Assessing the Potential Phytotoxicity of Digestates during Processing of Municipal Solid Waste by Anaerobic Digestion: Comparison to Aerobic Composts

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Abstract

As a preliminary evaluation of the progression of mixed municipal solid waste processing, we assessed digestates sampled at various stages of an enhanced anaerobic digestion process (Primary digestates: unwashed [PU] and washed [PW]; Steam disrupted primary digestate [ST]; Secondary digestate [SD]; and Finished 'peat-like' product [FP] for their potential phytotoxicity to the germination of cress (*Lepidium sativum* L. cv. Peppergrass) and radish (*Raphanus sativus* L. cv. Champion). A germination bioassay was conducted on both undiluted and diluted (3 and 10x) saturated extracts and expressed in terms of a germination index with all values relative to water (100%). For comparison, extracts from aerobically composted source-separated organic fraction of municipal solid waste (City of Guelph, GMC), yard waste compost (City of Toronto, TYC), and a commercial growing mixture (Sunshine Mix #2, SSM) were also included. The electrical conductivity (EC, dS/m; an indicator of soluble salts concentration) for undiluted extracts was highest for GMC (17.7) and lowest for FP (0.8), while SSM has an EC of 1.2. Germination index was negatively correlated with EC ($r = -0.65^{*}$, $p<0.05$, n=24). In undiluted extracts, the highest germination index occurred in SSM (141), followed by PW (108) and TYC (107), then ST (72), PU (71), FP (67) and SD (42), while GMC had the lowest (2). High soluble salts in the extracts appear to represent the major component of phytotoxicity.

INTRODUCTION

Municipal solid waste (MSW) totalled 30 million tonnes in Canada in 2001, a mere 30% of which was recycled. With organic material comprising 70% of MSW, the potential environmental problems associated with landfills could be reduced by diversion (Environment Canada, 1995).

Aerobic composting or anaerobic decomposition of the organic fraction of MSW diverts waste from landfills and produce organic by-products that can be used as horticultural substrates. However, incomplete stabilization of the organic matter, the presence of fugitive contaminants, as well as elevated concentrations of soluble salts (Chong, 1999; Zucconi and deBertoldi, 1987), heavy metals (Bourque et al., 1994), and alkalinity (Zucconi and deBertoldi, 1987), can lead to problems.

There are standards to ensure high and consistent quality of waste-derived composts for use in horticulture (CCME, 1996; Brinton, 2001) but no such criteria are available for anaerobic digestates. Super-Blue-Box-Recycling (SUBBOR) Corp., an affiliate of Eastern Power (Toronto, ON), the 10th largest independent power producer in Ontario and proprietor of the world's second and third largest biogas-fueled power plants (total 60MW), developed an innovative, patented process of extracting methane from MSW-derived digestates, producing a peat-like residual (Liu et al. 2002; Vogt et al. 2002). This residual has potential for use as a substrate amendment in the nursery and/or horticultural industry. As a preliminary to this work, the objectives of this study were to compare and chemically characterise the digestates at different stages of the SUBBOR anaerobic process and to evaluate their phytotoxicity using a seed germination bioassay.

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MATERIALS AND METHODS

Digestate and Compost Samples

Samples were obtained from progressive stages of anaerobic digestion (SUBBOR pilot testing facility, Guelph, ON): primary unwashed (PU), primary washed (PW), steam disrupted (ST), secondary (SD) and final product (FP). Aerobic composts were: leaf and yard waste from the City of Toronto, ON (TYC) and source-separated MSW from the City of Guelph, ON (GMC). Sunshine Mix #2 (SSM; JVK Ltd., St. Catharines, Ontario; 70% peat, 20% perlite, 10% gypsum/dolomitic lime, trace of wetting agent) was used as a reference material.

Chemical Analyses

Duplicate 250 g samples of each of the above test materials were analysed for pH, electrical conductivity (EC, a measure of total soluble salts), and nutrients from saturated paste extracts using accredited methods (Laboratory Services Division, University of Guelph, Guelph, ON).

Preparation of Extracts

A 200g sample of each test material was saturated with distilled water, centrifuged for 10 min at 10,000 rpm, and filtered through Whatman #5 filter paper. The supernatant (extract) was stored at -15^{o}C until used for bioassay.

Seed Germination Bioassay

Frozen extracts were thawed. One millilitre of undiluted (1x) or diluted (3x, 10x) extract from each test material, as well as distilled water and 0.015*M* acetic acid (used as controls), were transferred into a 50 mm petri dish lined with Whatman #3 filter paper. Ten seeds of radish (*Raphanus sativus* L. cv. Champion) or garden cress (*Lepidium sativum* L. cv. peppergrass) (Stokes Seeds Company, St. Catharines, ON) were placed on the filter paper in a circular pattern (Halet et al., 1996). Dishes were then covered, sealed with Parafilm, and placed in the dark at 27°C in a germination chamber according to a 3-factor factorial (2 species x 3 dilutions x 8 extracts). There were four replications (dishes) of each treatment extract, per species. After 24 hr, the petri dishes were unsealed. The number of seeds that germinated and root length measured to the nearest 0.5 mm were expressed as percentages of corresponding results in distilled water. The germination index (GI) was calculated as follows: GI = (% germination x % root length)/ 100) (Zucconi et al., 1981). A GI greater > 70% is considered non-phytotoxic, while < 70% is phytotoxic.

Statistical Design

Data for GI were subjected to analysis of variance, and means were separated using Tukey's test and compared separately to the distilled water and acetic acid controls using Dunnett's test.

RESULTS AND DISCUSSION

EC, Nutrients, and pH

Compared to Sunshine Mix #2, with an EC of 1.2 dS m^{-1}, the EC in the other materials ranged from 0.8 dS m^{-1} [SUBBOR's final product (FP)] to 17.7 dS m^{-1} [Guelph municipal compost (GMC)] (Table 1). Among the digestates, there was a decreasing trend from start material (PU, 5.9 dS m^{-1}) to end product (FP, 0.8 dS m^{-1}) as the digestion process progressed. The high EC values, especially in PU and GMC, were due primarily to elevated concentrations of Na, Cl, SO_4, and/or NO_3.

The pH of the digestates was alkaline (ranging from 7.8 to 9.1) and above values recommended for plant growth (OMAFRA, 2000) as were the two city composts (GMC, 7.2 and TYC, 7.9). Sunshine Mix #2 was the only material with desirable pH (6.5).

Germination Index

Analysis of variance for germination indices showed significant differences due to extracts from the test materials, their dilution levels, and the interaction of these factors (Table 2). There was no difference in response between the two species.

Figure 1 shows that there was little difference in germination indices between 3x (range 72-158, mean over all test materials =122) and 10x (range 90-160, mean =132) dilutions. However, undiluted extracts produced significantly lower indices (range 2-141, mean =76). Among all extracts and dilution levels, the only materials that were phytotoxic to germinating seedlings under the conditions of this study were undiluted extracts of GMC and SD (GI = 2 and 42, respectively, both values significantly lower than GI=100 in distilled water and similar to GI=12 in acetic acid). In this study with germinating seedlings of two species it is likely that the presence of soluble salts was the factor most responsible for phytotoxicity. In fact, in undiluted extracts there were significant negative correlations between germination index and EC, and also between germination index and various nutrients (Table 3). The strongest correlations occurred with both Na and Cl (r = -0.68).

In contrast, the PW and SSM extracts at both 3x and 10x dilutions (GI between 152 to 160) were stimulatory, as also the PU and TYC extracts at 10x dilution only (GI 143 to 158). Atzmon et al. (1997) hypothesized that increased root and shoot development of *Bougainvillea* cuttings in sewage sludge compost media (1.0 - 7.5% by vol) was due to the presence of auxins, cytokinins, and/or biocatalysts, such as enzymes, vitamins, and antibiotics. More research is required to evaluate the possible presence of these substances in digestates and composts (Atzmon et al. 1997).

Although cuttings are sensitive to salts, Chong (2002) indicated that many woody cuttings rooted well in media with salt levels <0.2 dS m^{-1}, measured in substrate and water (1:2 v/v) extracts. This threshold is in the same order of magnitude (0.9 dS m^{-1} in saturated media extract equivalent using conversion factors derived by McLachlan et al. 2002) as SUBBOR's final product (FP) (0.8 dS m^{-1}) and Sunshine Mix #2 (1.2 dS m^{-1}) (Table 1). Notwithstanding the better response of the germinating seedlings in Sunshine Mix #2 compared to SUBBOR's final product (Figure 1), the final product could potentially make a good nursery substrate component since nursery plants are much more tolerant than germinating seedlings to salts. However, growth trials are required to further assess or confirm its suitability

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Tables

Table 1. Chemical analysis of extracts from test materials.

	Digestates[1]					Composts[2]		
Variable	PU	PW	ST	SD	FP	SSM[3]	TYC	GMC
EC (dS m^{-1})	5.9	1.8	1.0	2.2	0.8	1.2	1.8	17.7
pH	8.8	9.1	7.8	9.0	8.5	6.5	7.9	7.2
NO_3-N[4]	12	5	4	52	17	3	17	1060
NH_4-N	77	9	8	23	5	5	5	15
P	9	5	0	3	1	0	2	5
K	349	134	66	137	32	3	750	1514
Ca	10	4	7	3	5	92	40	152
Mg	16	6	37	12	12	99	123	552
SO_4	590	351	177	750	112	15	575	3320
Na	724	237	127	459	209	612	78	1311
Cl	762	282	118	390	132	25	56	2481
Al	4.0	0.5	0.6	2.0	0.8	0.1	0.8	2.0
B	0.5	0.2	0.0	0.3	0.1	0.03	0.1	0.2
Cu	0.1	0.03	0.1	0.1	0.04	0.1	0.1	0.1
Fe	0.8	0.1	0.04	0.5	0.2	0.01	0.1	0.1
Mn	3.1	1.3	0.7	4.9	1.8	0.05	0.7	1.2
Mo	3.1	1.5	0.4	1.2	0.8	0.1	1.1	0.8
Zn	0.3	0.1	0.04	0.2	0.1	0.01	0.05	0.1

[1] Digestates: PU = primary digestate unwashed; PW = primary digestate washed; ST = steam disruption treatment; SD = secondary digestate; FP = final product.
[2] Composts: TYC = Toronto leaf and yard waste compost; GMC = Guelph municipal compost.
[3] SSM = Sunshine Mix #2 (reference material).
[3] Concentrations of all nutrients expressed in mg L^{-1}.

Table 2. Analysis of variance for germination indices.

Source	df	Mean square	
Extract (E)	7	23177	**
Dilution level (D)	2	56938	**
Species (S)	1	1704	
E x D	14	3952	**
E x S	7	2800	
D x S	2	1086	
E x D x S	14	580	
Replication	3	23672	**
Error	141	1522	

** significant at $p < 0.01$

Table 3. Correlation coefficients[z] (r) between germination indices and various parameters analysed from undiluted extracts.

Parameter[y]	r	Significance	N
Na	-0.68	*	32
Cl	-0.68	*	32
NO_3	-0.63	*	32
EC (dS m^{-1})	-0.62	*	24
K	-0.52	*	32
SO_4	-0.50	*	32
Ca	-0.50	*	32
Al	-0.46	*	32
Fe	-0.42	**	32
Zn	-0.34	NS	32
pH	-0.32	NS	28
Mo	-0.31	NS	32
P	-0.29	NS	32
Cu	-0.25	NS	32
Mg	-0.23	NS	32
NH_4	-0.19	NS	32
Mn	-0.14	NS	32
B	-0.12	NS	32

ns, *, ** not significant, significant at $p < 0.01$ and 0.05, respectively.

z correlation performed using Pearson's Correlation (r) procedure.

y all units are mg L^{-1} unless otherwise stated.

Figures

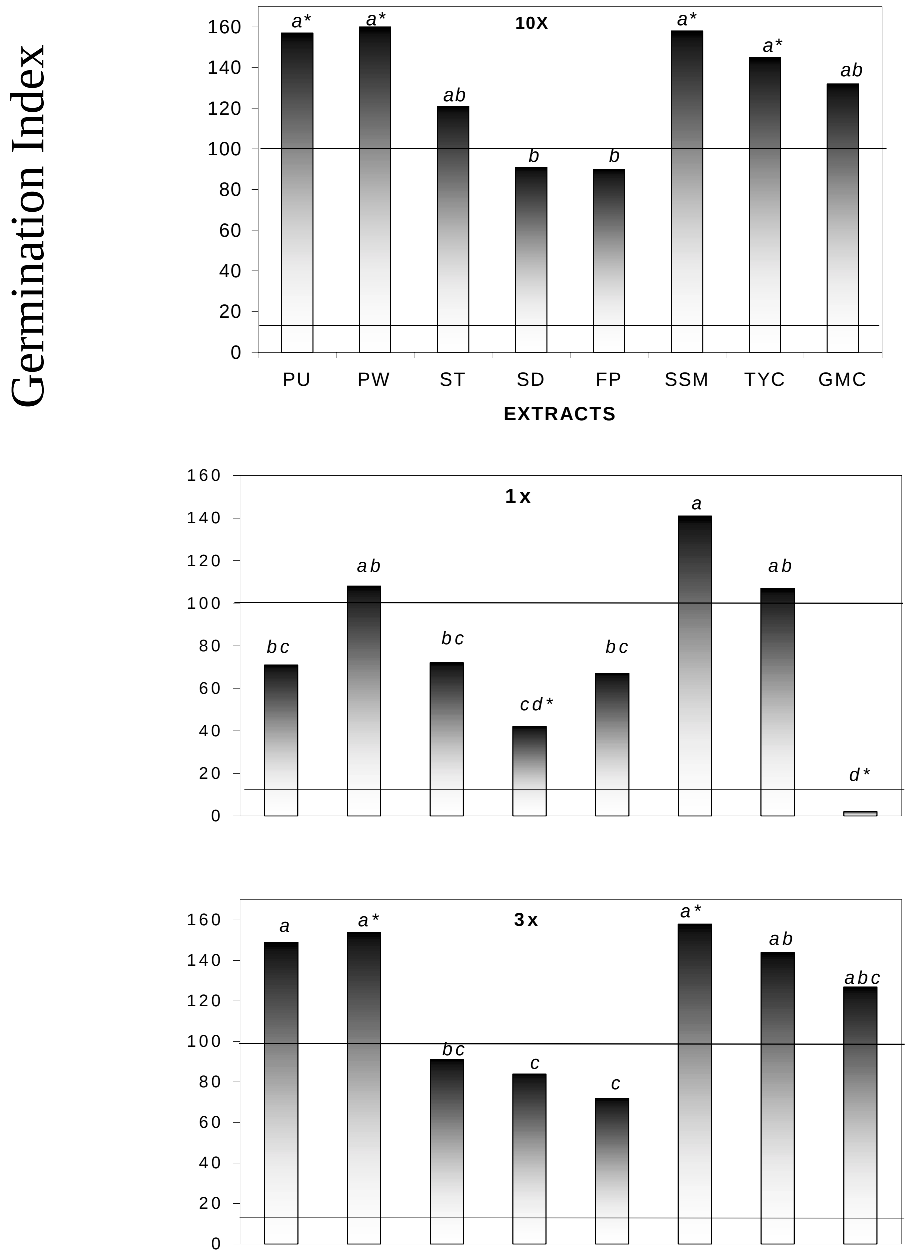

Fig. 1. Germination index (mean over two species) in response to undiluted (1x) and diluted (3x and 10x) water extracts from SUBBOR digestates (PU, PW, ST, SD, FP), city composts (TYC and GMC), and Sunshine Mix#2 (SSM). Within dilution levels, bars with the same letter are not significantly different from each other using Tukey's HSD test ($p<0.05$). The upper horizontal line represents the distilled water control (DW, GI=100) and the lower line represents acetic acid (GI=12). Bars with an asterick (*) are significantly different from distilled water using Dunnett’s test ($p<0.05$).