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Effect of Ruminant, Municipal Solid Waste and Biosolids Composts and Their Teas on Some Berry Crops, Vegetables and Soil Fertility

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ABSTRACT

Two types of non-aerated compost teas were made from their respective mature composts and used as sole fertility amendments in separate experiments for beans, sweet corn, greenhouse tomatoes, strawberries and blackberries grown in a relatively infertile Gibraltar sandy loam at Boutiliers Point, Nova Scotia. The teas were made from municipal solid waste (MSWC) and biosolids composts (BC). Each crop was grown using compost or compost tea in experiments as long as six years; in each experiment, compost applications were based on crop N requirements and were applied once or twice based upon their respective total N content. Compost tea applications, however, were normally based on weekly or bi-monthly spray applications to cover the surfaces of the leaves or as a soil drench and continued until the plants blossomed. Vegetable and berry yields were taken when cobs, beans or fruit matured, thus, multiple pickings each year. Leaf tissue and/or Mehlich-3 extractable levels of at least 10 soil elements were taken at the recommended time for each crop. The yield results indicated the compost and tea treatments produced equivalent berry or cob yields for the blackberry, strawberry and sweet corn experiments. Snap bean yields were highest with the MSWC and lowest with an organic fertilizer blend, while tomato fruit yields for soybean, BC and BC tea treatments were greater than the control. There were few effects of treatments on soil fertility or leaf tissue samples and non-significant correlation between the results of the Mehlich-3 extracts and tissue elemental content. The MSWC and its high tea spray had some effect on soil or tissue Na, likely because Na is the most soluble element in the tea treatments. Since Na is not essential for plant growth, there is a concern that increasing Na additions could affect K absorption and plant growth. Potentially toxic trace elements did not accumulate in any of the treated plants.

Keywords: beans, blackberries, Mehlich-3 soil extracts, plant tissue, strawberries, sweet corn, tomatoes

INTRODUCTION

Animal manures have been composted into more stable and slow-release amendments for thousands of years. More recently, legislation has mandated the composting of residential organic wastes in the province of Nova Scotia. Hargreaves *et al*. (2008a) reviewed the use of municipal solid waste compost (MSWC) in agriculture and cited numerous studies demonstrating the beneficial effects of its application. The addition of MSWC has been consistently shown to raise soil pH (Maynard 1995; Mkhabela and Warman 2005; Warman *et al*. 2009), which is particularly useful for the acidic soils of northeastern North America. Composts are also a potentially rich source of plant nutrients, since they are largely derived from plant-based materials. Soil concentrations of extractable plant nutrients have been shown to increase with MSWC application (Mkhabela and Warman 2005; Warman 2009; Warman *et al*. 2009).

Land application of sewage sludge has been extensively used as an effective dispersive method throughout Canada, the United States and Europe for more than forty years. Many studies have demonstrated the positive effect of land application of sewage sludge or biosolids compost on crop yields and soils, including a few studies conducted by the author in the greenhouse and field (Warman 1999; Warman and Termeeer 1996; Warman and Termeer 2005), as well as a critical review of the bioavailability and impact of heavy metals in MSWC and sludge compost by Smith (2009).

Compost teas are products now being used by organic growers to control plant disease (Scheuerell and Mahaffee 2002). The teas are produced through the incubation of well-characterized and mature compost in water for a defined period of time. Organic farmers are experimenting with teas not only because of a lack of approved disease management tools but also because it is assumed that compost teas may be incorporated into nutrient management strategies as a "stand alone" product. Compost teas have not been rigorously compared to existing organic or conventional agricultural practices as nutrient amendments. Compost teas are usually applied to plant foliage, where the nutrients in the teas may be absorbed more quickly than through the soil-root interface (Touart 2000); however, a soil drench or a combination of foliar and soil application may be more efficacious. Hargreaves *et al*. (2008b, 2008c, 2009a, 2009b) found that the foliar application of tea was as effective as soil application of compost for both raspberry and strawberry production. Welke (2004) found that cattle manure compost teas compared to chicken manure compost tea increased strawberry yields, indicating that compost source may have an effect on the efficacy of the tea. In a field study with Brussels sprouts, Radin and Warman (2010) saw potential for MSWC tea as a nutrient supplement in conjunction with soil-applied compost, but not as a complete nutritional source; whereas, they suggested the benefits of using MSWC teas for greenhouse tomatoes may be increased with more frequent applications (Radin and Warman 2011). Margarit (2010) evaluated biosolids compost (BC) and MSWC and their teas (with and without added blood meal and rock P) for asparagus production and soil fertility. He found few effects of the treatments on the elemental composition of soils, fern or spear tissue.

There is great potential for the use of high-quality com-

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Table 1 Physical and chemical characteristics of three composts and two compost teas.

Parameter	MSWC	MSWC Tea[b]	RUMC	BC	BC Tea[b]
% dry weight	60 ± 15	--[a]	41 ± 4.8	38 ± 12.5	--
pH	7.90 ± 0.4	7.6 ± 0.1	7.4 ± 0.3	7.3 ± 0.6	6.80 ± 0.07
C:N ratio	10.7 ± 0.6	--	11.2 ± 0.7	17.1 ± 0.6	--
N ($g \cdot kg^{-1}$)	22.0 ± 0.8	9.6 ± 0.3	19.2 ± 0.7	15.0 ± 0.1	3.1 ± 0.06
P	6.40 ± 1.44	4.7 ± 0.4	5.49 ± 1.11	5.35 ± 0.87	3.1 ± 0.18
K	6.13 ± 0.58	142 ± 22	6.50 ± 1.71	4.15 ± 2.91	4.8 ± 0.03
Ca	39.8 ± 3.52	49 ± 14	12.4 ± 2.95	9.2 ± 0.88	12.2 ± 0.3
Mg	4.19 ± 0.25	12 ± 3.0	4.10 ± 0.41	2.32 ± 0.80	1.5 ± 0.04
S	11.4 ± 1.38	113 ± 24	6.18 ± 0.47	4.15 ± 2.23	11.0 ± 0.3
Fe	10.6 ± 1.25	2.8 ± 0.2	7.30 ± 1.49	9.07 ±1.69	1.6 ± 0.2
Cu ($mg \cdot kg^{-1}$)	91.3 ± 11.6	0.2 ± 0.10	23 ± 2.4	148 ± 87	0.1 ± 0.00
Mn	858 ± 47	0.4 ± 0.04	526 ±161	790 ± 116	0.1 ± 0.01
Zn	197 ± 28	0.4 ± 0.07	224 ± 88	266 ± 46	0.05 ± 0.02
B	29.2 ± 5.6	0.5 ± 0.2	29.1 ± 21.0	19.9 ± 19.0	0.2 ± 0.04
Na	4732 ± 603	219 ± 58	527 ± 239	1522 ± 2294	5.5 ± 0.4
Cd	0.6 ± 0.4	N.D.[c]	0.1 ± 0.2	0.2 ± 0.01	N.D.
Cr	18.3 ± 1.2	0.01 ± 0.01	8.0 ± 2.2	24.7 ± 3.5	N.D.
Ni	10.4 ± 0.7	0.07 ± 0.05	4.9 ± 1.0	7.4 ± 2.8	N.D.
Pb	44.8 ± 9.4	0.03 ± 0.01	10 ± 3.5	22.6 ± 1.9	0.01 ± 0.00

*Values are means with one standard deviation (n=8)
[a] Not determined (--)
[b] Tea element concentrations expressed in $mg \cdot L^{-1}$
[c] Not detectable (N.D.)

posts and their teas for organic crop production including crops like blackberries which have relatively few pest and disease problems and appear to have relatively low nutrient demands. Few studies have looked at the effects of organic amendments on horticultural crops, especially blackberries, which are relatively under studied for soil-plant relations. The goal of this paper was to assess three composts and two compost teas, usually at different rates, as fertility amendments for five different crops. Crop yields, soil fertility and leaf tissue analysis acted as the evaluation criteria.

MATERIALS AND METHODS

All of the experimental plots were established at Boutiliers Point, N.S. (44°39′39″ N, 63°57′02″ W) in a Gilbraltar brown sandy loam (Ortho Humo-Ferric Podzol) with good to excessive drainage and mild slope. Initially (2003), the land had no history of crop production or fertilization for at least 10 years and was converted from scrub brush and weeds and rototilled at least three times prior to planting any of the crops by hand. In general, the surface soil was 7.6% in organic matter with a pH of 5.57; Mehlich 3 extractable plant nutrients prior to the application of any treatments were 37 $mg \cdot kg^{-1}$ of P, 53 $mg \cdot kg^{-1}$ of K, 1,015 $mg \cdot kg^{-1}$ of Ca, 171 $mg \cdot kg^{-1}$ of Mg, 21 $mg \cdot kg^{-1}$ of S, 111 $mg \cdot kg^{-1}$ of Fe, 2 $mg \cdot kg^{-1}$ of Cu, 19 $mg \cdot kg^{-1}$ of Mn, 4.2 $mg \cdot kg^{-1}$ of Zn, and 0.9 $mg \cdot kg^{-1}$ of B.

Fertility amendments were based on specific soil tests and the N.S. Soil Test Recommendations for each particular crop. All of the experimental plots were grown ‘organically’, thus only organically allowed insecticides were applied and the plots were hand-weeded. Irrigation was only necessary for the strawberries in 2009 which required about 20 L per plot during the fruiting period.

Preparation and characteristics of composts and compost teas

The ruminant compost (RUMC) was first prepared in 2003 using a windrow system with sheep manure, beef manure and sheep bedding consisting mostly of straw, mixed in a ratio of 1: 2: 3 (by volume), respectively. The pile was turned three times in a one-month period until a constant temperature of 45°C was maintained. Another batch of RUMC was made in 2006 using similar feedstocks. The municipal solid waste compost (MSWC) was obtained from the Lunenburg Regional Recycling and Composting Facility at Whynotts Settlement in Nova Scotia. Feedstocks were food, yard and wet paper wastes. Different batches of compost from the same facility were used throughout the 2004 to 2009 period. Biosolids compost (BC) was produced by Fundy Compost Inc. in windrows using bark blended with aerobically-digested sludge from the Colchester County Wastewater Facility and composted for eight months. The material was turned at least eight times with a Wildcat compost turner, screened through a 1.5 cm screen, stacked 6 m high and cured for the winter. The finished compost sat curing in a pile for a further 30 months before it was used in 2006. Composts were analysed prior to application every year for total N and later for 15 macro-, micro-, and trace elements.

Non-aerated compost teas were prepared using BC and MSWC following the bucket-fermentation method (Diver 2002). The compost teas were made at a dilution of 5 times fresh weight and left to steep for 72 h in glass or plastic containers with periodic mixing.

Soil samples were taken in each plot about the same time plant tissue was sampled. Extractable levels of soil elements were determined using the Mehlich-3 (M-3) extract (Mehlich 1984). Five g samples of air-dried soil were shaken in 50 ml M-3 solution for 15 min and filtered. Plant tissue was prepared using a one g sample of oven-dried ground tissue, digested in 10 ml of HNO3, filtered, and brought up to 50 ml volume with distilled H_2O. Two g samples of compost were similarly digested in 20 ml of acid; compost and tissue digestions followed the procedure of Zheljazkov and Warman (2002). Ten ml of compost tea was digested in 10 ml of HNO3 (as above) and brought to 50 ml. Filtrates of soil, tissue, tea, and compost were analyzed with inductively coupled argon plasma emission spectroscopy (ICAP) for the elements indicated in **Table 1**, except C and N, which were analysed using a LECO CNS-1000 Analyzer. A typical analysis of the composts and their teas is shown in **Table 1**.

Statistical analysis was completed using SAS software version 8.0 or SPSS 15.0 for Windows. After verifying normality, the GLM for randomized complete block (RCBD) or Latin square design (LSD) was used depending on the experimental design for each crop. Based upon the experiment, one- or two-factorial ANOVA was used to test for significant differences ($p<0.05$) among the means of all treatments for a particular factor, followed by Tukey’s post hoc multiple comparisons if the treatments were found to be significant at $P < 0.05$. If the treatments were not significant for a factor, data were expressed as the mean and standard deviation. Significant differences among all treatments were compared for each crop.

Snap bean (*Phaseolus vulgaris*) experiment

The experiment was a completely randomized design with one main plot factor (fertility treatment) and one subplot factor (variety). Each treatment was replicated three times on a site that had a previous Brussels sprouts experiment (Radin and Warman 2010). Plots measured 2.3 m × 2.3 m and were split in half into two subplots. Each plot was initially seeded on June 9, 2009 with three rows of 15 seeds each. The middle row was planted with 8 yellow (cv 'Pencil Pod Black Wax') and 7 green (cv 'Provider') or 7 yellow and 8 green, while the outside rows were seeded with 15 yellow and 15 green seeds, for a total of 45 plants per plot. Rows were spaced at 0.5 m and plants spaced at 10 cm within rows. In the end, plant numbers were reduced due to slugs feeding on the newly emerged seedlings.

Fertility treatments were broadcast by hand and incorporated into the soil; they consisted of the following: 1) Organic fertilizer (OF); 2) MSW compost (MSWC); 3) MSW compost tea spray (Low tea) and 4) High tea. The OF treatment consisted of 43 g m^{-2} of soybean meal (7% N), 42 g m^{-2} rock P (0-12-0), and 33 g m^{-2} SUL-PO-MAG (0-0-18K-11Mg-23S). Soil test P was used to determine the application rate of MSW compost, with the assumption of adequate N in the compost for growth. The compost contained 0.81% P (based on dry matter content); in order to achieve the recommended P application rate of 22 kg ha^{-1}, 271 g MSWC m^{-2} was applied (this also provided 5.6 g m^{-2} total N and 1.65 g m^{-2} total K).

Compost tea was made in the usual method (non aerated, 5: 1 water: moist MSWC, 72-h steeping time). Low tea consisted of foliar spraying 250 ml over the plants in each replicate once per week, for four weeks, resulting in four applications with a total of 1 L. High tea was the same quantity of tea per spray, but applied twice per week, resulting in eight applications with a total of 2 L applied. Spraying commenced on July 9.

Both the yellow and green beans were harvested, cleaned, air-dried and weighed when ripe about every two days; no soil or tissue samples were taken.

Sweet corn experiment

Hybrid sweet corn (*Zea mays*, cv. 'Geronimo') seeds were planted on May 16, 2008 and May 21, 2009 into each of 20 plots measuring 2.3 m × 2.4 m. The 2009 crop was grown in the same plots used in 2008. Three rows of seeds were spaced at 0.2 m within rows and 0.75 m between rows. Walkways between plots measured 0.8 m.

Five different fertility treatments consisted of the following amendments applied as a RCBD: (1) an organic fertilizer blend (OF) and (2) municipal solid waste compost (MSWC), both treatments were split into two applications (May and July), applied to the surface of the whole plot and raked into a depth of 10 cm; (3) MSW tea soil drench (MSWD), applied five times (25 ml each) to the soil at the base of each plant in a plot, once every two weeks; (4) MSW tea foliar spray-low rate (MSWTX1) and (5) MSW tea foliar spray- high rate (MSWTX2), applied five times or ten times (25 ml each) by hand-pump sprayer to each plant in a plot, once every two weeks or every week, respectively.

The OF was made from a mixture of dried blood (12-0-0), SUL-PO-MAG (0-0-18K-11Mg-23S) and rock phosphate (0-0-21) and applied at the recommended rate of 125 kg N ha^{-1}); 100 kg P and 170 kg Kha^{-1}. Compost was applied at a rate adjusted to provide 125 kg N ha^{-1} with the assumption that the plant nutrients in the compost were 50% plant-available.

Leaf tissue sampling began on August 20, 2008 and August 21, 2009 at the time when a minimum of nine plants per plot had nearly harvestable ears, and continued until August 28, 2008 and September 8, 2009. Ears were harvested within a few days of leaf sampling and their weights were recorded.

Greenhouse tomato experiment

Biosolids compost (BC) and three rates of biosolids compost tea (BCT3X, BCT6X, BCT12X) were compared to soybean meal (soy meal) and a control soil for tomato (*Lycopersicum esculentum* Mill. cv 'Vendor') production. Vendor seedlings were transplanted in May in a greenhouse (4 m × 5 m, natural light, 12-35°C) into large plastic cylinders (22 cm diameter × 34 cm high) containing a low-fertility Gibraltar sandy loam soil limed with wood ash (control). The BC and Soy Meal were incorporated into the soil to provide 0.54 g of total N/plant; the BC teas were produced in the usual way, and mixed periodically prior to their use as a foliar spray. The BCT was sprayed on the foliage at regular intervals during the growing season that extended through October 2006. Application rates were 3, 6 or 12 times per plant at 25 ml BCT for each spraying. All plants received equal daily watering by hand; marketable tomato fruit was picked at maturity and weighed.

Day-neutral strawberry experiment

Day neutral strawberries (*Fragaria x ananassa* cv. 'Seascape') were planted May 4, 2008 using 75 plants in 15 blocks of 5 plants each; each block was composed of 5 plants spaced 0.4 m in a row, giving a total plot dimension of 1.92 m^2 (2.4 m × 0.8 m). Three amendments were tested in a RCBD based on the N.S. Soil Test Rating and Plant Nutrient Requirement Tables for strawberries: 1) an 'organic' fertilizer (OF) was made by combining soybean meal (430 g $plot^{-1}$), rock phosphate (400 g $plot^{-1}$), and SUL-PO-MAG (0-0-18K-11Mg-23S) (130 g $plot^{-1}$) to provide the equivalent of 150-260-135 N-P_2O_5-K_2O; 2) MSWC at 869 g $plot^{-1}$ (providing 22 g kg^{-1} total N and 75.4% dry matter); 3) MSWC tea, sprayed 7 times at 250 ml $plot^{-1}$. In 2008, tea sprays were started August 11 and ended October 8, and yields were not taken. The plants were covered with straw over winter. In the spring of 2009, the mulch was pulled away, amendments were surface incorporated, and the mulch was moved to the borders. Amendments were applied on May 14 at the same rates as in 2008; the MSWC tea was sprayed weekly until June 26 when fruit harvesting commenced.

Blackberry experiment

Blackberry (*Rubus* spp. Cv. 'Lowden') plantings were established in May 2004. Three fertility treatments were replicated three times in nine plots, each measuring 3 m × 1 m and arranged in 3 blocks in a Latin square design. At the time of planting, treatments were MSW compost, ruminant compost, and mixed NPK fertilizer. Five rooted 'Lowden' cuttings were planted in line through the center of each plot, spaced at 0.5 m. Compost treatments were based on N recommendation of 120 kg·ha, using the composts' total N (based on dry weight). Treatments applied in 2004 and 2005 were: 1.71 kg·m^2 of MSW compost (66% dry matter), 2.91 kg·m^2 ruminant compost (46% dry matter), and NPK fertilizer (3.33 g·m^2 34-0-0, 30 g·m^2 0-20-0, and 6 g·m^2 0-0-60). Compost treatments were applied yearly, in the spring, through 2009. In 2006, no treatment was applied to what had been NPK plots. Starting In 2007, MSW compost tea was sprayed for three consecutive weeks on the original fertilizer plots, starting 17 June at 250 mL per plot. In 2008 and 2009, tea treatments were increased to 6 consecutive weeks, beginning at bud break.

RESULTS AND DISCUSSION

Beans

Variability prevented detection of differences between total per plot yields; however, since the number of plants per plot was highly variable as well, per plant yield was used for comparison. Yield per plant, regardless of variety, was highest in MSWC treated plots, and significantly higher than the yields of the OF and high frequency tea application plots, both of which had more plants per plot (**Table 2**). The results, therefore, may be a function of fewer plants providing better spacing and less competition for water and light, although moisture was adequate throughout the short growing season. It was noted that the beans planted in the MSWC plots germinated more quickly and grew more rapidly. No significant differences in yields per plant were detected between the two varieties with green and yellow bean yields at 74.5 and 57.2 g, respectively. Again, high plot variability influenced these results.

Sweet corn

Because of unequal plant populations among plots in 2008 and 2009, due to 60% germination and insect problems, mean ear weight was the tested yield parameter. No significant differences were found between treatments in either year (**Tables 3a, 4a**); ear weight decreased in 2009 to 115 g

Table 2 Mean per plant and per plot yields (g) of green and yellow beans.

Treatment	OF		MSWC		Lo Tea		Hi Tea	
	Green	Yellow	Green	Yellow	Green	Yellow	Green	Yellow
Plants per plot by variety	13.0	15.0	12.3	13.3	13.0	14.3	15.0	15.3
Plants per plot by treatment	14.0		12.8		13.7		15.2	
Plot yield by variety	678	731	1203	935	1013	972	980	724
Plot yield by treatment	705		1069		993		852	
Yield per plant by variety	57.1	46.9	96.3	68.1	77.9	67.4	66.5	46.6
Yield per plant by treatment	52.0 b		82.2 a		72.7 ab		56.6 b	

* Different letters within a row indicate significant differences according to Tukey's test ($P < 0.05$).

Table 3a 2008 Mean corn ear weight, soil pH, and M-3 extracted soil nutrients (mg kg^{-1}).

	OF	MSWC	MSWD	MSWTX1	MSWTX2	Mean	Std.dev.
Ear weight	142	139	126	128	131	133	7
pH	5.61	5.86	5.88	5.79	5.75	5.78	0.11
P	115	135	94	110	102	111	16
K	119	108	75	58	69	86	26
Ca	1316	1479	1375	1337	1295	1360	73
Mg	253	250	226	195	232	231	23
S	42 a	32 ab	22 b	26 b	27 b		
Fe	103	97	89	94	99	96	5
Cu	3.8	2.1	2.7	2.1	2.0	2.5	0.8
Mn	13.8	13.6	12.5	14.9	15.1	14.0	1
Zn	4.2	3.3	3.9	4.6	4.3	4.1	0.5
B	0.7	0.7	0.5	0.5	0.5	0.6	0.11
Na	13.0 b	30.8 a	8.5 b	7.8 b	8.1 b		

Table 3b 2008 Corn ear leaf tissue elemental concentrations.

	OF	MSWC	MSWD	MSWTX1	MSWTX2	Mean	Std. dev.
P	2.09	2.15	2.10	2.13	2.21	2.14	0.05
K	19.0	18.8	18.2	17.4	18.2	18.3	0.63
Ca	4.28	4.51	4.83	5.31	5.09	4.80	0.42
Mg	2.79	2.42	2.81	2.89	3.21	2.83	0.28
S	4.07	4.28	4.04	4.06	4.21	4.13	0.11
Fe	66.5	55.8	70.2	82.0	76.4	70.2	10.0
Cu	6.87	5.62	7.23	5.69	6.49	6.38	0.71
Mn	51.1 a	26.2 b	27.8 ab	30.6 ab	32.9 ab		
Zn	26.0	23.7	20.6	20.6	20.8	22.3	2.5
B	5.55	5.14	3.47	5.19	4.66	4.80	0.81
Na	41 c	61 c	48 c	232 b	406 a		

Units are g kg^{-1} for macronutrients, and mg kg^{-1} for micronutrients

* Different letters within a row indicate significant differences according to Tukey's test ($P < 0.05$).

from 133 g in 2008. Yields in both years, however, were only 55-60% of those reported for the same cultivar grown in another N.S. sandy loam soil (unpublished research).

No significant differences between plots' soil pH were found among the treatments in either year; mean soil pH, however, increased from 5.78 in 2008 to 5.97 in 2009. The only significant treatment effects found on M-3 extractable soil elements in 2008 were on S and Na (**Table 3a**), and in the case of the former, this was most likely due to the use of SUL-PO-MAG as the K source. The Na concentration was highest in the MSWC-treated soils, which was not unexpected based upon previous studies which indicated increased M-3 Na due to MSWC treatments (Hargreaves *et al*. 2009a, 2009b). Compared to the other treatments, the effect of OF on M-3 S was also found in 2009 (**Table 4a**). Soil K in the OF plots was also higher than in the tea treatments in 2009.

Manganese and Na were the only tissue elements affected by treatment in 2008. Manganese concentration was significantly higher in plots treated with OF; compost tea had a positive incremental effect on tissue Na, the higher the tea spray the larger the Na content. In 2009, tissue K concentration was highest in MSWC plots while tissue Na responded similarly as in the previous year, the tea application with the highest frequency of spray resulting in the statistically highest concentration of tissue Na with the lower spray rate higher in leaf Na than the OF and tea drench.

Mehlich-3 soil P was half as high in 2009 compared to the previous year, and about the same level as it was prior to 2008, while K was somewhat lower in 2009; low soil levels of these two macronutrients may have contributed to the overall poor performance in the second year, along with probable N deficiency (not analysed), which was exhibited by poor vigor throughout the season, even while soil Ca, Mg, S, Fe, Mn and B were at higher levels than in the previous year. Tissue K was lower in 2009, as well as Cu, which was also present at lower concentration in the soil. Higher soil Ca, Mg and Fe in 2009 were reflected in higher tissue Ca, Mg and Fe. Tissue P was very nearly the same in both years, and while the 2009 plants were not vigorous, few plants exhibited typical P deficiency in the form of purple leaf pigments. Comparing the soil and tissue results for this experiment with Warman et al. (submitted) or Mkhabela and Warman (2005) growing the same corn cultivar in another sandy loam in N.S. using different rates of MSWC and/or fertilizer, one notes noticeably lower soil P and K and tissue P and K here. Thus, the combination of potential N and K deficiencies with the cooler growing conditions (data not reported here) and heavier cloud cover prevented good growth, especially in June and July of 2009.

Greenhouse tomatoes

Fruit yields showed that the soybean meal and the lowest rate of BCT produced the highest yields, statistically higher than the unamended control (**Table 5**). It was interesting that the lowest spray application numerically outyielded the 6X and 12X sprays; also, I noted that the low spray produced comparatively more fruit later in the year than the other treatments, hence, its higher final yield. In another experiment conducted by the author using a similar type of

Table 4a 2009 Corn yield parameters, soil pH, and M-3 extracted soil nutrients.

	OF	MSWC	MSWD	MSWTX1	MSWTX2	Mean	Std.dev.
Ear weight	115	117	127	105	108	115	8
Plot weight	1136	931	931	903	895	959	100
Cobs per plot	8.50	7.50	7.50	8.25	8.50	8.05	0.51
Soil pH	5.71	6.12	5.99	6.12	5.88	5.97	0.17
P	61.5	59.5	53.7	54.0	48.3	55.4	5.2
K	91.3 a	78.5 ab	49.5 bc	60.1 abc	39.2 c		
Ca	1386	1703	1557	1821	1524	1598	168
Mg	259	262	226	255	259	252	15
S	177.8 a	84.8 b	91.0 b	94.2 b	97.1 b		
Na	28.0	126.6	54.2	62.0	37.3	61.6	38.7
Fe	119	106	124	109	108	113	8
Cu	1.82	1.88	1.86	1.85	2.02	1.88	0.08
Mn	19.3	21.3	21.9	22.8	24.0	21.9	1.8
Zn	3.56	4.40	4.20	4.81	4.82	4.36	0.52
B	0.77	0.61	0.78	0.85	0.73	0.75	0.09
Cd	0.11	0.10	0.10	0.10	0.10	0.10	0.00
Cr	0.08	0.08	0.10	0.08	0.08	0.08	0.01
Ni	0.26	0.29	0.32	0.27	0.28	0.28	0.02
Pb	1.75	2.19	2.42	2.10	2.09	2.11	0.24

Table 4b 2009 Corn leaf tissue elemental concentrations.

	OF	MSWC	MSWD	MSWTX1	MSWTX2	Mean	Std.dev.
P	1.94	2.37	1.89	2.08	2.10	2.08	0.19
K	16.6 ab	18.7 a	14.6 ab	13.3 b	13.8 b		
Ca	4.48	5.15	4.27	5.81	5.72	5.09	0.70
Mg	2.93	3.02	2.98	3.01	3.39	3.06	0.18
S	3.79	4.37	3.80	4.08	4.14	4.04	0.24
Na	92.2 c	115 bc	84.4 c	163 b	244 a		
Fe	109.9	116.9	167.7	121.0	149.1	132.9	24.5
Cu	3.83	4.42	3.50	3.72	3.79	3.85	0.34
Mn	52.8	34.2	28.8	32.7	37.4	37.2	9.3
Zn	27.3	31.5	25.6	24.3	29.2	27.6	2.9
B	5.04	3.87	4.35	4.93	5.30	4.70	0.58
Cd	0.38	0.38	0.25	0.19	0.24	0.29	0.09
Cr	0.73	1.23	0.76	1.10	0.78	0.92	0.23
Ni	0.27	0.11	0.24	0.24	0.18	0.21	0.07

Units are g kg^{-1} for macronutrients, and mg kg^{-1} for micronutrients and trace elements

* Different letters within a row indicate significant differences according to Tukey's test ($P < 0.05$).

Table 5 Soil extractable (M-3) plant nutrients (mg kg^{-1}) and tomato fruit yields (g).

Treatments	P	K*	Ca	Mg	S	Fe*	Mn	Cu	Zn	B	Yield*
Control	71	567 b	4454	423	237	106 ab	87	12	47	4.0	131 a
Soy Meal	61	396 ab	4745	459	234	121 b	111	15	57	4.4	546 b
BC	79	331 a	4511	406	182	110 ab	104	13	50	5.4	402 ab
BCT3X	71	392 ab	5354	439	242	97 a	97	15	54	5.0	532 b
BCT6X	86	394 ab	4858	407	194	113 ab	95	17	59	4.4	398 ab
BCT12X	94	336a	4046	321	155	109 ab	84	13	46	4.2	397 ab
Mean	77		4661	409	207		96	14	52	4.6	
Std. dev.	10.8		402	43.5	32.5		9.3	1.7	4.9	0.48	

* Different letters within a column indicate significant differences according to Tukey's test ($P < 0.05$).

BC and Vendor tomatoes, it was found that the BC produced the numerically highest yields, compared with peat or peat-BC treatments, however, supplemental fertilizer was added to all the plants (Warman 1999). Growing Vendor tomatoes, Radin and Warman (2011) compared fertilizer with OF, MSWC and MSWC teas (as a soil drench) in one experiment and fertilizer, MSWC teas (as a spray) with or without MSWC in another experiment. In the first experiment, the fertilizer and OF out produced the MSWC and teas treatments; however, in the second experiment, the low rate MSWC + high rate tea and the high rate MSWC + both low and high rate tea spray treatments produced the most yields.

The M-3 extractable nutrient content of the cylinders is shown in **Table 5**. Treatments had a significant effect on K and Fe, only, and in each case the P values were numerically at 0.05. The Control had more soil K than the BC and BCT12X, while the Soybean meal produced higher soil Fe than the BCT3X; there is not a good explanation for either result.

Day-neutral strawberries

'Seascape' strawberry yields were 372, 390 and 491 g m^{-2} for the MSWC, MSWC tea and OF, respectively, with no significant differences between treatments, primarily due to high replicate and block variability. Compared to the summer-bearing 'Sable' variety, the 'Seascape' yields were similar to those of Hargreaves *et al*. (2009b) but only a fraction of the yields reported in Hargreaves *et al*. (2008c) using MSWC and MSWC teas; those authors also found no differences in yields due to similar treatments. In this 'Seascape' experiment, the plants suffered from N deficiencies and disease. I believe the soil these strawberries were growing in was much lower in fertility (no data available) and poorer in soil tilth than reported in Hargreaves *et al*. (2008c); thus, the plants would have benefited from higher rates of all amendments. Growing conditions were adequate and the plants received regular irrigation. There was a wide range in block yields per treatment, from 200 to 300 g m^{-2} at the low end to 650 to 1000 g m^{-2} at the high end of the grouping.

Table 6 2008 Blackberry fruit yields, M-3 extractable soil nutrients, and leaf tissue content.

	RUMC	MSWC	MSW Tea	Mean	Std. dev.
Yield (g)	5971	5483	5362	5605	322
Soil					
P	145 a	129 ab	72 b		
K	84.1	65.8	43.4	64.4	20.4
Ca	1494 ab	2046 a	935 b		
Mg	345 a	181 b	209 b		
S	26.4	24.6	21.8	24.3	2.4
Fe	65.1	66.3	63.2	64.9	1.6
Cu	0.6	0.8	0.6	0.7	0.15
Mn	19.3	17.1	11.3	15.9	4.1
Zn	6.6 a	3.3 b	2.1 b		
B	1.3	1.5	1.2	1.3	0.15
Na	11.1 b	20.8 a	9.1 b		
Tissue					
P	1.81	2.02	1.71	1.84	0.16
K	5.75	6.81	9.13	7.23	1.73
Ca	5.85	7.03	9.50	7.46	1.86
Mg	3.22	3.24	3.37	3.28	0.08
S	3.18	3.80	6.99	4.66	2.05
Na	53	101	312	155	138
Fe	20.2	26.2	30.1	25.5	5.0
Cu	6.70	8.09	7.27	7.35	0.70
Mn	81.5	67.0	51.3	66.6	15.1
Zn	12.5	22.5	17.1	17.4	5.0
B	21.3	23.3	21.4	22.0	1.1

Units for M-3 soil is mg kg^{-1}; units for plant tissue are g kg^{-1} (macronutrients) or mg kg^{-1} (micronutrients/trace elements)
* Different letters within a row indicate significant differences according to Tukey's test ($P < 0.05$).

Table 7 2009 Blackberry fruit yields, M-3 extractable soil nutrients, and leaf tissue content.

	RUMC	MSWC	MSW Tea	Mean	Std.dev.
Yield (g)	1473	1256	1716	1482	230
Soil					
pH	6.38	6.50	6.14	6.32	0.25
P	104.2	70.2	36.7	70.3	23.7
K	75.4 a	83.2 a	38.2 b		
Ca	1628	2776	948	1784	1293
Mg	348	245	194	262	36
S	116	142	104	121	27
Fe	113	104	102	106	2
Cu	1.69	2.27	1.84	1.93	0.30
Mn	22.5	21.4	13.2	19.0	5.8
Zn	7.75	5.95	2.25	5.32	2.61
B	0.69	0.76	0.39	0.61	0.27
Na	90	195	68	117	57
Cd	0.09	0.10	0.09	0.09	0.006
Cr	0.16	0.16	0.17	0.16	0.01
Ni	0.11 b	0.14 ab	0.17 a		
Pb	1.39	1.77	0.81	1.32	0.28
Tissue					
P	1.20	1.35	1.36	1.30	0.09
K	5.00	5.23	4.51	4.91	0.37
Ca	4.20	4.09	4.17	4.15	0.06
Mg	2.54	2.18	2.60	2.44	0.22
S	2.66	2.85	2.62	2.71	0.12
Na	28.9	23.1	25.8	25.9	2.32
Fe	38.3	44.7	32.5	38.5	3.04
Cu	3.47	3.29	3.60	3.45	0.26
Mn	41.2	29.9	44.2	38.4	7.50
Zn	14.4	16.9	14.0	15.1	1.84
B	13.6	13.0	13.2	13.3	0.95
Cd	0.07	0.04	0.04	0.05	0.02
Cr	1.02	0.96	1.21	1.06	0.12
Ni	0.49	0.43	0.81	0.58	0.08
Pb	1.39	1.25	1.64	1.43	0.24

Units for M-3 soil is mg kg^{-1}; units for plant tissue are g kg^{-1} (macronutrients) or mg kg^{-1} (micronutrients/trace elements)
* Different letters within a row indicate significant differences according to Tukey's test ($P < 0.05$).

Blackberry

Fruit yields were not influenced by treatments in either year (**Tables 6, 7**); in fact, for the four years that fruit yields were recorded (2005 to 2009), there were no treatment effects on yield any year (Warman *et al*. 2010). The 2008 fruit yields were far away the highest of any year of the study, likely due to excellent pollination and moisture when the fruit was ripening.

There were few effects of treatments on soil fertility or leaf tissue content. In 2008, M-3 soil P and Ca was lowest in the tea treatment while M-3 Mg and Zn was highest in the RUMC soil and M-3 Na was highest in the MSWC soil. In 2009, only soil K and soil Ni was affected by treatments and that occurred with the MSW tea treatment, which had the lowest K and highest Ni. No treatment induced an effect on leaf elemental content in any year, although leaf Ni was highest in tea-treated leaves ($P = 0.09$). Of the other studies where similar MSW tea treatments were used (Hargreaves *et al*. 2008b, 2008c, 2009a, 2009b; Margarit 2010; Radin and Warman 2011), only Hargreaves *et al*. (2009a) reported an increase in M-3 Ni in one year compared to MSWC; however, the strawberry leaf did not show any detectable levels of Ni. In comparison with other fertility studies, Spiers (1993) looked at the relationship between applied fertilizer K and Na and leaf nutrient content and growth of 'Shawnee' in sand culture while Nelson and Martin (1986) evaluated the effect of soil-applied N and K to a thornless variety. These other studies are practically the only ones dealing with blackberry fertility (soil-plant relations) and the concerns were with N and K response and no other nutrient.

CONCLUSIONS

Crop yields indicated the compost and tea treatments produced equivalent berry or cob yields for the blackberry, strawberry and sweet corn experiments. The bean yields were highest with the MSWC and lowest with the OF, although plant numbers differed among treatments, while tomato fruit yields for soybean, BC and BC tea treatments were greater than the Control. There were also few effects of treatments on soil fertility or leaf tissue samples and low correlations existed between Mehlich-3 extract results and tissue elemental content (data not presented). The MSWC and its high tea spray had some effect on soil or tissue Na, likely because Na is the most soluble element in the tea treatments. Since Na is not essential for plant growth, increasing Na additions could affect K absorption and plant growth. Lastly, potentially toxic trace elements were not high in any of the treated plants, so all the composts and their teas would be suitable amendments for these five crops at the rates used in this study.

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REFERENCES

Diver S (2002) Notes on Compost Teas: A Supplement to the ATTRA Publication: Compost Teas for Plant Disease Control. Appropriate Technology Transfer for Rural Areas (ATTRA). Available online: http://www.attra.ncat.org

Hargreaves JC, Adl MS, Warman PR (2008a) A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems and the Environment* **123 (1-3)**, 1-14

Hargreaves JC, Adl MS, Warman PR, Rupasinghe HPV (2008b) The effects of organic amendments on mineral element uptake and fruit quality of raspberries. *Plant and Soil* **308**, 213-226

Hargreaves JC, Adl MS, Warman PR, Rupasinghe HPV (2008c) The effects of organic and conventional nutrient amendments on strawberry cultivation: Fruit yield and quality. *Journal of the Science of Food and Agriculture* **88**, 2669-2675

Hargreaves JC, Adl MS, Warman PR (2009a) Are compost teas an effective nutrient amendment in the cultivation of strawberries? – Part I: Soil and plant tissue effects. *Journal of the Science of Food and Agriculture* **89**, 390-397

Hargreaves JC, Adl MS, Warman PR (2009b) The effects of municipal solid waste compost and compost tea on mineral element uptake and fruit quality of strawberries. *Compost Science and Utilization* **17 (2)**, 85-94

Margarit SX (2010) Evaluation of conventional and alternative soil fertility strategies in the management of asparagus. MSc thesis, Dalhousie University, 87 pp

Maynard A (1995) Cumulative effect of annual additions of MSW compost on the yield of field-grown tomatoes. *Compost Science and Utilization* **3 (2)**, 47-54

Mehlich A (1984) Mehlich 3 soil test extractant, a modification of Mehlich 2 extractant. *Communications in Soil Science and Plant Analysis* **15 (12)**, 1409-1416

Mkhabela MS, Warman PR (2005) The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. *Agriculture, Ecosystems and Environment* **106**, 57-67

Nelson E, Martin LW (1986) The relationship of soil-applied N and K to yield and quality of 'Thornless Evergreen' blackberry. *HortScience* **21 (5)**, 1153-1154

Radin AM, Warman PR (2010) Assessment of productivity and plant nutrition of Brussels sprouts using municipal solid waste compost and compost tea as fertility amendments. *International Journal of Vegetable Science* **16 (4)**, 374-391

Radin AM, Warman PR (2011) Effect of municipal solid waste compost and compost tea as fertility amendments on growth and tissue element concentration in container grown tomato *Lycopersicon esculentum* Mill. *Communications in Soil Science and Plant Analysis* **42 (11)**, 1349-1362

Scheuerell S, Mahaffee W (2002) Compost tea: Principles and prospects for plant disease control. *Compost Science and Utilization* **10 (4)**, 313-338

Smith SR (2009) A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environment International* **35 (1)**, 142-156

Spiers JM (1993) Potassium and sodium fertilization affects leaf nutrient content and growth of 'Shawnee' blackberry. *Journal of Plant Nutrition* **16 (2)**, 297-303

Touart AP (2000) Time for (compost) tea in the northwest. *BioCycle* **41 (10)**, 74-77

Warman PR (1999) Sewage sludge compost as a growth medium for tomatoes. In: Wenzel WW, Adriano DC, Alloway B, Doner HE, Keller C, Lepp NW, Mench M, Naidu R, Pierzynski GM (Eds) *Proceedings 5th International Conference On Biogeochemistry Trace Elements,* Vienna'99, Austria, pp 334-335

Warman PR (2009) Soil and plant response to applications of municipal solid waste compost and fertilizer to Willamette raspberries. *International Journal of Fruit Science* **9**, 35-45

Warman PR, Termeer WC (1996) Composting and evaluation of racetrack manure, grass clippings and sewage sludge. *Bioresource Technology* **55**, 95-101.

Warman PR, Termeer WC (2005) Application of biosolids and biosolids compost to corn and forage: Yields and N, P, and K content of crops and soils. *Bioresource Technology* **96**, 955-961

Warman PR, Burnham JC, Eaton LE (2009) Effects of repeated applications of municipal solid waste compost and fertilizers to three lowbush blueberry fields. *Scientia Horticulturae* **122**, 393-398

Warman PR, Hargreaves JC, Radin AM (2010) Are compost teas suitable fertility sources for berry crops? In: Lasardi K, Manios T, Bidlingmaier W, Abeliotis K, de Bertoldi M, Diaz L, Stentiford I (Eds) *Proceedings of the 7th International Conference, Orbit 2010*, Heraklion, Crete, Greece, pp 516-521

Welke SE (2004) The effect of compost extract on the yield of strawberries and the severity of *Botrytis cinerea*. *Journal of Sustainable Agriculture* **25 (1)**, 57-68

Zheljazkov VD, Warman PR (2002) Comparison of three digestion methods for the recovery of 17 plant essential nutrients and trace elements from six composts. *Compost Science and Utilization* **10 (3)**, 197-203