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Fertigation of Cool Season Turfgrass Species with Anaerobic Digestate Wastewater

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ABSTRACT

Wastewater, uniquely derived from the anaerobic digestion of MSW and containing high contents of essential plant nutrients, was used as a primary N source for turfgrass cultivation. Creeping bentgrass (*Agrostis palustris* Huds.) and Kentucky bluegrass (*Poa pratensis* L.) were grown under controlled growth room conditions and fertilized with nutrient solution supplied from wastewater or from a commercial soluble turf fertilizer. Bentgrass supplied with wastewater-N grew similarly to those plants supplied with commercial-N in the second of three clipping harvests. In the third harvest, bentgrass supplied with wastewater-N slightly outperformed those fertilized with commercial-N. In the first harvest of bentgrass, as well as with all three harvests of bluegrass, clipping yields were comparable up to the recommended N application rate of 25 kg N·ha^{-1}, while at higher rates, growth with commercial-N exceeded that with wastewater-N. Poor plant growth response at high rates of wastewater addition was related to high concentrations of soluble salts in the wastewater. Field trials were also conducted on three established turfgrass plots typical of PGA regulation turf. *Green*-area turf was treated with fertilizer solutions supplied at 25, 50, and 100 kg·ha^{-1} from each of commercial-N, wastewater-N, wastewater-N + calcium nitrate, or 50 kg·ha^{-1} of a granular control fertilizer. *Landing*- and *rough*-area turf received half of each of these rates of N. All turf areas receiving the recommended or lower rates of N performed as well with wastewater-N versus commercial-N. Response of shoot chlorophyll content followed a similar trend as clipping yields, while soil moisture and shoot color were not significant for any treatment on any area.

Keywords: digestion, re-use, ammonium, nitrate, SUBBOR

Abbreviations: CEC, cation exchange capacity; **EC**, electrical conductivity; **GTI**, Guelph Turfgrass Institute; **ICP**, inductively coupled plasma; **MSW**, municipal solid waste; **PGA**, Professional Golfers Association of America; **PP**, Plant Products 35:5:10 soluble turf fertilizer; **SUBBOR**, Super Blue Box Recycling Corporation; **SW**, unamended anaerobic digestate wastewater; **SWA**, amended anaerobic digestate wastewater

INTRODUCTION

As an alternative solution for the management of liquids associated with solid wastes and related residuals, wastewaters are increasingly applied as supplemental irrigation and fertilizer sources in agricultural and horticultural production systems (Bouwer *et al*. 1998; Sumner 2000; Brady and Weil 2001; Epstein 2003; Alam and Chong 2006). Due to high inherent contents of essential plant nutrients, numerous wastewaters of different origins have been used in this regard (Michitsch *et al*. 2007). Notwithstanding, use of waste-derived nutrients for plant culture reduces dependence on synthetic fertilizers, provides savings in energy and minimizes inappropriate environmental discharges (Alam and Chong 2006).

Grass species, such as turfgrasses grown on golf courses, sod farms, and athletic fields, are good candidates for this form of wastewater re-use due to their high nutrient (i.e. 50 kg·ha^{-1} N) requirements and ability to effectively filter nutrient-rich wastewaters, thereby reducing wasteful emissions to local water-bodies (Johnson 1975; Moore 1994; OMAFRA 1998, 2000). Turfgrasses have been successfully grown using municipal wastewater (Mancino 1994; Allhands *et al*. 1995; Jiggens 1995; Beltrao *et al*. 1999), landfill and industrial wastewaters (Revel *et al*. 1999), liquid by-products of anaerobic digestion (Riggle 1996; Wu and Liu 1998; Little and Grant 2002), and compost teas (Anonymous 2001; Grobe 2003).

A wastewater uniquely derived from the enhanced digestion stage of the Super Blue Box Recycling Corporation (SUBBOR) process, which produces biogas and stabilized organic residuals from the anaerobic digestion of source-separated household municipal solid waste (MSW; Vogt *et al*. 2002), was used in this study to supplement turfgrass growth as a primary N source. However, this wastewater contained elevated contents of N (as NH_4–N), K, and other plant nutrients, and exhibited higher pH and electrical conductivity (EC) levels than other liquid by-products used in previously reported research. For these reasons, its re-use is a unique application and essential for the development of a complete wastewater handling capability to convey overall acceptance of the SUBBOR technology.

As the main objective of this research, the growth and mineral nutrient status of two commonly grown cool season turfgrasses, creeping bentgrass and Kentucky bluegrass, were evaluated in this wastewater with or without additional nutrients, such as calcium nitrate to adjust the ammonium to nitrate ratio. Comparison of the wastewater to a conventional commercial water-soluble fertilizer was incorporated in all experiments. Trials were conducted using pot-culture in a controlled growth-room and subsequently in unsheltered experimental field plots.

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MATERIALS AND METHODS

Controlled growth room studies

Plant material and cultural conditions

Seeds of No. 1 Cert. 18th Green creeping bentgrass (*Agrostis palustris* Huds.) and No. 1 Cert. Minnfine Kentucky bluegrass (*Poa pratensis* L.) were sown in plastic containers (8.3 cm diam.; 20 cm deep) filled with a 4:1 sand:peat mixture. Seeds were sown at 80% of the recommended maximum rates of 1.0 and 2.0 kg·100 m^{-2} for bentgrass and bluegrass, respectively (OMAFRA 2000). The sand:peat mixture, which was used to construct the field *green* root-zone area at the Guelph Turfgrass Institute (GTI; Guelph, ON), exhibited the following properties: pH, 8.0; EC, 0.2 mS·cm^{-1}; cation exchange capacity (CEC), 10.0 cmol·kg^{-1}; and nutrients (in mg·L^{-1}): NO_3–N, 14, NH_4–N, 7, and Cl, 143 (specific ion electrode method); P, 11, K, 51, Ca, 2935, Mg, 88, and Na, 35 (inductively coupled plasma {ICP}–mass spectrometric method) according to AOAC (1990) standards.

From 10 June to 10 September 2002, both grasses were grown in a growth room maintained with a 16-hr photoperiod, using 215/40 W incandescent tubes/bulbs with a photosynthetic photon flux density of 300 μmol·m^{-2}·s^{-1} measured at plant level (Quantum Meter Model QMSS, Apogee Instruments Inc., Logan, UT), temperature of 18°/15°C day/night, and relative humidity of 50%. Treatments (2 species × 5 N rates × 2 N sources) were arranged using a randomized complete block design and replicated three times. Two pots were used per plot to increase plant biomass for analysis.

Treatment solutions

The grasses were fertigated with solutions containing N at rates of 25, 50, 100, 200 and 400% the recommended rate of 25 kg N·ha^{-1} (i.e. kg N·100 m^{-2}; 0.0625, 0.125, 0.25, 0.50, and 1.00; OMAFRA 2000) and derived from both diluted (with de-ionized water) unamended anaerobic digestate (i.e. SUBBOR) wastewater (SW) and a typical commercially available soluble turf fertilizer (PP) having an analysis of 35:5:10 (as N:P_2O_5:K_2O; Plant-Prod, 2001). Analysis of the wastewater (mean of duplicate samples ± standard error) indicated: pH, 8.7 ± 1.5, EC, 18 ± 1 mS·cm^{-1}, and the nutrients (in mg·L^{-1}) NO_3–N, 0.6 ± 0.6, NH_4–N, 1590 ± 76, and Cl, 1500 ± 100 (specific ion electrode method); P, 25 ± 1, K, 1005 ± 125, Ca, 39 ± 6, Mg, 53 ± 1, Na, 2209 ± 43, Zn, 2.4 ± 1.3, Mn, 0.4 ± 0.3, Cu, 0.4 ± 0.2, Fe, 20.0 ± 13.0, and B, 1.4 ± 1.3 (ICP–mass spectrometric method) according to AOAC (1990) standards. Once per week, a total of 44 mL of each rate of fertilizer was injected with a 60 mL syringe to a depth of 1 cm in each pot. This volume corresponded to typical regional precipitation levels and irrigation recommendations (OMAFRA 2000).

Clipping harvest

Clippings from each plot (i.e. two pots) were harvested on each of three dates (13 July, 8 August, 10 September), dried at 70°C for 48 hours, and weighed. Harvest occurred approximately monthly to ensure sufficient dry matter was available for elemental analysis. Sub-samples (~0.5 g) of clippings from both SW and PP sources at the lowest, recommended, and highest rates of N, were analyzed for total-N (combustion method) and P, K, Ca, Mg, Na, Cl, Zn, Mn, Cu, Fe, and B (ICP method) according to AOAC (1990) standards.

Regression analyses (proc rsreg and proc reg; SAS Institute 2001) were performed on data for clipping (dry weight) yields and rates of N. For bentgrass at the second harvest, yield data for SW and PP were regressed together due to non-significant individual responses. Nutrient uptake yields were determined (dry weight yield × tissue nutrient content) to identify any potential nutrient specific responses.

Unsheltered field trials

Areas and plots

From 21 June to 22 September 2002, three trials were conducted at the GTI (43° 33′ N latitude, 80° 13′ W longitude, 346 m altitude) on three different established turfgrass areas encompassing 12 m × 10 m and typical of Professional Golfers Association of America (PGA) regulation turf: *green* (creeping bentgrass on sand/peat), *landing* (creeping bentgrass on soil), and *rough* (Kentucky bluegrass on soil). Treatments were completely randomized within each area with subdivision into five 1.2 m × 2 m sub-plots. Analysis of soil nutrients from all treatments from the three turfgrass areas prior to treatment application showed similar values, as represented by the *green*-area in **Table 1**. The *green* and *landing* areas were treated for dollar spot (*Sclerotinia homoeocarpa*) as required using thio-phanate methyl 2.30% fungicide.

Treatments

The *green* area was fertigated with N at rates of 0.25, 0.50 (recommended; OMAFRA 2000), and 1.00 kg N·100 m^{-2} (kg·ha^{-1}; 25, 50, and 100) supplied from three nutrient sources: Plant Products 35:5:10 commercial turf fertilizer (PP), diluted unamended SUBBOR wastewater (SW) or diluted SUBBOR wastewater (80% total-N) amended with $Ca(NO_3)_2 \cdot 2H_2O$ (20% total-N; SWA). The recommended rate for the *green* area was 50 kg·ha^{-1} (OMAFRA 2000). Analysis of the wastewater (i.e. new batch, duplicate samples) showed: pH, 8.6 ± 0.2; EC, 18 ± 1 mS·cm^{-1}; and nutrients (in mg·L^{-1}): NO_3–N, 0.3 ± 0.9; NH_4–N, 1695 ± 236; P, 19 ± 4; K, 943 ± 81; Ca, 70 ± 21; Mg, 53 ± 1; Cl, 1888 ± 54; Na, 2014 ± 136. Granular 18:6:15 fertilizer (as N:P_2O_5:K_2O) applied at 0.50 kg N·100 m^{-2}, which was typically applied to this area by the GTI manger, was used as a control. The *landing* and *rough* areas each

Table 1 Soil analysis of specific treatment plots on the *green* area from the unsheltered field trial at experiment end. Constituent levels compared to composite soil analysis prior to trial initiation.

Measurement	Unit	Initial[1]	PP[2]		SW		SWA	
			0.5[3]	1.0	0.5	1.0	0.5	1.0
pH	-	7.8	7.5	7.8	7.9	7.9	7.9	7.9
Total salts	mmhos·cm^{-1}	0.5	0.6	0.6	0.6	0.6	0.6	0.5
OM	%	2.5	3.0	2.5	2.9	2.0	3.2	2.6
CEC	meq·100g^{-1}	19	21	21	22	23	23	23
N	mg·L^{-1}	11	16	25	16	12	14	16
P	mg·L^{-1}	17	18	34	16	16	15	18
K	mg·L^{-1}	77	55	60	67	75	64	52
Ca	mg·L^{-1}	3208	3645	3611	3724	3600	3898	3846
Mg	mg·L^{-1}	191	215	212	254	204	265	252
Zn	mg·L^{-1}	4	5	5	5	5	6	5
Mn	mg·L^{-1}	21	23	24	23	24	22	23
Cu	mg·L^{-1}	1	1	1	1	1	1	1
Fe	mg·L^{-1}	15	22	21	20	18	20	20
B	mg·L^{-1}	0.2	0.3	0.3	0.5	0.4	0.4	0.5

[1] due to similarity, values for 'initial' refer equally to the *green*, *landing* and *rough* turfgrass areas

[2] treatment abbreviations: Plant Products (PP), SUBBOR unamended wastewater (SW), SUBBOR amended wastewater (SWA)

[3] indicated rates in kg N·100m^{-2} (multiply by 100 for equivalent rates in kg N·ha^{-1})

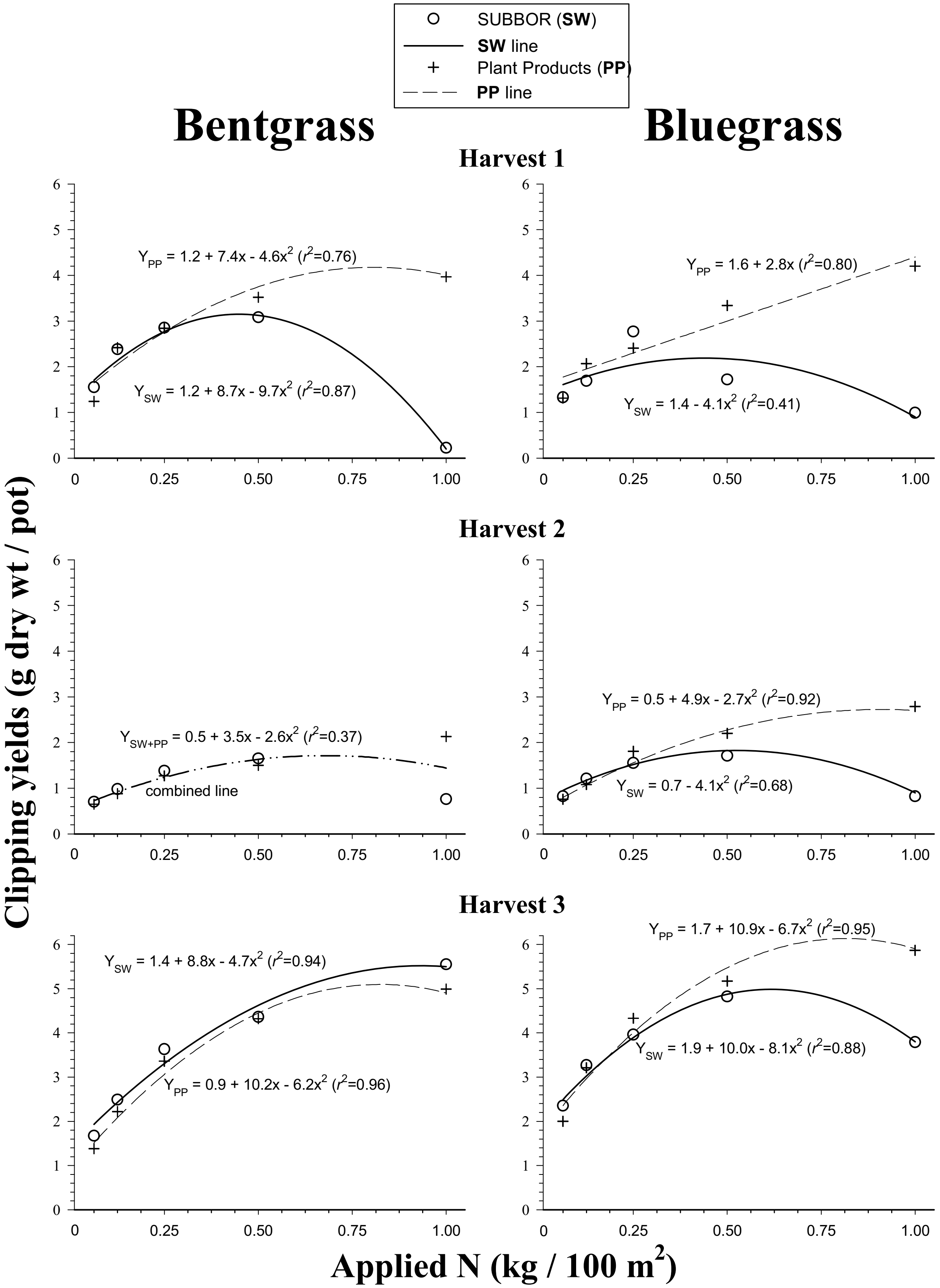

Fig. 1 Effect of rates of N supplied from SUBBOR wastewater (SW) or Plant Products commercial fertilizer (PP) on clipping yields of turfgrass species in the controlled growth room study. The regression of each N source is represented separately or combined.

received half of each of the rates of N described above per recommendations (OMAFRA 2000), including the control. Fertilizer treatments were applied manually with watering cans (20 L per sub-plot) every two weeks from 21 June to 30 August. Areas were irrigated on non-treatment days according to conventional turfgrass management practices (OMAFRA 2000) supported by weather data collected on-site.

Physical and clipping analyses

Shoot chlorophyll content (Spectrum Technologies Inc. Field Scout CM1000 Chlorophyll Meter, East-Plainfield, IL), shoot color (as hue, value, chroma; Konica Minolta Business Solutions Canada Ltd. CR-310 Colorimeter, Mississauga, ON), qualitative visual observations and soil moisture content (12 cm depth; Campbell Scientific Canada Corp. HydroSense System, Edmonton, AB) were recorded weekly at the same time. On four occasions between early July and September, clippings were harvested separately from each sub-plot, and similarly dried and weighed. With one pass of a greens mower (53 cm blade length), each sub-plot was harvested from its central portion (53 cm×147cm) by clipping to conventional GTI practices (heights: *green*-7.5 mm; *landing*-15 mm; *rough*-23 mm). Data are presented as means over the four harvest dates and five sub-plots for each of the three turfgrass areas. Clippings from the fourth (i.e. final, most mature) harvest were analyzed for selected nutrients, as well as composite soil samples (i.e. 5 cores per plot, 0-10 and 10-20 cm depths) collected at this time from plots on the *green* receiving the 0.5 and 1.0 kg N·100 m^{-2} solutions of PP, SW, and SWA, to comprehensively highlight differences imposed on the turfgrasses by the fertilizer treatments.

Regression analyses (previously described) were performed on clipping dry weight yields and shoot chlorophyll content data. For the SW and SWA (*green*), and PP and SW (*rough*) treatments, yield data were combined and regressed together due to non-significant individual responses. Dunnett's procedure (proc glm; SAS Institute 2001) was performed on clipping yield averages, and shoot chlorophyll content and color data, to identify any potential differences in these data between the nutrient solutions and the granular (control) fertilizer. Turfgrass nutrient uptake yields were similarly calculated.

RESULTS

Controlled growth room studies

At the first harvest (**Fig. 1**), mean clipping yields (per two pots) of bentgrass fertilized with PP and SW solutions increased curvilinearly with increasing rates of N to a calculated maximum of 4.2 and 3.2 g dry wt at 0.80 and 0.45 kg N·100 m^{-2}, respectively. Growth response of bentgrass to PP and SW treatments at the second harvest showed a similar trend (common curve, peak of 1.7 g dry wt at 0.68 kg N·100 m^{-2}). At the third harvest, SW-fertilized bentgrass slightly outgrew (peak of 5.5 g dry wt at 0.94 kg N·100 m^{-2}) those fertilized with PP (peak of 5.1 g dry wt at 0.82 kg N·100 m^{-2}). For bluegrass at each of the three harvests (**Fig. 1**), clipping yields peaked higher with PP (range 6.1 to 4.4 g dry wt between 0.81 and 1.00 kg N·100 m^{-2}) than with SW (2.2 to 5.0 g dry wt between 0.44 and 0.61 kg N·100 m^{-2}) solutions. The sharp decline in growth of both turfgrasses in the high-N rate SW treatment was confined to the first harvest or the 1.00 kg N·100 m^{-2} applications. Furthermore, increased K, Na, Mn and B contents were noted for both species in the high-N rate SW treatment, but not the similarly applied rate of PP (**Table 2**). Leachates obtained from high-N wastewater treatments (i.e. 1.00 kg N·100 m^{-2}), collectively exhibited EC levels as high as 7 mS·cm^{-1}, while low-N wastewater treatments, and all PP and control leachate samples, had comparably lower EC levels of 1 mS·cm^{-1} (data not shown).

Table 3 Analysis of regression for chlorophyll content (as chlorophyll index value) of shoots for each area from the unsheltered field trials. All measurement times are regressed together.

Area	Source	Regression equation	Components	
			Linear	Quadratic
GREEN	PP^1	$y = 260 + 201x$	**	NS
	SW	$y = 259 + 375x - 419x^2$	**	**
	SWA	$y = 196 + 580x - 551x^2$	**	**
LANDING	PP	$y = 381 + 6x$	**	NS
	SW	$y = 309 + 317x - 185x^2$	**	**
	SWA	$y = 396 + 41x$	*	NS
ROUGH	PP	y = NS	NS	NS
	SW	$y = 610 - 185x$	**	NS
	SWA	$y = 615 - 173x$	*	NS

**, * significant at $\underline{P} \leq 0.01$ or 0.05, NS = not significant, respectively

^{1} treatment abbreviations: Plant Products (PP), SUBBOR unamended wastewater (SW), SUBBOR amended wastewater (SWA)

Unsheltered field trials

For the *green* area, clipping yields (per sub-plot) of the unamended (SW) and amended (SWA) wastewater solutions (combined curve) increased with increasing rates of N to a peak of 11.5 g dry wt at 0.58 kg N·100 m^{-2} (**Fig. 2**). The regression of clipping yields for turf receiving different rates of N in the PP solution was not significant (mean response of 10.1 g dry wt). For the *landing* area, clipping yields increased linearly up to 11.4 g dry wt at the 0.5 kg N·100 m^{-2} maximum level in response to the SW solutions, but were unresponsive to PP or SWA (mean clipping yields of 7.5 and 9.4 g dry wt, respectively). For the *rough* area, clipping yields increased linearly with all treatment solutions, though growth was better with the PP and SW solutions (combined line; 40.5 g dry wt at the 0.50 kg N·100 m^{-2} maximum rate) than with the SWA solution (36.3 g dry wt).

Nutrient uptake determination indicated that contents of each nutrient for plants treated with both nutrient sources responded similarly, and were either similar to the trend for clipping yields or stayed constant as the rate of applied N increased (data not shown). Notwithstanding, the various treatments resulted in neither soil nutrient depletion nor enrichment for the macro- and micro-nutrients indicated (**Table 1**), while the response of shoot chlorophyll content followed a similar trend as clipping yields (**Tables 3, 4**). Soil moisture content and shoot color (i.e. hue, value and chroma) measurements per plot were not significantly different for any treatment on any area (data not shown); however, the SUBBOR wastewater was observed to temporarily darken plots receiving these solutions following application. Qualitative visual observations were similarly inconclusive.

DISCUSSION

The results of this study show that the use of anaerobic digestate wastewater derived from the SUBBOR process is comparable to commercial fertilizer as a source of N for turfgrass production at rates recommended for turf in Ontario (OMAFRA 2000). The SUBBOR wastewater contained

Table 2 Tissue nutrient contents for turfgrasses (both species combined) from the controlled growth room study.

Treatment	N^3	P	K	Ca	Mg	Na	Cl	Zn^3	Mn	Cu	Fe	B
	--------------------	% dry wt	--------------------						------------ mg/kg ------------			
SW^1 (0.0625^2)	2.21	0.21	1.59	0.51	0.23	0.22	0.70	32	258	16	332	10
SW (0.25)	2.90	0.13	1.86	0.44	0.23	0.45	1.45	43	197	17	402	16
SW (1.0)	3.11	0.15	2.25	0.67	0.20	0.77	1.20	60	343	18	293	51
PP (0.0625)	2.24	0.24	1.52	0.60	0.26	0.16	0.95	33	278	14	315	8
PP (0.25)	2.96	0.18	1.53	0.56	0.31	0.34	0.85	48	171	15	330	6
PP (1.0)	4.28	0.19	1.98	1.24	0.27	0.26	0.53	40	181	16	345	4

^{1} treatment abbreviations: Plant Products (PP), unamended SUBBOR wastewater (SW)

^{2} indicated rates in kg N·100 m^{-2} (multiply by 100 for equivalent rates in kg N·ha^{-1})

^{3} Target values (Hopkins 1999): (*as %*): N:1.5; P:0.20; K:1.00; Ca:0.50; Mg:0.20; Cl:0.01; Na: n/a; (*as mg·kg^{-1}*): Zn:20; Mn:50; Cu:6; Fe:100; B:20

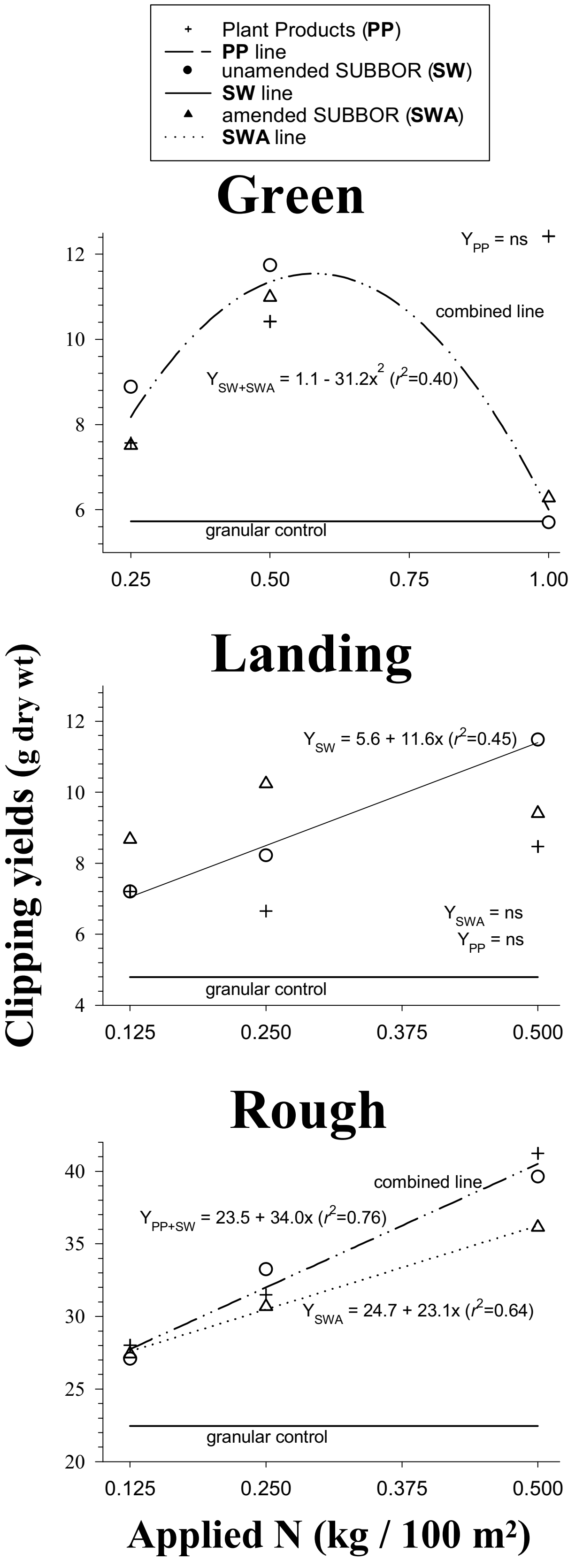

Fig. 2 Effect of rates of N supplied from unamended SUBBOR wastewater (SW), amended SUBBOR wastewater (SWA) or Plant Products commercial fertilizer (PP) on clipping yields (per 2.4 m^2 sub-plot) from each of three established turfgrass areas in the unsheltered field trials. The regression of each N source is represented separately or combined. The horizontal solid line represents yield data of granular fertilizer (control) applied at the recommended rate of N (indicated by arrow). Each plotted point represents the mean over four harvest dates and five sub-plots.

levels of N comparable to that of landfill leachate, which is known to contain high concentrations of nitrogenous compounds (Revel *et al.* 1999), or approximately 15 times greater than local sewer discharge limits of 100 mg L^{-1} (City of Guelph 1996).

The main form of N in the SUBBOR wastewater and the selected commercial fertilizer was ammonium-N (total-N: ~90% NH_4–N; ~10% NO_3–N). While a 5:1 NO_3:NH_4 ratio has been suggested for optimal plant growth (Warncke and Barber 1973; Steiner 1984; Barber and Pierzynski 1991), the present study showed generally positive plant growth using the wastewater and the commercial-N sources at low NO_3:NH_4 ratios (~1:9). Furthermore, the substitution of N from calcium nitrate as $Ca(NO_3)_2{\cdot}2H_2O$ to provide a more balanced NO_3:NH_4 ratio had no significant benefit in improving plant response to the wastewater for any of the field test areas. Thus, these results support previous findings that the NO_3:NH_4 ratio is not the exclusive factor in growth response of turfgrass to N fertilization (Eggens *et al.* 1989; Sady *et al.* 1995; Strojny 1999).

For the controlled growth room experiments, in which early-stage growth in the wastewater was significantly less compared to the commercial fertilizer above the recommended (i.e. 25 kg N·ha^{-1}) or higher levels of N, the growth response patterns of plants fertilized with both nutrient sources became more similar with succeeding harvests, especially at higher rates of applied N (**Fig. 1**). Irrigation saturation, drainage improvement attributed to root growth, increased plant biomass, initial plant immaturity, and elevated Na and B values inherent of the wastewater, may all have impacted or interacted to cause this effect. Moreover, the plant roots may have initially been more sensitive to high nutrient-salt concentrations and/or imbalances (Bernstein 1964). This was supported by EC levels found as high as 7 mS·cm^{-1} in leachates collected from high-N wastewater treatments, which is double the recommended 3.5 mS·cm^{-1} threshold (Pescod 1992). The low-N treatments had comparably lower EC levels of 1 mS·cm^{-1}. Furthermore, nutrient uptake determination indicated that contents of each nutrient, for plants treated with both nutrient sources, responded similarly and either mimicked the trend for clipping yields or stayed constant as the rate of applied N increased (data not shown). Na, Cl, and Mn (bentgrass; data not shown), and K and B (both species; **Table 2**) contents, were higher for the wastewater treated plants, a reflection of high levels of these nutrients in the wastewater. These elevated levels may have led to greater luxury consumption and possible exclusion of other nutrients, such as NH_4–N, in the wastewater treated plants, which may have contributed to lower clipping yields at higher rates of applied N.

Regarding the field trials, comparison of soil parameter levels indicated that the treatment solutions similarly affected the underlying soil, noting only a slight increase in N and P for those receiving the 1.0 kg N·100 m^{-2} rate of PP (**Table 1**). The levels for all parameters were generally higher than initial background levels (except K), attributed to additions of treated plant material (i.e. non-collected clippings) and fertilizer sources over the course of the growing season. These inherent macro- and micro-nutrient levels were sufficient to mask additions from respective wastewater and PP treatment solutions, as nutrient uptake determinations for both experiments confirmed that levels of nutrients (other than N) generally mimicked the trend for clipping yields, or stayed constant, as the rate of applied N increased. Shoot chlorophyll content in the field trials followed the same trends as clipping yields (**Tables 3, 4**) and nutrient uptake yields (data not shown). Notwithstanding this variation, it is noteworthy that clipping yield responses to all rates of N from PP, SW, and SWA solutions within all three areas exceeded that due to the granular fertilizer, except on the *green* area in which the SW and SWA solutions at the highest (i.e. 1.0 kg N·100 m^{-2}) rate 'burned' the turfgrass (**Fig. 2; Table 4**).

The observed 'burning' effect is explainable and attributed to the high salt (i.e. K, Na, SO_4, Cl) content of the wastewater. However, these burning symptoms were not observed to the same extent with similar and higher N rates

Table 4 Dunnett's procedure comparisons of chlorophyll content of shoots for each nutrient solution to the granular (control) fertilizer, and of clipping yields (g dry weight/plot) from each nutrient solution to the granular (control) fertilizer, for all four harvests combined for each area from the unsheltered field trials.

Treatment	**Chlorophyll Content Comparison**			**Clipping Yield Comparison**		
	Green	**Landing[3]**	**Rough[3]**	**Green**	**Landing[3]**	**Rough[3]**
PP[1] (0.25[2])	*	NS	NS	NS	NS	*
PP (0.5 rate)	*	NS	NS	*	NS	*
PP (1.0 rate)	*	NS	NS	*	NS	*
SW (0.25 rate)	*	NS	NS	NS	NS	NS
SW (0.5 rate)	*	NS	NS	*	NS	*
SW (1.0 rate)	NS	NS	NS	NS	*	*
SWA (0.25 rate)	*	NS	NS	NS	NS	*
SWA (0.5 rate)	*	NS	NS	*	*	*
SWA (1.0 rate)	NS	NS	NS	NS	*	*

* significant at $P \le 0.05$, NS = not significant, respectively

[1] treatment abbreviations: Plant Products (PP), SUBBOR unamended wastewater (SW), SUBBOR amended wastewater (SWA)

[2] indicated rates in kg N·100 m^{-2} (multiply by 100 for equivalent rates in kg N·ha^{-1})

[3] *landing* and *rough* areas received half the indicated rates of the *green* area

of wastewater solutions in the growth room experiment. Immobilization of trace elements by complexation with the applied fungicide (for dollar spot control) may have contributed to the burn, as well as variations in growth response and tissue nutrient contents (Weissmahr and Sedlak 2000), since Na and B were present in these burned tissues at elevated levels. Field conditions were very hot and dry during the summer of 2002 and may have exacerbated the burning effect from high salt content at low wastewater dilution (i.e. from enhanced evapotranspiration in the plants). However, no significant differences in soil moisture content were indicated at any time for any area (data not shown), even though puddles were observed on the *landing* following irrigation events. While shoot color was not significant for the three individual components of color (hue, value, chroma) for any treatment on any area (data not shown), application of the wastewater temporarily darkened plots receiving these solutions on treatment day, a coloration attributed to suspended solids and tannins. This darkening effect may have contributed to enhanced daytime heating of shoots, thereby promoting burning by increasing evapotranspiration and leading to fatal water deficits in the aboveground biomass (pers. obs.). Application of readily-available N as NH_4–N may also have promoted the burning effect in the absence of other mitigating factors, such as luxury consumption or exclusion of certain elements, since quick-release fertilizers have higher burn potential (Turgeon 2002). The burning effect was not observed on the *landing* and *rough* areas, attributed to N application rates at half those of the *green* area and much greater mowing heights (i.e. *green*-7.5 mm; *landing*-15 mm; *rough*-23 mm). Applied at recommended rates and based on related results (Michitsch *et al.* 2007), the researchers do not view salt accumulation as a substantial concern, even though only one season of data was obtained. Further data was to be collected to confirm field-based results and to explore issues of 'burning' and elemental accumulation in the underlying soil.

Dollar spot (*Sclerotinia homoeocarpa*) infection was observed on the *green* and *landing* areas. Plots receiving higher N treatments (especially those treated with SUBBOR wastewater treatments) showed decreased incidence; this observation was interesting since the small and infrequent applications of thio-phanate methyl 2.30% fungicide to combat dollar spot invasion were considered insignificant to affect soil parameter levels due to uniform application over entire turfgrass areas. Organic waste-derived N fertilizers have been reported to offer disease suppression by increasing soil microbial activity, which decreases further pathogen activity (Scheuerell 2003; Scheuerell and Mahaffee 2003; Ingham 2004), and dollar spot presence has been observed to decrease using organic waste-derived N fertilizers (Davis and Dernoeden 2002). Since the wastewater was high in N, this may in part explain the observed decrease in dollar spot invasion in comparison to other treatments. Further study is warranted.

SUMMARY AND CONCLUSIONS

This study demonstrated the ability to re-use wastewater from anaerobically-digested MSW using the SUBBOR process as an adequate nitrogen source for turfgrass culture. For bentgrass in the growth room experiment, optimum rates of wastewater-N varied between 0.45 and 0.94 kg N·100 m^{-2}, while for bluegrass, optimum rates were more restricted (range between 0.44 and 0.61 kg N·100 m^{-2}). Under field conditions, optimum rates for the *green* area were 0.50 kg N·100 m^{-2}, the rate of N recommended for turf application in Ontario. For the *landing* and *rough* areas, optimum rates were also 0.50 kg N·100 m^{-2}, or double the recommended rate. Nitrogen form and NO_3:NH_4 ratio had no observable effect on field turfgrass response.

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REFERENCES

Alam MZ, Chong C (2006) Recycling compost wastewaters and nutrients in container ornamental production. *Recent Research Developments in Agronomy and Horticulture* **2**, 39-69

Allhands MN, Allick SA, Overman AR, Leseman WG, Vidak W (1995) Municipal water reuse at Tallahassee, Florida. *Transactions of the ASAE* **38**, 411-418

Anonymous (2001) Compost tea protects greens on Presidio Golf Course. *BioCycle* **42**, 6

AOAC (1990) *Official Methods of Analysis* (16th Edn), Association of the Official Analytical Chemists, Washington, DC

Barber KL, Pierzynski GM (1991) Ammonium and nitrate source effects on field crops. *Journal of Fertilizer Issues* **8**, 57-62

Beltrao J, Gamito P, Guerrero C, Arsenio A, Brito JC (1999) Grass response to municipal wastewater reuse as compared to nitrogen and water application. In: Anac D, Martin-Prevel P (Eds) *Improved Crop Quality by Nutrient Management*, Kluwer Academic Publishers, MD, pp 263-265

Bernstein L (1964) *Salt Tolerance of Plants*, Agriculture Information Bulletin No. 283, USDA, Washington, DC, 23 pp

Bouwer HP, Fox P, Westerhoff P (1998) Irrigating with treated effluent. *Water Environment and Technology* **10**, 115-120

Brady NC, Weil RR (2001) *The Nature and Properties of Soils*, Prentice Hall, NJ, 960 pp

City of Guelph (1996) *By-law Number (1996)-15202 and Municipal Code Amendment #187*, Corporation of the City of Guelph, Guelph, ON

Davis JG, Dernoeden PH (2002) Dollar spot severity, tissue nitrogen and soil microbial activity in bentgrass as influenced by nitrogen source. *Crop Science* **42**, 480-488

Epstein E (2003) *Land Application of Sewage Sludge and Biosolids*, Lewis Publishers, NY, 201 pp

Eggens JL, Wright CPM, Carey K (1989) Nitrate and ammonium nitrogen effects on growth of creeping bentgrass and annual bluegrass. *HortScience* **24**, 952-954

Grobe K (2003) Golf courses find value in compost tea programs. *BioCycle* **44**, 22-23

Hopkins WG (1999) *Introduction to Plant Physiology*, John Wiley & Sons, Toronto, ON, 512 pp

Ingham E (2004) Compost tea and hydroponics. *The Growing Edge* **15**, 14-19

Jiggens M (1995) Irrigating with effluent water. *Turf and Recreation* **8**, 9-19

Johnson GV (1975) Land application of municipal effluent waste on turf. In: *Annual Technology Conference Proceedings of the Sprinkler and Irrigation Association*, pp 196-203

Little CM, Grant AA (2002) Making integrated anaerobic digestion projects a reality. *BioCycle* **43**, 64-68

Mancino CF (1994) Irrigation of turfgrass with wastewater. In: USGA (Ed) *Wastewater Reuse for Golf Course Irrigation*, Lewis Publishers, MI, pp 174-191

Michitsch RC, Chong C, Holbein BE, Voroney RP, Liu H-W (2007) Use of wastewater and compost extracts as nutrient sources for growing nursery and turfgrass species. *Journal of Environmental Quality* **36**, 1031-1041

Moore J (1994) Coping with wastewater: Management strategies and information sources. In: USGA (Ed) *Wastewater Reuse for Golf Course Irrigation*, Lewis Publishers, MI, pp 193-201

OMAFRA (1998) *Soil Fertility Handbook*, Publication 611, Ontario Ministry of Agriculture, Food and Rural Affairs, Toronto, ON, 169 pp

OMAFRA (2000) *Turfgrass Management Recommendations*, Publication 384, Ontario Ministry of Agriculture, Food and Rural Affairs, Toronto, ON, 44 pp

Pescod MB (1992) *Wastewater Treatment and Use in Agriculture*, FAO, Rome, 122 pp

Plant-Prod (2001) *Water Soluble Fertilizers: Fertilizer Guide for Horticulture and Agriculture*, Plant Products Company Limited, Brampton, ON, 50 pp

Revel JC, Morard P, Bailly JR, Labbe H, Berthout C, Kaemmerer M (1999) Plants' use of leachate derived from municipal solid waste. *Journal of Environmental Quality* **28**, 1083-1089

Riggle D (1996) Anaerobic digestion for MSW and industrial wastewater. *BioCycle* **37**, 77-81

Sady W, Rozek S, Myczkowski J (1995) Effect of different forms of nitrogen on the quality of lettuce yield. *Acta Horticulturae* **401**, 409-416

SAS Institute (2001) *The SAS System for Windows* (*Release 8.2*). SAS Inst., Cary, NC

Scheuerell S (2003) Understanding how compost tea can control disease. *BioCycle* **44**, 20-25

Scheuerell SJ, Mahaffee WF (2003) Compost teas for plant disease control: Production, application and results. *Proceedings of the ASA-CSSA-SSSA Annual Meetings*, Denver, CO, 2-6 November 2003

Steiner AA (1984) The universal nutrient solution. In: *ISOSC Proceedings*, pp 633-649

Strojny Z (1999) Effect of nutrient solution concentration and NH_4: NO_3 ratio on maranta growth. *Scientia Horticulturae* **80**, 105-112

Sumner ME (2000) Beneficial use of effluents, wastes and biosolids. *Communications in Soil Science and Plant Analysis* **31**, 1701-1715

Turgeon AJ (2002) *Turfgrass Management* (6th Edn), Prentice Hall, NJ, 391 pp

Vogt GM, Liu H-W, Kennedy KJ, Vogt HS, Holbein BE (2002) Super blue box recycling (SUBBOR) enhanced two-stage anaerobic digestion process for recycling municipal solid waste: Laboratory pilot results. *Bioresource Technology* **85**, 291-299

Warncke DD,Barber SA (1973) Ammonium and nitrate uptake by corn (*Zea mays* L.) as influenced by nitrogen concentration and NH_4/NO_3 [ammonium/ nitrate] ratio. *Agronomy Journal* **65**, 950-952

Weissmahr KW, Sedlak DL (2000) Effect of metal complexation on the degradation of dithiocarbamate fungicides. *Environmental Toxicology and Chemistry* **19**, 820-826

Wu YZ, Liu KJ (1998) An introduction to the state of research and development of biogas in rural areas of China in recent years and discussion on improvement of old biogas technology (Chinese). *Biogas Technology and Utilization Research*, 13 pp