and C substrates (Table 3), suggesting that the composted materials were

Table 3. Total number of mature, immature and marketable fruits per plant.

Substrates	Total		Mature		Immature		Marketable	
Fertilizer supply	NSF	F	NSF	F	NSF	F	NSF	F
A	9.3^{a}	10.4^{a}	7.0^{a}	8.4^{a}	2.3^{a}	2.2^{a}	3.3^{c}	3.0^{c}
B	9.5^{a}	8.2^{b}	7.6^{a}	6.8^{ab}	1.9^{a}	1.4^{b}	3.0^{c}	4.3^{ab}
C	9.3^{a}	9.4^{a}	7.5^{a}	6.8^{ab}	2.3^{a}	2.6^{a}	3.1^{c}	3.9^{b}
Mean of composts	9.4	9.3	7.4	7.3	2.2	2.1	3.1	3.8
Fertilizer supply	Total		Mature		Immature		Marketable	
	MEL	F	MEL	F	MEL	F	MEL	F
Pr	7.2^{b}	7.6^{b}	7.2^{a}	5.5^{b}	0^{c}	1.9a	5.7^{a}	5.5^{a}
Gs	4.3^{c}	6.6^{bc}	4.1^{c}	6.6^{b}	0.2^{b}	0.5^{b}	3.9^{b}	5.4^{a}
BE/S	3.8^{d}	5.8^{c}	3.8^{c}	5.6^{b}	0^{c}	0.2^{b}	3.0^{c}	4.8^{ab}
Mean of controls	5.1	6.7	5	6.6	0.1	0.9	4.2	5.2
Total mean	7.3	8	6.2	6.6	1.2	1.5	3.4	4.5

NSF, not-supplementary fertilized treatments; F, fertilized treatments; MEL, minor elements fertilization; A, duck excreta enriched wood shaving compost (DMC) + organic fraction of municipal solid waste (MSW) (3:2 M/M); B, 85% substrate A + 15% brick dust, C, 85% substrate A + 15% shredded plastic; Pr, commercially available peat-based substrat; Gs, in-house sphagnum peat-based substrate; BE/S, black earth + loam soil. ^{a,b,c,d}Values followed by different letter within a column are significantly different (P<0.05) according to Duncan's multiple range test.

Table 4. Plant dry weight of tomato grown in compost and control substrates.

Substrates	Total		Fruits		Leaves + stem		Roots	
Fertilizer supply	NSF	F	NSF	F	NSF	F	NSF	F
A	76.3^{b}	84.9^{ab}	46.5^{a}	53.2^{a}	26.8^{b}	28.6^{c}	3.0^{c}	3.0^{b}
B	74.1^{b}	79.3^{ab}	44.5^{a}	47.0^{ab}	26.6^{b}	29.0^{c}	3.0^{c}	3.1^{b}
C	77.4^{b}	81.5^{ab}	45.8^{a}	48.2^{ab}	28.6^{b}	30.0^{b}	3.0^{c}	3.4^{b}
Mean of composts	75.9	81.9	45.6	49.5	27.3	29.2	3	3.2
Fertilizer supply	Total		Fruits		Leaves + stem		Roots	
	MEL	F	MEL	F	MEL	F	MEL	F
Pr	94.0^{a}	101.5^{a}	44.9^{a}	42.8^{b}	43.7^{a}	52.9^{a}	5.3^{a}	5.8^{a}
Gs	52.7^{c}	77.1^{b}	23.9^{b}	36.6^{bc}	24.4^{bc}	35.5^{b}	4.4^{b}	5.1^{a}
BE/S	34.4^{d}	61.6^{c}	15.9^{c}	29.7^{c}	16.5^{c}	28.9^{c}	2.0^{d}	3.0^{b}
Mean of controls	60.4	80.1	28.2	36.4	28.2	39.1	3.9	4.6
Total mean	68.2	81	36.9	43	27.8	34.1	3.5	3.9

NSF, not-supplementary fertilized treatments; F, fertilized treatments; MEL, minor elements fertilization; A, duck excreta enriched wood shaving compost (DMC) + organic fraction of municipal solid waste (MSW) (3:2 M/M); B, 85% substrate A + 15% brick dust; C, 85% substrate A + 15% shredded plastic; Pr, commercially available peat-based substrate; Gs, in-house sphagnum peat-based substrate; BE/S, black earth + loam soil. ^{a,b,c}Values followed by different letter within a column are significantly different (P<0.05) according to Duncan's multiple range test.

able to fully supply N, P, and K throughout the growing period. Raviv *et al*. (1998) reported that substrates made with biosolid composts improved lettuce (*Lactuca sativa* L.) and cabbage (*Brassica oleracea* L. var. *capitata*) growth by releasing notable amounts of nutritional essential elements and by forming a base nutrient supply.

The proportion of fruits marketable was highest for tomato grown in control Gs, comprising 91% of the total fruit produced (Table 3). Marketable fruits were 79% of the total fruit produced with Pr and BE/S; however, the total fruit numbers were on average 7.2 and 3.8 fruits per plant, respectively (Table 3). In contrast, substrates A, B, and C yielded significantly fewer marketable fruits (means of composts) than substrates used as controls (means of controls), although the total fruit numbers were 33% greater (Table 3). This can be explained not only by a lower number of fruits (weight <40 g) harvested from substrates A, B, and C, but also by possible lower water availability and/or presence of blossom-end rot (BER). This physiological disorder in tomato is associated with a localized inadequacy of calcium but also in relation with other nutrients, water fluxes, and different conditions (Shear, 1975; Ho and White, 2005). The enhanced growth of vegetative parts results in competition for available Ca with fruits. Hence, Ca translocation from vegetative parts to the fruits is reduced; the results are the appearance of a dry, rotten area near the fruit apex (Shear, 1975; Ho and White, 2005). Resistance to BER is due to differences in the efficiency of Ca uptake and its accumulation and thus, the signs of BER may vary for each fruit on the same plant. Nitrogen, which is one of the most important nutrient factors affecting vegetative growth, has a direct effect on Ca. Excessive vegetative growth promoted by the large amount of available N could result in rapidly growing shoots with high Ca demands. Fertilization had a more pronounced effect on the dry biomass of aerial parts (fruit, stem and leaf) than root biomass (Table 4).

For substrates A, B, and C, total plant mass was mainly attributed to fruit mass contribution (Table 4). For instance, between 59 and 63% of the total plant dry mass for plant growing not-supplementary fertilized and fertilized A, B, and C substrates was due to fruit dry mass. In Pr, Gs and BE/S, the fruit dry mass accounted for 42.8 and 44.9% of the total plant dry mass (Table 4). For the not-supplementary fertilized and the fertilized A, B, and C substrates, total plant dry mass was on the average 19% lower than Pr in similar treatments (Table 4) and the fruit dry mass of plants grown in no-supplementary fertilized and fertilized A, B, and C substrates was 8% higher than Pr. This suggests that substrates A, B, and C had appropriate physical and chemical characteristics for greenhouse tomato growth, except for Ca. The non significant difference for most of the measured characteristics between not-supplementary fertilized and fertilized compost based substrates (Tables 3, 4, 5 and 6) confirmed that substrates A, B, and C probably contained enough macro- and micro-nutrients sufficient to supply plant needs during the full growth cycle period (Raviv *et al*., 1998), except for Ca that was insufficient to assure yield of high marketable fruits.

Other plant characteristics, such as chlorophyll concentration (Table 5), plant height and stem diameter (Table 6) indicated that tomato plants grew more in substrates A, B and C than in Pr, Gs and BE/S. For instance, by day 70, overall height was 31% higher for plants in no-supplementary fertilized A, B, and C substrates than in Pr, Gs and BE/S, and 22% higher in the fertilized ones (Table 5). In addition, the overall stem diameters were 2 and 3 times larger in substrates A, B, and C than in Pr, Gs, and BE/S (Table 6). Similar trend was also observed for chlorophyll concentration (Table 5). Raviv *et al*. (1998) reported increases in height of lettuce and cabbage plants grown in substrates made with composts compared to conventional peat based substrates, but similar chlorophyll contents for all tested substrates.

Table 5. Plant chlorophyll concentration at days 56 and 97 after transplanting and daily water demand of tomato in compost and control substrates.

Fertilizer supply	Chlorophyll concentration Day 56		Day 97		Water demand mL 100g^{-1} d^{-1}	
	NSF	F	NSF	F	NSF	F
A	51.2^{a}	53.0^{a}	39.6^{a}	36.2^{a}	723.5^{d}	622.7^{d}
B	49.5^{ab}	50.4^{ab}	36.2^{a}	35.2^{a}	767.6^{cd}	731.4^{c}
C	50.6^{ab}	50.4^{ab}	36.0^{a}	38.9^{a}	733.5^{d}	700.1^{c}
Mean of composts	50.4	51.3	37.3	36.8	741.5	684.7
Fertilizer supply	**MEL**	**F**	**MEL**	**F**	**MEL**	**F**
Pr	46.2^{b}	45.2^{c}	19.8^{c}	20.9^{c}	949.7^{c}	902.6^{b}
Gs	46.5^{b}	48.3^{b}	25.7^{b}	22.8^{c}	1324.0^{b}	892.4^{b}
BE/S	46.1^{b}	48.4^{b}	26.3^{b}	26.3^{b}	2031.0^{a}	1168.4^{a}
Mean of controls	46.3	47.3	23.9	23.3	1434.9	987.8
Total mean	48.4	49.3	30.6	30.1	1088.2	836.3

NSF, not-supplementary fertilized treatments; F, fertilized treatments; MEL, minor elements fertilization; A, duck excreta enriched wood shaving compost (DMC) + organic fraction of municipal solid waste (MSW) (3:2 M/M); B, 85% substrate A + 15% brick dust; C, 85% substrate A + 15% shredded plastic; Pr, commercially available peat-based substrate; Gs, in-house sphagnum peat-based substrat; BE/S, black earth + loam soil. ^{a,b,c,d}Values followed by different letter within a column are significantly different (P<0.05) according to Duncan's multiple range test.

Table 6. Cumulative plant height and crossing diameter measurements at first internode on days 35, 54 and 70 of tomato grown in compost and control substrates.

Substrates / Fertilizer supply	Height (cm) Day 35		Day 54		Day 70		Diameter (cm) Day 35		Day 54		Day 70	
	NSF	F	NSF	F	NSF	F	NSF	F	NSF	F	NSF	F
A	14.4^{b}	15.7^{b}	36.3^{b}	33.0b	46.5^{a}	50.1^{a}	3.0^{a}	2.8^{a}	4.2^{a}	3.7^{a}	4.4^{a}	3.7^{a}
B	18.1^{a}	15.6^{b}	43.7^{a}	39.5^{a}	51.5^{a}	46.4^{bc}	2.5^{b}	2.7^{a}	3.2^{b}	3.9^{a}	3.3^{b}	3.9^{a}
C	18.0^{a}	17.4^{a}	36.6^{a}	40.0^{a}	48.7^{a}	51.8^{a}	2.8^{a}	2.6^{a}	3.5^{b}	3.8^{a}	3.5^{ab}	4.0^{a}
Mean of composts	16.8	16.2	38.9	37.5	48.9	49.4	2.8	2.7	3.6	3.8	3.7	3.9
Fertilizer supply	**MEL**	**F**	**MEL**	**F**	**MEL**	**F**	**MEL**	**F**	**MEL**	**F**	**MEL**	**FPr**
Pr	17.2^{a}	21.5^{a}	37.1^{b}	40.2^{a}	38.2^{b}	42.9^{bc}	1.0^{c}	1.0^{b}	1.5^{c}	1.8^{b}	1.5^{c}	1.8^{b}
Gs	16.4^{ab}	18.3^{a}	32.2^{c}	36.2^{a}	36.6^{b}	41.5^{c}	0.8^{c}	1.5^{b}	1.4^{c}	1.8^{b}	1.4^{c}	1.8^{b}
BE/S	19.4^{a}	15.7^{b}	33.6^{c}	30.0^{b}	37.3^{b}	37.0^{d}	0.8^{c}	1.1^{b}	1.3^{c}	1.5^{b}	1.3^{c}	1.5^{b}
Mean of controls	17.7	18.5	34.3	36.5	37.4	40.5	0.9	1.2	1.4	1.7	1.4	1.7
Total means	17.3	17.4	36.6	37	43.2	45	1.9	2	2.5	2.8	2.6	2.8

NSF, not-supplementary fertilized treatments; F, fertilized treatments; MEL, minor elements fertilization; A, duck excreta enriched wood shaving compost (DMC) + organic fraction of municipal solid waste (MSW) (3:2 M/M); B, 85% substrate A + 15% brick dust; C, 85% substrate A + 15% shredded plastic; Pr, commercially available peat-based substrate; Gs, in-house sphagnum peat-based substrate; BE/S, black earth + loam soil. ^{a,b,c}Values followed by different letter within a column are significantly different (P<0.05) according to Duncan's multiple range test.

Water demand

An important physical property of growth substrates is their capacity to absorb and retain large quantities of plant available water while maintaining effective drainage avoiding waterlogging conditions (Beardsell *et al*., 1979). Optimal physical conditions contribute to a better nutrient uptake by roots and facilitate gas exchange (Gallardo-Lara and Nogales, 1987). Water demand of substrates A, B, and C did not significantly differ among them, but was much lower than that of Pr, Gs and BE/S (Table 5). Comparing Pr to substrates A, B, and C, water demand was 24% lower for substrates derived from composted materials than from sphagnum-peat sources (Pr and Gs) (Table 5). In Gs and BE/S, water demand was significantly different between minimal fertilization level and fertilized substrates (Table 5). The water consumption per plant was calculated from the data of water demand and the total plant dry matter mass (Table 5). These values varied between 529 and 580 for A, B, and C, between 688 and 720 for Gs and BE/S, and between 893 and 916 for Pr (both fertilized and control treatments). This situation may be explained by the fact that these two substrates contain large amounts of mineral materials as perlite, brick fragments and sand which increase bulk density and reduce the use of substrate and the water holding capacity. Furthermore, the quality of organic matter, and the chemical and physical properties in composted materials and peat are not similar. Compost is a fully bio-stabilized organic matter, whereas sphagnum peat is not; therefore, sphagnum peat may be able to retain more water, but it would release the water more rapidly and more easily. Thus, substrates derived from composted material allow a better use of water by the plant than substrates produced with other organic sources (Maynard and Hill, 1994). In fact, studying the effect of composts application on various soil types for greenhouse broccoli (*Brassica oleracea* L. var. *capitata*) and lettuce growth, Shiralipour *et al*. (1996) reported that high rate of compost addition to a sandy loam increases water holding capacity which might aid plant survival in drought conditions.

Conclusions

Vegetable growing in soilless culture offers a valuable alternative compared to crop production in soil, and can give higher yield and quality when compared to soil. Soilless culture has been extensively adopted by specialist producers of greenhouse crops, and particularly in tomato production. The properties of different materials used as growing substrates in soilless culture can influence the yield and quality of crop production. The selection and use of a particular material depends by cost and local availability. Substrates derived from MSW and DMC composts are suitable for making tomato plant growth media, once Ca/N has been adjusted or corrected. Plant biomass (fruits, stem + leaves, roots) and growth characteristics indicate that the derived substrates can fulfill plant nutrient demands by providing a long lasting nutrient background. However, in order to get this potentially sustainable material utilized in the production of vegetables, research on plant nutrition will be need to process the physical and chemical characteristics of these substrates, and to extend their use as growth substrates for other horticultural crops.

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