Evaluation of Waste Gypsum Wallboard as a Composting Additive

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Executive Summary

A series of studies were conducted to evaluate the possibility of diverting Waste Gypsum Wallboard (WGW) from C&D and municipal landfills in Nova Scotia. Previous studies have shown the potential to use wallboard gypsum as an agricultural amendment but the materials used were primarily from clean sources. The feasibility of using WGW as a feedstock in compost systems was examined through three different studies over two years at the Faculty of Agriculture, Dalhousie University. An initial investigation to characterize and determine the potential compostability of WGW was conducted using a pilot scale in-vessel composting unit at the Bio-Environmental Engineering Centre, Bible Hill, NS. Papered-WGW was blended with wheat straw and a Class B biosolids (Colchester Wastewater Treatment Facility) at a ratio of 40:20:40 and composted for six weeks. Results of this study identified Cd, Co, and Pb at slightly elevated concentrations relative to the control compost (biosolids:straw – at a ratio of 64:34). A subsequent field study was conducted using three concrete lysimeter cells with a packed bed of soil in each cell. Three compost treatments were established with a control compost (biosolids:straw:horse bedding –ratio of 17:63:20), and a papered/de-papered WGW compost (WGW:biosolids:straw:horse bedding – ratio of 34:11:41:14). Samples were collected over multiple time periods during the study from the composts and soils, as well as water samples using a leachate collection hut linked to each lysimeter cell through individual drain lines. Results from this study indicated a slight increase in bio-available Co in one WGW compost treatment relative to the control and a decrease in bio-available Zn. Soil concentrations of heavy metals did not increase but bio-available Co in the soil was slightly elevated in the Papered-WGW relative to the De-Papered WGW but no different than the control. Leachate water samples from WGW treatments had slightly elevated concentrations of Ni, Pb, and Zn relative to the control but high variability in the values obtained from the samples made statistical comparisons difficult. A final study was conducted using hay and horse bedding as the primary feedstocks with a control compost (hay:horse bedding – ratio of 67:33) and a Papered –WGW compost (hay:horse bedding: WGW – ratio of 55:27:18). The study was conducted under covered bins and was intended to focus on the effects of WGW on the composting processes of decomposition. The results of this study indicated that WGW did not interfere with the composting processes of decomposition at a ratio of 18%. Carbon loss and nitrogen conservation in the WGW compost followed similar trends as the control compost. Heavy metal concentrations were higher in the final WGW compost product for Cd, Co, Pb, and Ni relative to the control compost. However, WGW compost product heavy metal concentrations for Cr, Cu, and Zn were lower than the control. The concentrations of heavy metals in the initial compost mixture was higher in the WGW compost than the control. All the heavy metal concentrations were below the CCME standards for Class A compost.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS USED

AAS	Atomic Absorption Spectrometry
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
BEEC	Bio-Environmental Engineering Centre
BF	Bioavailability Fraction
C&D	Construction and Demolition
CCME	Canadian Council of Ministers of the Environment
C:N	Carbon to Nitrogen Ratio
D-WGW	De-papered Waste Gypsum Wallboard
EC	Electrical conductivity
FDG	Flue Gas Desulfurization Gypsum
NSAC	Nova Scotia Agricultural College
NSE	Nova Scotia Department of Environment
P-WGW	Papered Waste Gypsum Wallboard
SBR	Sequential Batch Reactor
TMEEC	Testing Methods for the Evaluation of Composting and Compost
WGW	Waste Gypsum Wallboard
XRF	X-Ray Fluorescence Spectrometry

1. Introduction

Wallboard is one of the most widely used interior wall construction materials in North America today (Gratton and Beaudoin, 2010). Typically, wallboard is sold with a white facing paper allowing for ease of finishing and painting (Certain Teed, 2011a). Wallboard is manufactured by injecting a slurry of calcined gypsum between two sheets of paper, compressing, and subsequently drying it. According to the Gypsum Association (2004), twenty four different types of gypsum wallboard are available in North America ranging from 2.4 to 4.3 meters in length and with thicknesses between 6.35 mm to 25.4 mm. Traditionally, mined gypsum has been the primary source of production material. During the manufacturing process, different chemical additives are used. For example, adhesives are used in the paper edging (Certain Teed, 2011a), anti-fungal agents are used in wallboard that may be exposed to high moisture, and glass fibers are incorporated in fire resistant wallboard for boilers or connecting walls (Certain Teed, 2011b). The primary regulatory concern is associated with post-consumer chemicals used in wall coverings, such as paints and wallpaper, which may contain heavy metals and contaminants.

It is estimated that approximately 20% of the material delivered to construction and demolition disposal sites is gypsum wallboard either from new construction or renovation/demolition of buildings (WasteCap Wisconsin Inc., 2005). Each year approximately 200,000 tonnes of C&D waste is generated in Nova Scotia. Across many jurisdictions, the average make up of wallboard residuals entering C&D sites is approximately 25% by weight of all waste (Dillon Consulting, 2006; Brown and Alcock, 2008). Currently in Nova Scotia, there are no operating wallboard manufacturers that could potentially take this material to be recycled into new wallboard. Due to this, the majority of this material is disposed of in secure landfills. The material placed in landfills can lead to the buildup and emission of hydrogen sulphide gases under anaerobic conditions. This gas is a health and environmental hazard (Flynn, 1998).

Waste wallboard can be associated with some potential hazards and health concerns. Until recently, the use of lead-based paints was quite common in Nova Scotia. Since some of the C&D debris is collected from older homes and buildings, there is the potential for used wallboard to contain lead. A further complicating factor is that the production of new wallboard uses an industrial by-product called synthetic gypsum, derived from industrial emissions scrubbing systems, as the main source of gypsum for their products.

2. Objectives

A research project was developed to examine the potential to safely divert and use waste wallboard generated across sites in Nova Scotia in composting systems. The objectives of the project were:

a) Characterize selected chemical properties of gypsum wallboard available commercially in Nova Scotia, including the identification of potential contaminants;

b) Analyze waste wallboard for identified potential contaminants, eg. NSE regulated heavy metals, sulphur, chloride, vanadium, selected inorganic particulates, and organic contaminants;

c) Evaluate the effectiveness of composting with waste wallboard as a feedstock along with municipal biosolids and/or agricultural organic by-products;

d) Evaluate the impact of waste wallboard on heavy metal concentrations and bio-availability in composts;

e) Evaluate the impact of waste wallboard on compost quality;

f) Provide recommendations for best management practices to safely manage compost systems using waste wallboard as a feedstock additive.

3. Waste Wallboard Characterization and Composting Studies

The overall project consisted of three studies:

(i) Chemical characterization of commercial and waste gypsum wallboard;
(ii) Study 1: In-vessel composting study to characterize WGW compost with biosolids;
(iii) Study 2: Field scale composting study in enclosed lysimeter cells to evaluate transport and bio-availability of heavy metals from compost through soil to water;
(iv) Study 3: Field scale bin composting study to evaluate the influence of WGW on composting parameters over time.

3.1 Characterization of Gypsum Wallboard

Samples of commercially available gypsum wallboard were obtained from several hardware stores in the Truro and Halifax areas and tested for heavy metal content. These samples were tested with and without the covering paper attached. Waste wallboard samples were obtained from Halifax C&D and Colchester Country Balefill, with and without paper, at different times throughout the study period. The samples were collected at different times in order to represent the seasonal shift and variability of materials which will arrive at C&D sites or landfills. The average results from these analyses are presented in Table 1-1. The heavy metal concentrations for all four materials were similar for all metals tested although chromium and nickel concentrations were higher in the waste wallboard samples analyzed. The de-papered wallboards were higher in zinc compared to the whole (papered) wallboard.

Table 1-1. Heavy Metal Analysis of New and Waste Gypsum Wallboard and CCME Class A Compost Guidelines.

Gypsum	Cd	Co	Cr	Cu	Pb	Ni	Zn
				mg kg^{-1}			
New Papered	6.5	12.0	6.9	16.6	62.0	9.0	46.8
New De-Papered	5.9	11.0	5.7	14.1	65.7	9.7	68.1
WGW - Papered	4.6	16.6	10.9	19.3	60.3	21.1	24.9
WGW - De-Papered	4.3	13.6	16.1	43.2	48.7	21.2	61.0
CCME (Compost Class A)	3	34	210	400	62	150	700

The waste papered wallboard was higher in lead than the waste de-papered wallboard. Both new wallboards had similar lead concentrations as the waste papered wallboard. Comparing the results to the CCME Class A compost guidelines it was evident that the high concentration of cadmium and lead could pose a potential problem for composting. This could be the limiting factor on the addition of this material to compost. The compost facility operator would also have to be aware of the concentrations of these metals in other feedstocks used to generate the compost. Limitations in available methodological approaches for organic contaminants in gypsum resulted in no analysis being conducted for potential organic chemicals in the wallboard samples taken. A component of the testing of raw materials involved evaluation of different approaches for sampling and analysis for heavy metals. We evaluated a field-based portable X-Ray Fluorescence (XRF) spectrometer to determine if this was suitable for field testing of wallboard and compost samples. While there appears to be some potential to use this technology for rapid evaluation in the field of heavy metal concentrations in different materials further study needs to be conducted on the calibration requirements for each metal relative to standard laboratory approaches, e.g. ICP and Atomic Absorption Spectrometry (Table 1-2). XRF spectrometry allowed for some measurement and detection of some industrial contaminants such as vanadium, thallium, tin, and antimony. Detection using XRF, but not validated through conventional analysis, in the gypsum wallboard of vanadium ranged from 9 to 15 ppm, 0 ppm for thallium, 20 ppm for antimony and 6 ppm for tin. Further work in this area is needed.

Table 1-2. Comparison of heavy metal analysis using Atomic Absorption Spectrometry (AAS) vs. X-Ray Fluorescence (XRF) with Waste Gypsum Wallboard Compost (WGW) and Biosolids Compost (Control) samples from In-Vessel Study (Study 1).

Treatment	Heavy Metal Concentrations (mg kg^{-1})†											
	Zn		Cu		Cr		Co		Ni		Pb	
Week	AAS	XRF	AAS	XRF	AAS	XRF	AAS	XRF	AAS	XRF	AAS	XRF
Three												
Control	293	91	274	58	24	22	2	0	16	66	22	13
WGW	225	255	166	191	19	22	8	0	10	78	49	23
Week Six												
Control	286	118	280	66	25	22	6	0	20	68	24	14
WGW	201	259	181	200	18	21	8	0	8	76	49	29

† dry basis

3.2 Study 1: In-Vessel Composting with WGW

3.2.1 Material and Methods

A controlled environment experiment was conducted using an in-vessel composter located at the BEEC. This device has a total compost capacity of 365 liters. It is constructed of a stainless steel U-shaped chamber with a removable cover (Figure 1). The device is equipped with an internal mixer consisting of a central shaft with four equidistantly placed mixing paddles. The central shaft is powered with a variable frequency electrical drive that allows for speed control. The staff speed is set and maintained with electrical controls. For this study, the in-vessel composter was kept running at a slow speed for the duration of the study. The composter is equipped with a small electrically controlled exhaust fan to remove odors through a port in the cover. The composter has a water jacket for temperature control (not used for this study) and rigid foam insulation to minimize loss of internal heat.

Two six week trials were run with two mix designs: 1) Class B municipal biosolids and straw and 2) Class B municipal biosolids, straw, and papered waste gypsum wallboard. The WGW addition rate for this study was 40% by weight (Table 2). Three feedstocks were used to prepare the compost treatments for this study, namely: barley straw, Class B municipal biosolids from a Sequential Batch Reactor (SBR) system, and crushed waste gypsum wallboard (WGW).

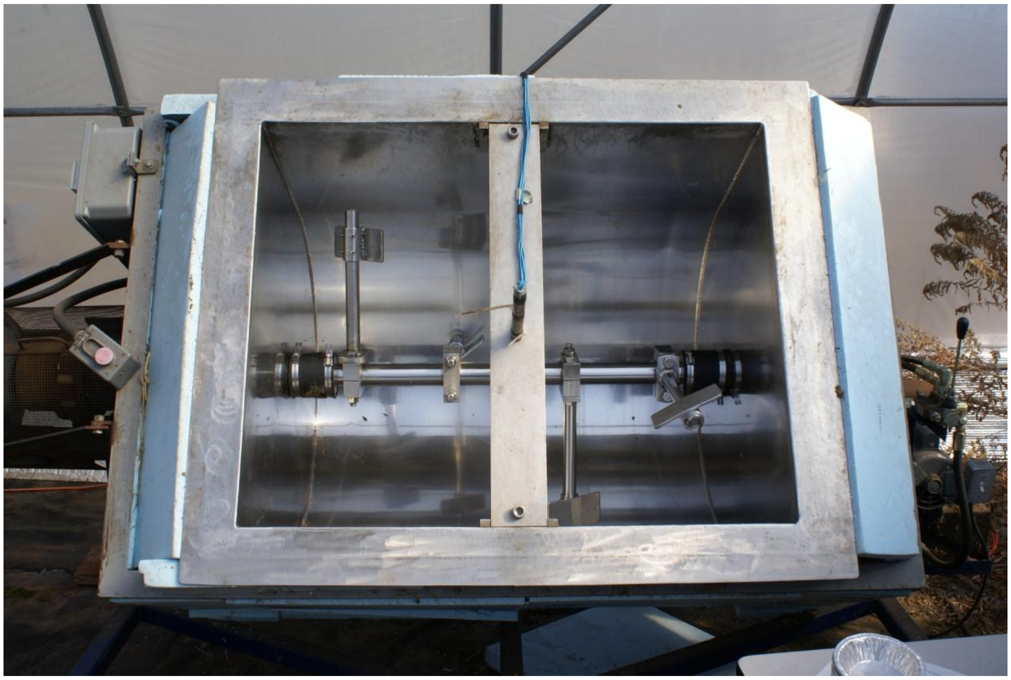

Figure 1. In-Vessel Composter located at the Bio-Environmental Engineering Centre, Faculty of Agriculture, Dalhousie University.

The waste gypsum wallboard (WGW) was obtained from Halifax C&D Recycling Ltd. located in Goodwood, Nova Scotia, Canada. This facility receives construction and demolition (C&D) waste from the greater Halifax area, including WGW. The WGW was a combination of new construction scraps and material from building demolitions and /or home renovations. The WGW used for this study had all foreign objects (nails, screws, etc.) removed and was crushed using a plate grinder to less than 9 cm in size. Weighed materials were introduced into the composter and mixed continuously for 6 weeks. During the composting operation, samples were collected on a weekly basis. These samples were tested for moisture content, total carbon, total nitrogen, and heavy metal content. Total heavy metal concentrations of the feedstocks used in the study are shown in Table 3.

Table 2. In-Vessel Compost Treatment Designs, Feedstock Ratios, C:N Ratios, and Moisture Content.

Compost Treatment	Raw Materials (%)			C:N Ratio	Moisture Content (%)
	Biosolids	Wallboard	Straw		
Design				27.3:1	60
WGW	40	40	20	27.4:1	59.1
Control	64	0	36	27.0:1	65.6

Table 3. Mean Total Heavy Metal Concentrations of Raw Feedstocks for In-Vessel Study.

Heavy Metals	Metal Concentrations, mg kg^{-1} (dry basis)		
	Biosolids	Wallboard	Straw
Cadmium	1.82	6.22	1.45
Zinc	440	57.47	11.27
Copper	434	15.32	4.76
Chromium	24.80	6.38	26.49
Cobalt	5.67	11.53	6.73
Nickel	9.47	9.32	nd
Lead	52.45	63.88	12.99
Selenium	1.80	1.84	1.84
Molybdenum	nd	nd	3.67
Mercury	2.65	0.61	0.11

Note: nd indicates analysis was below the detection limit

3.2.2 Results and Discussion

During the composting process microorganisms consume carbon as a food source therefore a reduction of total carbon is expected as the feedstocks decompose. Both of the treatment composts exhibited a significant decrease in total carbon content (Figure 2 and 3). The reduction in both treatments was rapid initially but gradually plateaued in both composts after week 5. It should be noted that the WGW compost had a lower overall total carbon content due to the mineral content (gypsum).

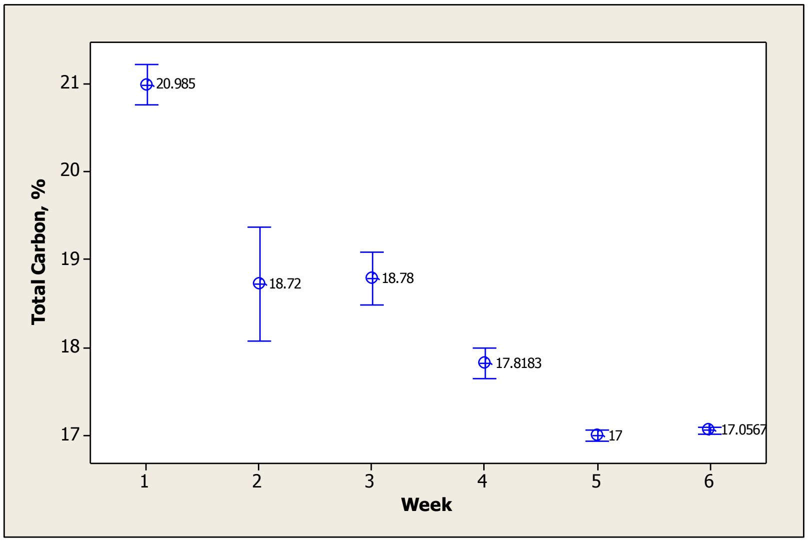

Figure 2. Total Carbon content from WGW amended compost treatment sampled weekly from in-vessel compost.

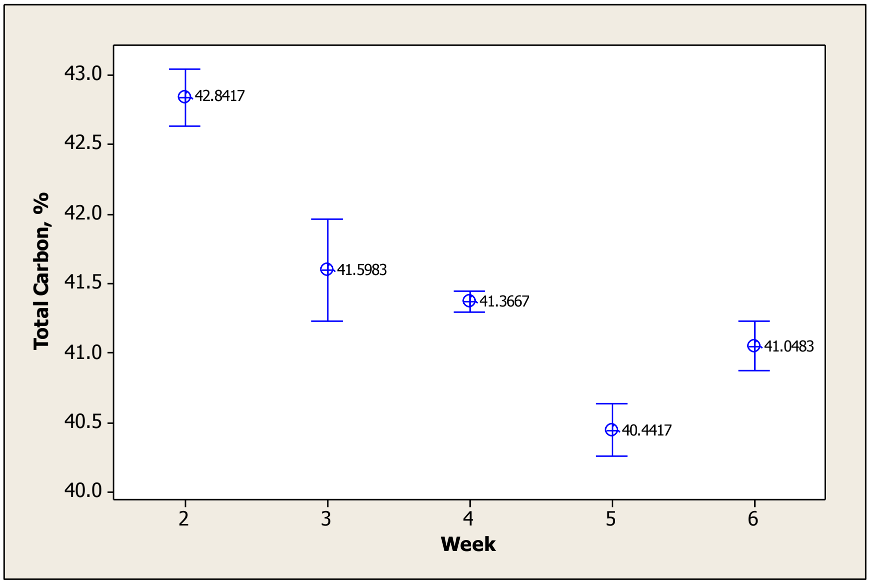

Figure 3. Total Carbon content from Control composts sampled weekly from in-vessel compost.

The total nitrogen content of the WGW compost increased slightly through the process but declined over the final two weeks (Figure 4). The nitrogen content of this compost had a very narrow range (0.8 to 0.87 %) over the study period. The control compost increased over the length of the trial, as would be expected the compost mass is reduced and the concentration of the constituents increases (Figure 5). The nitrogen content of the WGW compost was less than half of the control compost.

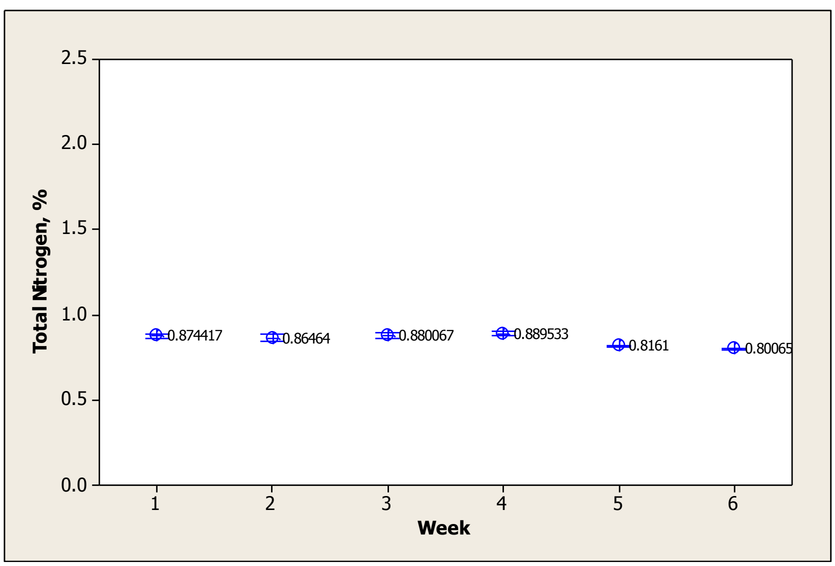

Figure 4. Total Nitrogen content from WGW amended compost treatment sampled weekly from in-vessel compost.

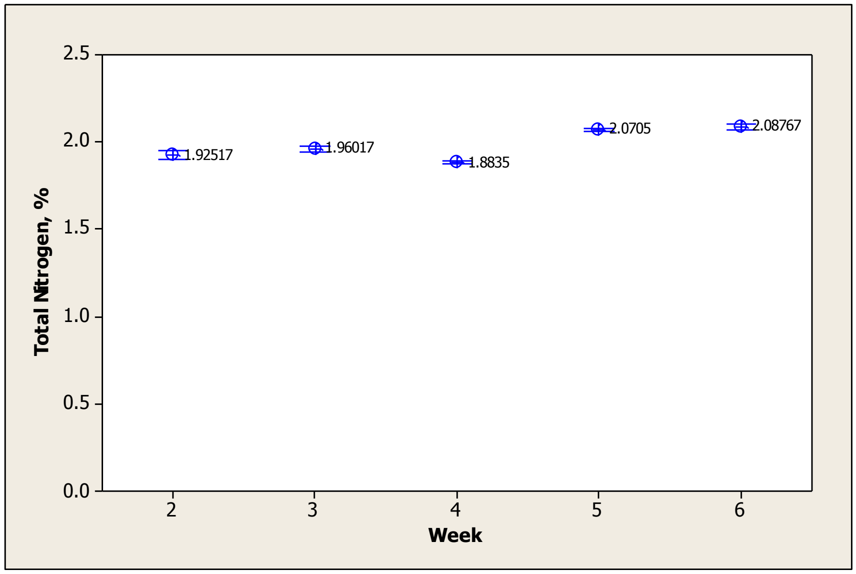

Figure 5. Total Nitrogen content from Control compost sampled weekly from in-vessel compost.

At the end of the study, the composts were analyzed for total heavy metal concentrations. The results are presented in Table 4. The control compost had greater concentrations of zinc, copper, chromium, and nickel. While these heavy metals were lower in the WGW compost, most likely due to a lower biosolid content, the cadmium and lead concentrations were almost double as a result of the wallboard.

Table 4. Week Three and Final Total Heavy Metal Concentrations in Compost Treatments from In-Vessel Study.

	Heavy Metal Concentrations (mg kg^{-1})†									
Treatment	Cd	Zn	Cu	Cr	Co	Ni	Pb	Se	Mo	Hg
Week Three										
Control	1.9	293	274	24.4	2.0	16.4	22.4	1.8	1.3	1.8
WGW	3.3	225	166	18.7	7.9	10.4	49.3	1.8	0.6	1.5
Week Six										
Control	1.7	286	280	25.1	5.9	20.1	24.3	1.8	1.3	1.7
WGW	3.5	201	181	18.3	8.3	7.9	48.6	1.8	0.7	1.3

† Dry weight basis

3.2.3 Conclusions

The heavy metal concentrations from the compost treatments analyzed in the study were highest for zinc, copper and mercury in the control (biosolids) treatment whereas the treatment with added wallboard had the highest concentration of cadmium, cobalt and lead. At a ratio of 40% waste wallboard, and using a Class B municipal biosolid as a compost feedstock, the final compost would potentially exceed the Nova Scotia limits for Class A compost based on cadmium and mercury concentrations. The higher concentrations of cadmium and mercury may be of potential concern at this high rate of mixing of WGW and Class B biosolids which suggests that a lower ratio of WGW is recommended particularly with this feedstock. Overall, there did not appear to be any obstacles to the composting process from the addition of WGW based on the changes in carbon and nitrogen. The compost treatments in this study did not achieve thermophilic temperatures due to the small volume of material and constant mixing.

3.3 Study 2: Heavy Metal Fate and Movement during WGW Composting

3.3.1 Material and Methods

Three identical concrete lysimeter cells located at the Bio-Environmental Engineering Centre (BEEC) in Bible Hill, Nova Scotia, Canada (Lat 45.386383, Long -63.242005) were used for this study. The cell dimensions measured 4.47 m in length x 2.64 m in width x 1.5 m high. The cells are aligned side by side in a row and are separated by a 3 m buffer space. Each cell slopes toward a central floor drain that is directed to double tipping buckets located in a heated sampling hut. The cells were exposed to local climatic conditions but were isolated from any groundwater influence. Five feedstocks were used to generate compost mixtures for this study: horse bedding, barley straw, Class B biosolids from a Sequential Batch Reactor (SBR) system, crushed WGW and crushed de-papered WGW (Table 5-1 and 5-2). Large hemlock wood chips were added to improve bulk density and porosity. The horse bedding was obtained from local horse farmers and the Truro Raceway, a standard bred harness racing track located in Bible Hill, Nova Scotia, Canada. The horse bedding was a mixture of horse manure, sawdust, wood shavings and hay. The barley straw was sourced from agricultural fields located at the BEEC facility. The Class B biosolids were provided by the County of Colchester Wastewater Treatment Facility located in Lower Truro, Nova Scotia, Canada. This facility receives sewage and storm drain wastes from the municipalities in central Colchester County. The waste gypsum wallboard (WGW) was obtained from Halifax C&D Recycling Ltd. located in Goodwood, Nova Scotia, Canada. This facility receives construction and demolition (C&D) waste (including WGW) from the greater Halifax area, including WGW. The WGW was a combination of new construction scraps and material from building demolitions and /or home renovations. The WGW used for this study had all foreign objects removed and was crushed using a plate grinder. To obtain de-papered WGW, the crushed material was further processed by sizing to < 9 cm with a trommel screen. This process removed approximately 98% of the paper.

The study was set up as a Randomized Complete Block Design with three compost treatments (control compost with no wallboard, compost with de-papered wallboard, and compost with papered wallboard) and three (seasonal) blocks. Time of year, or seasonality, was used as a blocking factor to account for the small number of lysimeter cells available. In this study, the compost treatments were placed in cells over a 30 cm layer of soil and any leachate water was collected through the graded drainage inlet within each cell. Treatments were randomly assigned a cell at the beginning of each season (block). Compost treatments were managed as static piles and were not mixed at any point during each season. New compost treatments were made up from fresh feedstocks and new soil was brought for each season. All feedstocks were obtained from the original sources. The blocking factor was also used to account for differences in raw materials used between batches. The soil in this study was obtained from the BEEC site and consisted of an acidic sandy loam till of the Woodville group (Webb et al., 1991). The same soil was used for all experimental trials.

Figure 6. Picture of Lysimeter Cell used located at the BEEC research site, Bible Hill, NS.

The compost treatments were prepared using a Supreme Enviro Processor Model 300 Pull Type (Supreme International Limited, Wetaskwin, Alberta, Canada) with a 7.9 m^3 capacity. Compost treatments were all based on a dry weight percentage basis but were prepared using wet weights. The compost treatments were designed to have a carbon to nitrogen ratio (C:N) of 28:1 and a moisture content of 65%. The components of each treatment are presented in Table 5-3. Each compost treatment was approximately 7 m^3 in size. The compost was mixed and then placed on top of the soil in each lysimeter cell with the highest point being the center while covering all of the soil. The pile was approximately 1.5m at the peak height and covered an area of 11.8 m^2. Once the compost treatments were placed, type K thermocouples were placed at the 60 cm, 90 cm and 120 cm depths in each compost pile to measure temperature fluctuations over the season. All temperature data was collected and stored using a Campbell Scientific (Campbell Scientific Inc., Logan, Washington, U.S.A.) CR10X data logger. Temperature measurements were taken every ten minutes. The ambient temperature was also measured and recorded at the site of the lysimeter cells.

Compost samples were tested for moisture content by placing a representative subsample (approximately 50 grams) in an oven at 105°C oven and dried to constant weight (Carter, 1993. All compost samples were then screened through a 12.5 mm sieve to remove oversize materials. A representative portion (approximately 10 g dry weight) of the compost sample was dried at 36°C to constant weight. Drying at this temperature prevents the potential loss of mercury during the drying process (TMECC). Dried samples were size reduced using a Waring professional specialty blender (Waring Products, Torrington, CT, USA). Samples were then ground using a Retsch MM300 ball mill (Retsch GmbH & Co. KG, Haan, Germany). A concentrated nitric acid microwave digestion method (TMECC) was used for total metals using the ground compost samples and a CEM MARS microwave digester (CEM, Matthews, NC, U.S.A.). Bio-available metals were extracted using the ground compost samples and a Mehlich III extraction method (Carter,1993). Extracted samples were tested for metal concentrations using a Varian 240FS Fast Sequential Atomic Absorption Spectrometer (Agilent Technologies, Santa Clara, CA, U.S.A.) equipped with a Varian SIPS 10/20 Sample Introduction Pumps System. The instrument was calibrated using multi-element 10 ppm and 100 ppm standards prepared by Plasma-Cal (Plasma-Cal, Baie D'Urfe, Quebec, Canada).

Feedstock materials were tested in an identical manner as compost samples except for material preparation. In the case of feedstocks the entire sample was size reduced then milled (<2mm) prior to analyses being performed. Soil was taken from each treatment (10 grams) for gravimetric moisture analysis by oven drying at 105°C until a constant weight was obtained (Carter, 1993). Soil samples were sieved to pass a 2mm sieve and air dried. A 20 g portion of the air dried sample was then ground using a Retsch MM300 ball mill. Analyses for soil total metal and bio-available metal concentration were all performed on the ground samples. Total and bio-available metals were extracted and analyzed by the same methods and procedures described for the compost samples. Leachate water flow was monitored in the sampling hut where double dipped valves were installed. The number of buckets tips was recorded using Campbell Scientific Labview Software.

Statistical Analysis

Data were analyzed using Minitab v. 16.2.2 (Minitab Inc., 2010) for descriptive statistics and SAS v. 9.3 (SAS Institute Inc., 2010) was used to complete the analysis of variance and covariance. ANOVA using seasonality as a blocking factor was used for analysis of variance within treatments. ANCOVA (using initial values as a covariate) was used for analysis of variance between treatments. The LSMEANS test was used for mean comparisons and all significant differences were considered at the $P<0.05$ probability level. Blocking was used for the within treatment ANOVA analysis was to account for seasonality. This is due to the blocks being run at different times during the year. Each season had its own unique weather pattern (especially precipitation and temperature) and blocking was used to account for different influences of varying climatic conditions. Blocking for the ANCOVA analysis was used to account for seasonality as mentioned previously and differences associated with initial treatment compost heavy metal concentrations. The feedstocks used to prepare compost treatments for each block were from the same source but not the same batch (each batch was sourced at the time of compost treatment preparation).

3.3.2 Results and Discussion

The three compost treatments were prepared with feedstock ratios as shown in Table 5-3 to have the same carbon nitrogen ratios. The WGW composts had a WGW content of 34% on a dry basis.

Table 5-1. Chemical Analysis of Compost Feedstocks.

Compost Feedstock	Moisture Content (%)	Total Carbon (%)	Total Nitrogen (%)	C to N Ratio	pH	EC (dS m^{-1})
Bedding	69.2	36.9	0.9	41	7.3	3.4
Straw	27.8	42.6	0.4	107	7.4	3.2
Biosolids	88.8	35.0	6.6	5.3	6.6	9.9
P-WGW†	44.8	4.5	0		6.6	2.9
D-WGW†	27.4	3.6	0		6.9	2.1

† P-WGW – papered waste gypsum wallboard, D-WGW – de-papered waste gypsum wallboard

Table 5-2. Heavy Metal Analysis of Compost Feedstocks, Mean and Standard Error (n=6 to 12).

Compost Feedstock	Cd	Co	Cr	Cu (mg kg^{-1})	Pb	Ni	Zn
Bedding	0.3±0.1	3.3±0.8	40.1±5.9	20.9±1.4	7.7±2.8	10.7±1.3	58.3±5.4
Straw	0.6±0.4	4.0±2.6	21.0±8.9	4.3±2.1	7.7±3.5	8.5±1.9	16.4±0.2
Biosolids	1.6±0.6	8.1±2.1	26.7±2.9	342±12	67.4±6.0	18.8±1.9	470±24
P-WGW	4.6±0.4	16.6±1.2	10.9±1.6	19.3±5.4	60.3±5.1	21.1±3.1	24.9±5.6
D-WGW	4.3±0.3	13.6±1.5	16.1±1.3	43.2±8.7	48.7±7.6	21.2±1.9	61±14

Table 5-3. Compost Treatment Feedstock Ratios (dry basis).

Treatment	Feedstock Ratio (%)			
	Biosolids	Straw	Bedding	WGW
Control	17	63	20	0
P - WGW	11	41	14	34
D - WGW	11	42	13	34

The treatments were exposed to three very different seasonal conditions. The blocks (season) represented variable environmental conditions and treatment responses partially reflected these significant shifts in temperature and precipitation (see Tables 6 and 7). Block 1 was in late fall/winter, Block 2 was in spring/summer, and Block 3 was in summer/fall. Due to this timing, the rainfall during each block was quite different with Block 1 receiving the highest total rainfall and largest range in temperatures. In contrast, Block 2 had the lowest range of temperature and lowest amount of rainfall.

Table 6. Total Rainfall and Leachate Flow over the study period.

Block (Season)	Total Rainfall (mm)	Leachate Flow Through Cell (L)		
		Control	P-WGW	D-WGW
1	3970	6408	6835	6220
2	284	1077	1368	1270
3	697	1395	1913	1991

Table 7. Environmental Conditions during Composting Study. †

Block	Ambient Temperature Extremes Minimum (°C)	Maximum (°C)
1	-28.3	26.7
2	-0.4	28.8
3	-10.5	23.1

† www.climate.weatheroffice.ca/climatedata/dailydata

Figures 7, 8 and 9 show the temperature profiles for all treatments during the study periods. Block 1 had the lowest compost temperatures of the three blocks with only the P-WGW achieving thermophilic temperatures. In all the blocks, the composts rapidly increased in temperature and then decreased towards ambient after periods ranging from 14 to 35 days. The WGW treatments generated higher temperatures across all three blocks relative to the control.

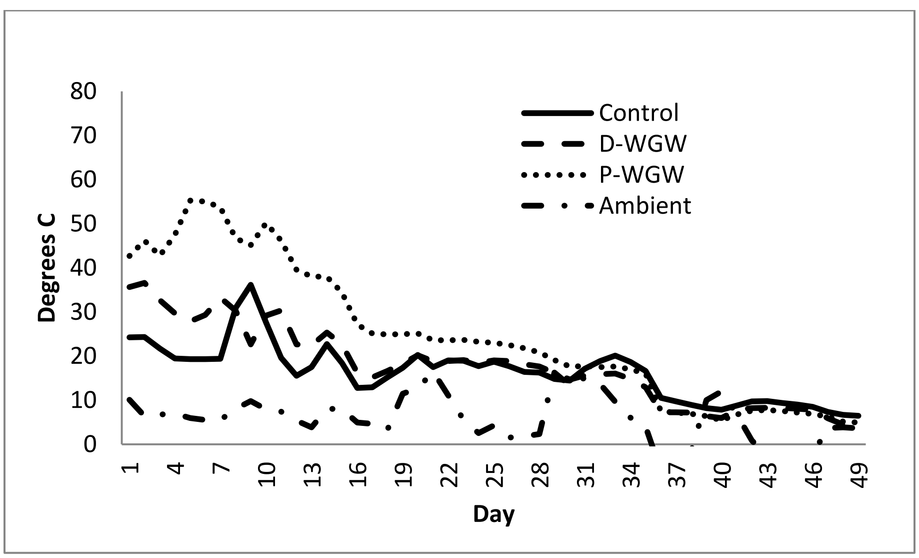

Figure 7. Temperature profiles for compost treatments (WGWs vs. Control) and Ambient temperature conditions in Fall/Winter (Block 1).

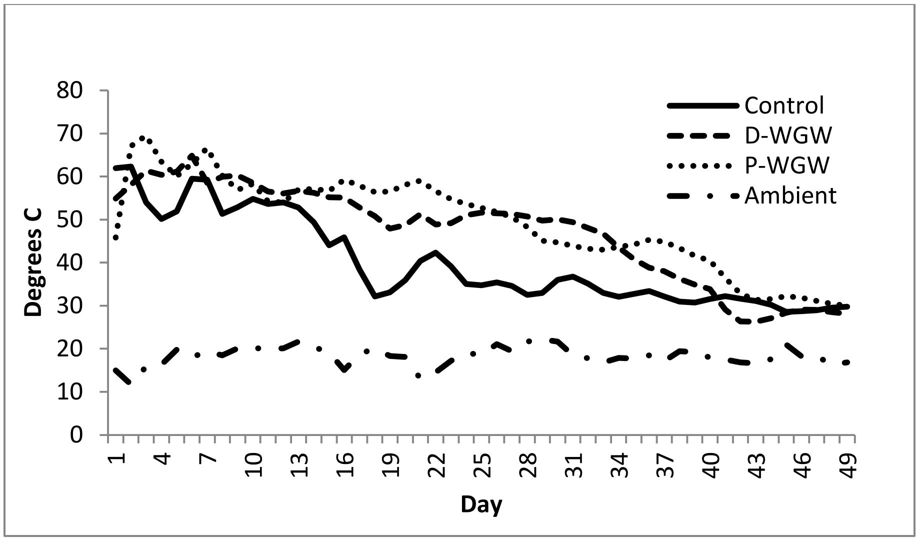

Figure 8. Temperature profiles for compost treatments (WGWs vs. Control) and Ambient temperature conditions in Spring/Summer (Block 2).

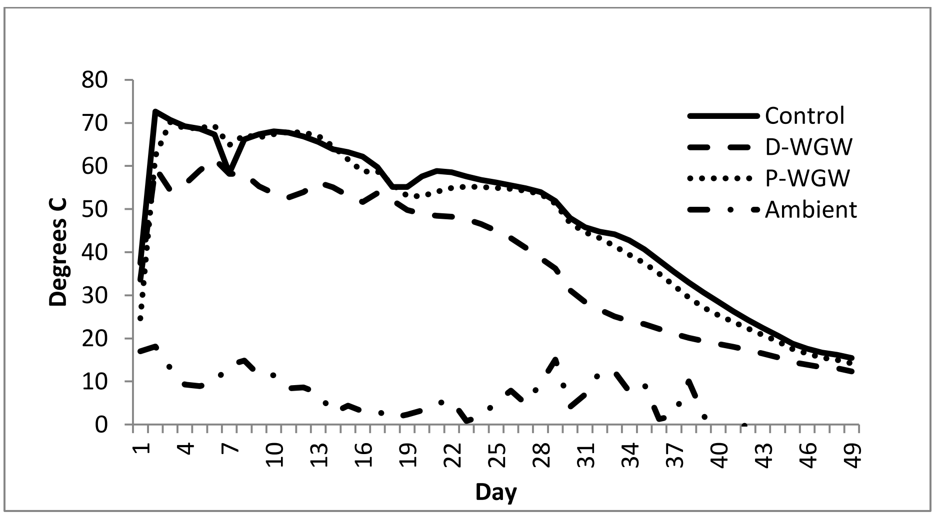

Figure 9. Temperature profiles for compost treatments (WGWs vs. Control) and Ambient temperature conditions in Summer/Fall (Block 3).

3.3.2.1 Compost

Statistical analyses using the ANCOVA are presented in the following two sections (3.3.2.1 and 3.3.2.2) for the compost treatments and soils associated with these treatments. The format of the ANCOVA analyses consists of two tables: the first table reports the P-values for the sources of variation, including Block, Treatment and Initial Condition (covariate) with a significant difference considered to be at the 95% probability level (P-value < 0.05), and the second table consists of an adjusted mean value for each measured parameter from the final compost treatment samples. Tables with only a single adjusted mean value presented in the column means that no significant differences between the treatments were detected. Where significant differences between the treatments were measured then all three adjusted means are presented with LSMEANS letter groupings to identify which treatments were greater or lower for the measured parameter. The first table examines the data statistically to determine whether the Block (Season), Treatments, or Initial Condition of the Treatment had an effect on the outcomes measured. The second table describes whether the final compost treatments are in fact different from each other, for each measured parameter, and what those differences are. For the following compost response variables: pH, electrical conductivity, chloride concentration, total carbon, total nitrogen and C:N ratio, no significant differences between the treatments were detected as noted in Tables 8 and 9.

Significant block (season) effects were noted for EC and chloride as a result of the differences in precipitation observed over the seasons. C:N ratio was also affected by the variability associated with ambient temperatures which impacted compost temperatures and microbial activity resulting in different rates of decomposition in the compost piles.

Table 8. Analysis of Covariance (ANCOVA) P-Values for specific compost response variables by Block, Treatment and Initial Compost condition.

Source	Compost Response Variables ANCOVA P-Values					
	pH	Electrical Conductivity	Chloride	Total Carbon	Total Nitrogen	C:N Ratio
Block	0.967	**0.004**	**0.001**	0.244	0.127	**0.004**
Treatment	0.769	0.074	0.230	0.375	0.624	0.840
Initial	0.165	0.095	**0.029**	0.314	0.655	0.624

Table 9. Analysis of Covariance (ANCOVA) Adjusted Means for specific compost response variables by treatment.

Treatment	Compost Response Variables Adjusted Means					
	pH	Electrical Conductivity dS m^{-1}	Chloride mg kg^{-1}	Total Carbon %	Total Nitrogen %	C:N Ratio
Control P-WGW D-WGW	6.7	4.0	188	25.6	1.5	17.2

3.3.2.2 Heavy Metal Concentrations

No significant differences between the compost treatments in this study for total heavy concentrations were detected between the initial and final compost samples (Tables 10 and 11). In this study, there were no detectable amounts of arsenic, boron, selenium, or mercury in the compost samples and the data are not shown in the tables. Total heavy metal concentrations in all the final compost treatments were below the CCME guidelines for a Class A compost. Total Cr and Pb concentrations were affected only by seasonal differences and by the initial compost mixture for Pb but the final heavy metal concentrations, for all elements measured, of the WGW treatments were not statistically different than the control.

Table 10. Analysis of Covariance (ANCOVA) P-Values for total heavy metals in compost by Block, Treatment and Initial Compost condition.

Source	Compost Total Heavy Metals ANCOVA P-Values						
	Cd	Co	Cr	Cu	Ni	Pb	Zn
Block	0.253	0.953	**0.034**	0.155	0.788	**0.005**	0.133
Treatment	0.473	0.411	0.470	0.723	0.831	0.292	0.576
Initial	0.286	0.788	0.490	0.064	0.610	0.059	0.073

Table 11. Analysis of Covariance (ANCOVA) Adjusted Means for Total Heavy Metals in compost by treatment and CCME Class A Compost Guidelines.

Treatment	Compost Total Heavy Metals Adjusted Means†						
	Cd mg kg^{-1}	Co mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}
Control P-WGW D-WGW	1.4	27.7	24.3	82.3	19.1	48.5	148
CCME	3	34	210	400	62	150	700

† Dry weight basis

Significant differences were observed between the compost treatments for bio-available Cd and Zn (Tables 12 and 13). Cadmium was higher in both WGW treatments compared to the control treatment. Bio-available Zinc (M-3 extracted) was greater in the control treatment than the WGW treatments.

Table 12. Analysis of Covariance (ANCOVA) P-Values for Bio-available Heavy Metals in compost by Block, Treatment and Initial Compost condition.

Source	Compost Bio-available Heavy Metals ANCOVA P-Values						
	Cd	Co	Cr	Cu	Ni	Pb	Zn
Block	**0.021**	0.071	0.055	0.746	0.673	**0.046**	0.100
Treatment	**0.022**	0.232	0.154	0.352	0.804	0.208	**0.036**
Initial	**0.028**	0.295	0.204	0.523	0.685	0.483	**0.001**

Table 13. Analysis of Covariance (ANCOVA) Adjusted Means for Bio-available Heavy Metals in compost by treatment.

Treatment	Compost Bio-available Heavy Metals Adjusted Means†¥						
	Cd mg kg^{-1}	Co mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}
Control	0 b						120 a
P-WGW	1.6 a	1.3	0.9	17.5	1.6	11.5	96 b
D-WGW	1.3 a						95 b

† Dry weight basis

¥ Letter grouping indicates significant differences between final adjusted means between treatments

3.3.2.3 Soil

No statistical differences in total heavy metal concentrations in the soils associated with each compost treatment were detected (Tables 14 and 15). There was a significant difference in bio-available cobalt between the treatments with the control and P-WGW treatments being higher than the D-WGW treatment (Table 16 and 17).

Table 14. Analysis of Covariance (ANCOVA) P-Values for Soil Total Heavy Metals by Block, Treatment and Initial Compost condition.

Source	Soil Total Heavy Metals ANCOVA P-Values						
	Cd	Co	Cr	Cu	Ni	Pb	Zn
Block	0.799	0.131	0.298	0.069	0.177	0.953	**0.047**
Treatment	0.573	0.693	0.282	0.590	0.460	0.411	0.346
Initial	0.790	0.383	0.256	0.330	0.196	0.788	0.100

Table 15. Analysis of Covariance (ANCOVA) Adjusted Means for Soil Total Heavy Metals by treatment.

Treatment	Soil Total Heavy Metals Adjusted Means†						
	Cd mg kg^{-1}	Co mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}
Control							
P-WGW	0.8	31.2	15.5	31.2	25.7	27.7	51.9
D-WGW							

† Dry weight basis

Table 16. Analysis of Covariance (ANCOVA) P-Values for Soil Bio-available Heavy Metals by Block, Treatment and Initial Compost condition.

Source	Soil Bio-available Heavy Metals ANCOVA P-Values						
	Cd	Co	Cr	Cu	Ni	Pb	Zn
Block	0.110	**0.001**	0.531	0.060	**0.000**	**0.024**	0.126
Treatment	0.661	**0.045**	0.790	0.641	0.468	0.081	0.091
Initial	0.498	0.784	0.897	0.507	0.104	0.783	0.069

Table 17. Analysis of Covariance (ANCOVA) Adjusted Means for Soil Bio-available Heavy Metals by treatment.

Treatment	Soil Bio-available Heavy Metals Adjusted Means†¥						
	Cd mg kg^{-1}	Co mg kg^{-1}	Cr mg kg^{-1}	Cu mg kg^{-1}	Ni mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}
Control		1.7 a					
P-WGW	0.7	1.9 a	5.1	10.5	4.5	0.2	1.4
D-WGW		1.4 b					

† Dry weight basis

¥ Letter grouping indicates significant differences between final

3.3.2.4 Leachate Water

Leachate water collected from the composting cells exhibited a similar pH for all three treatments over all three seasons (Figures 10 to 12). The leachate water from all three treatments were slightly alkaline and slowly decreased to neutral or slightly acidic by the end of the study.

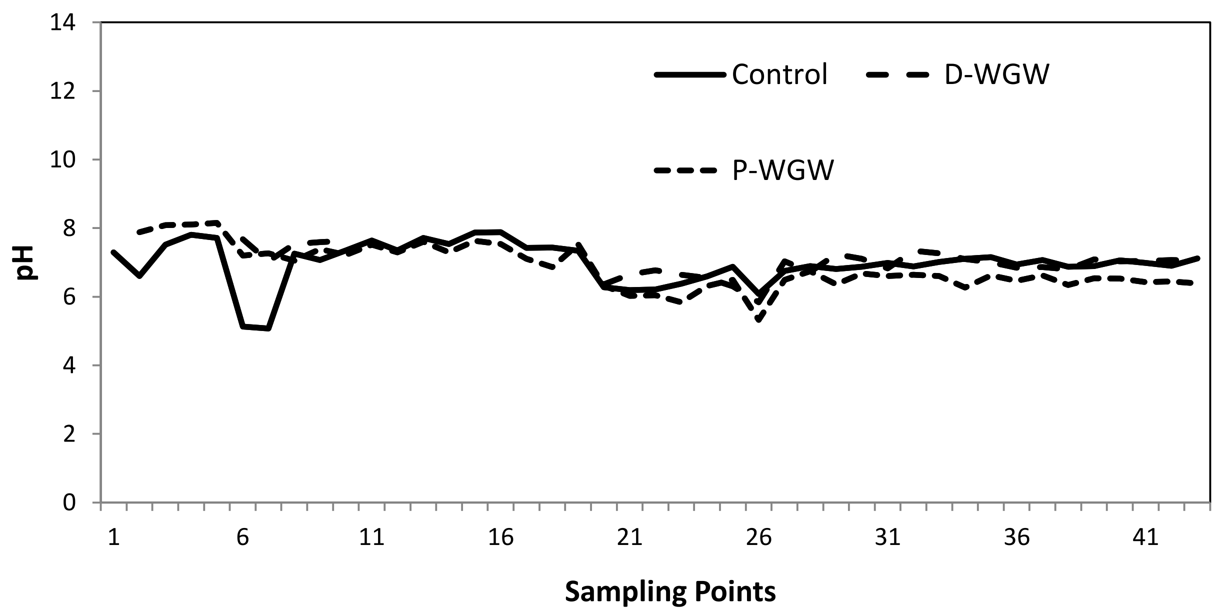

Figure 10. Leachate Water pH from compost treatments at Periodic Sampling Points over the study period (days) in the Fall/Winter Season (Block 1).

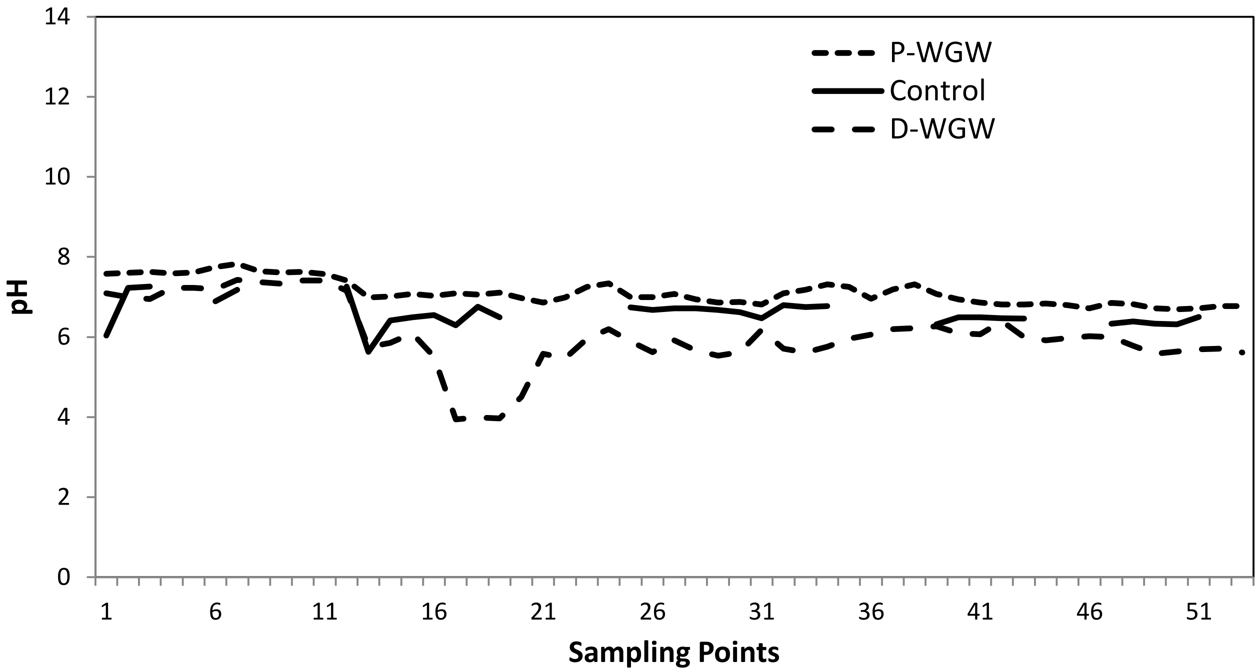

Figure 11. Leachate Water pH from compost treatments at Periodic Sampling Points over the study period (days) in the Spring/Summer Season (Block 2).

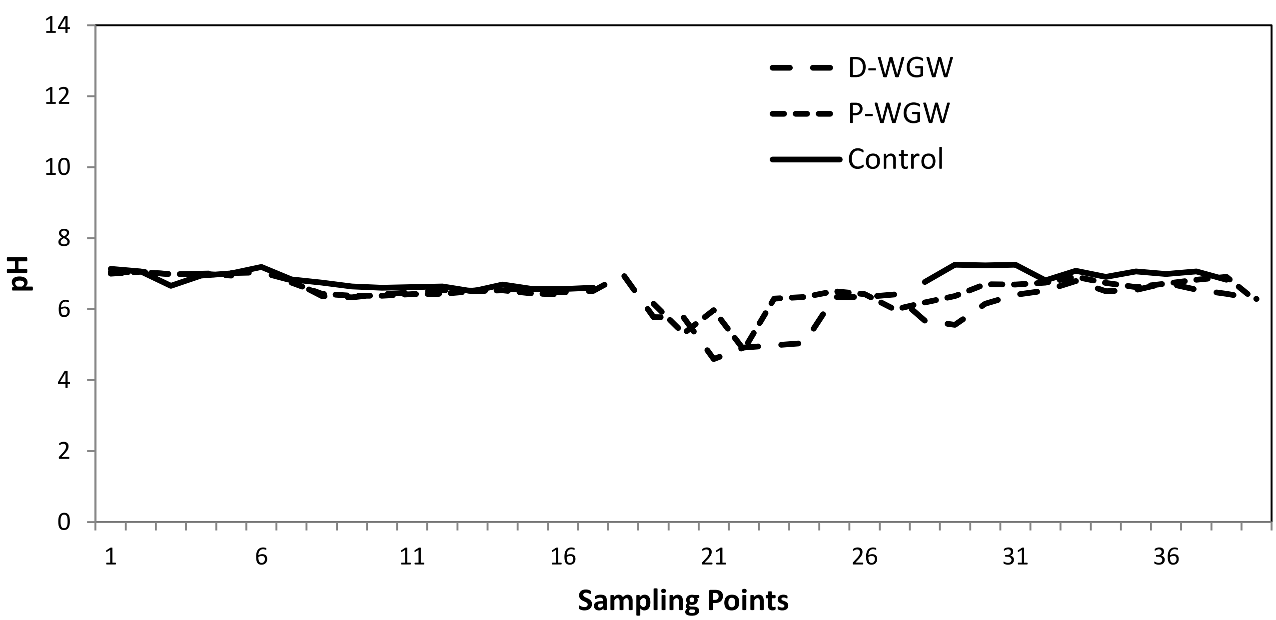

Figure 12. Leachate Water pH from compost treatments at Periodic Sampling Points over the study period (days) in the Summer/Fall Season (Block 3).

For the two seasons with higher rainfall (Blocks 1 and 3), the two WGW treatments had higher electrical conductivity (EC) in the leachate water, by almost a factor of two compared to the control (Figures 13 to 15). This was despite WGW treatment leachate water starting at similar initial electrical conductivity as the control. Lower precipitation events during the second season (Block 2) resulted in reduced leachate water with much higher EC levels for all three treatments compared to the other two seasons. However, during this season, the P-WGW had a lower EC than the D-WGW treatment and control.

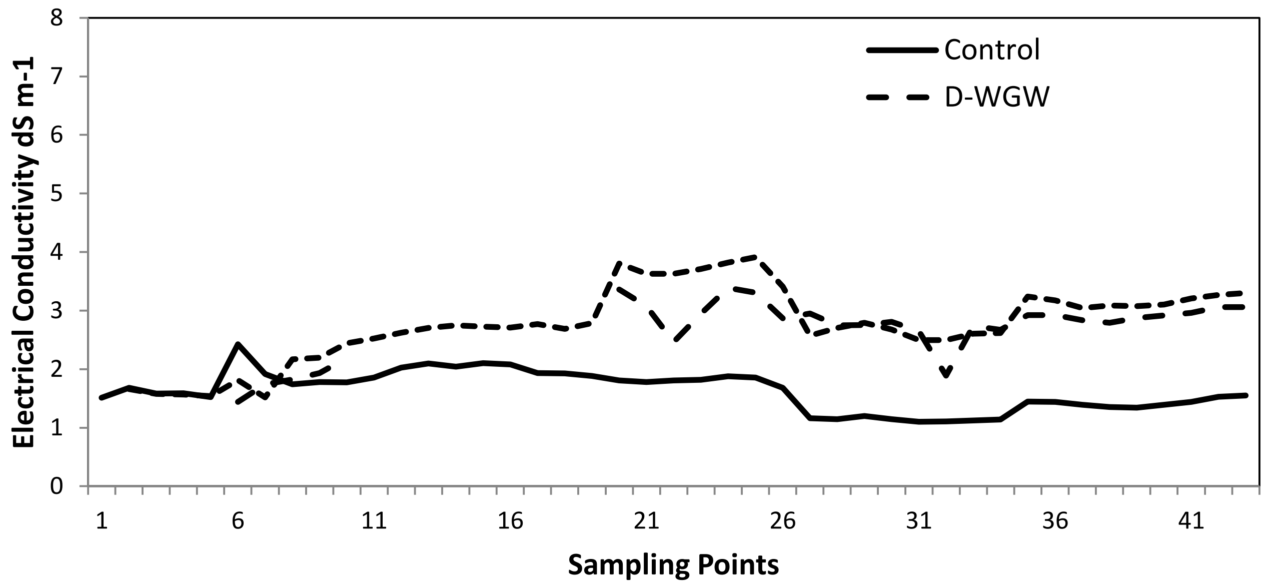

Figure 13. Electrical Conductivity (dS m^{-1}) from compost treatments at Periodic Sampling Points of leachate collected over the study period in the Fall/Winter Season (Block 1).

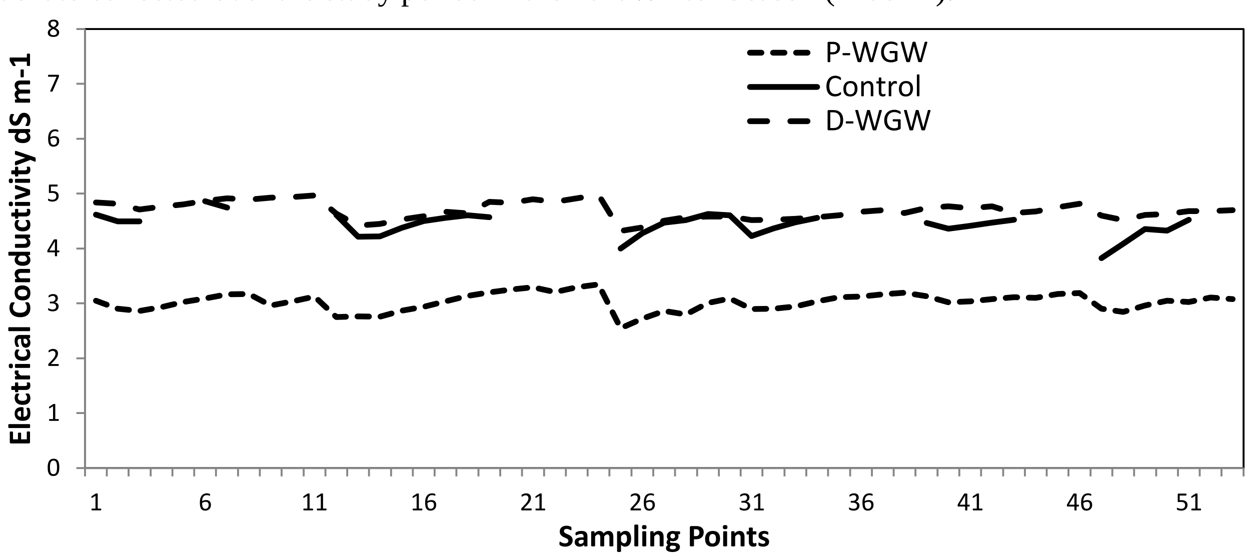

Figure 14. Electrical Conductivity (dS m^{-1}) from compost treatments at Periodic Sampling Points of leachate collected over the study period in the Spring/Summer Season (Block 2).

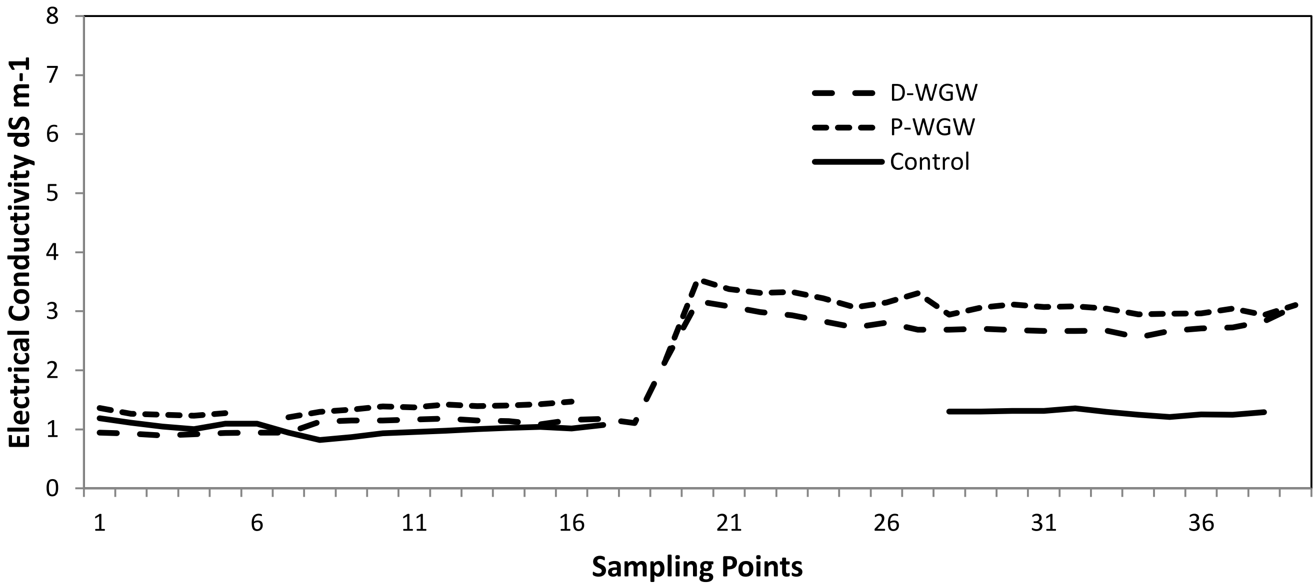

Figure 15. Electrical Conductivity (dS m^{-1}) from compost treatments at Periodic Sampling Points of leachate collected over the study period in the Summer/Fall Season (Block 3).

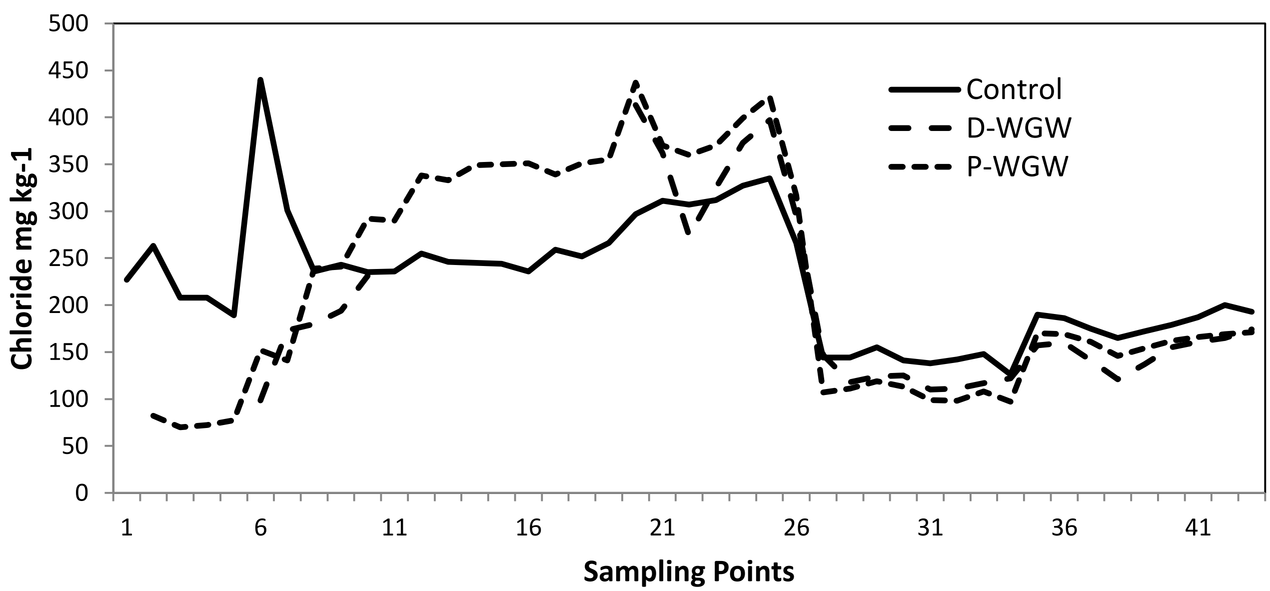

Figure 16. Chloride concentrations (mg kg^{-1}) from compost treatments at Periodic Sampling Points of leachate collected over the study period in the Fall/Winter Season (Block 1).

All the treatments had similar chloride concentration profiles in the leachate water during all three seasons but were slightly elevated in the WGW treatments (Figures 16 to 18). High precipitation levels observed in the Fall/Winter season (Block 1) resulted in a rapid initial increase in chloride concentrations and a subsequent decline. The Summer/Fall season had a similar rapid increase half way through the study when some large rainfall events occurred. The pattern of chloride and electrical conductivity coincides with precipitation events leaching the salts from the compost through the soil into drainage water. The WGW were a significant source of salts in the leachate water samples which might explain the lower chloride concentration in the final composts.

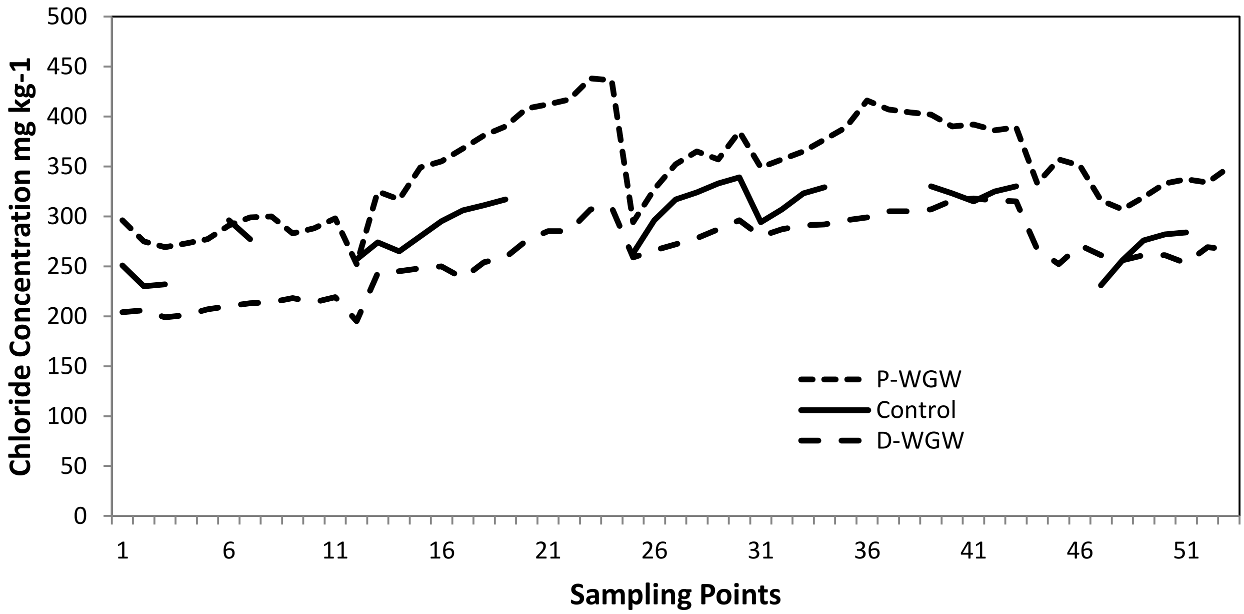

Figure 17. Chloride concentrations (mg kg^{-1}) from compost treatments at Periodic Sampling Points of leachate collected over the study period in the Spring/Summer Season (Block 2).

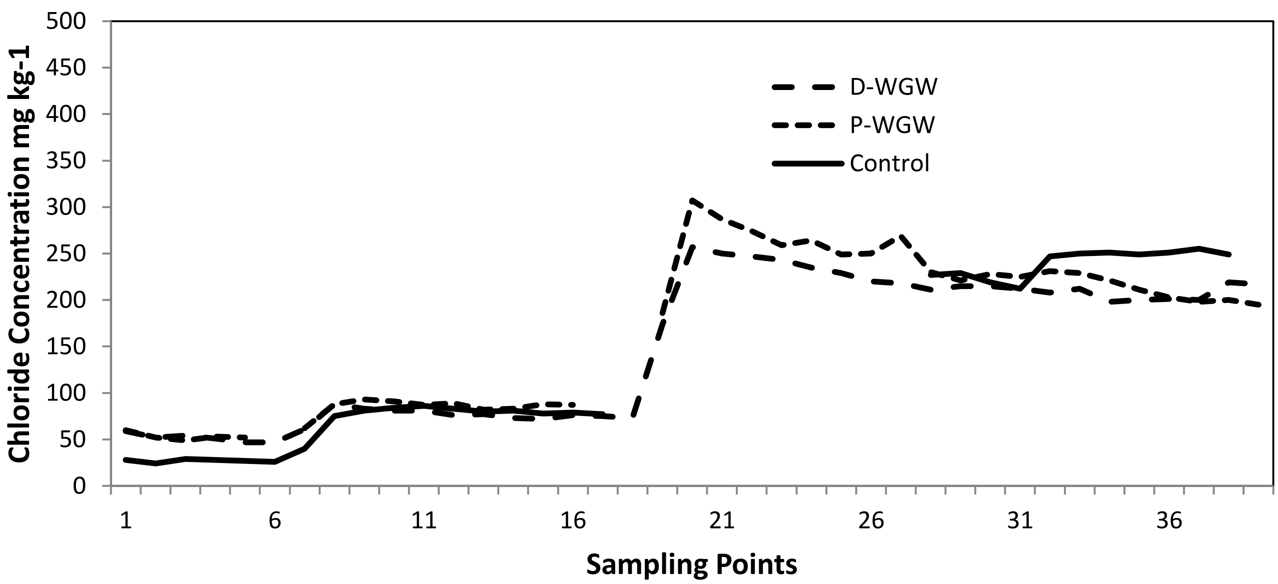

Figure 18. Chloride concentrations (mg kg^{-1}) from compost treatments at Periodic Sampling Points of leachate collected over the study period in the Summer/Fall Season (Block 3).

Leachate water samples collected over the entire study period were analyzed for total heavy metal concentrations. The concentration for each individual sample was multiplied by the flow for that sample period to generate a total mass for each metal in the leachate water for each day. A total mass for each heavy metal transported into the leachate water over the entire was determined (Table 18). The soluble total metals in the leachate water from all three treatments was highly variable. This variability was a factor in not being able to determine if significant compost treatment differences existed. Overall, the WGW treatments had a pattern of higher cadmium (Cd), nickel (Ni), and zinc (Zn) while the control had copper (Cu) concentrations which were almost double the WGW treatments.

Table 18. Total Heavy Metal Loading (g) in Leachate Water over the entire study period (±SEM).

Heavy Metal	Heavy Metal Mass (g)		
	Control	P-WGW	D-WGW
Cd	0.9 ± 0.9	3.9 ± 1.9	3.7 ± 0.3
Co	6.1 ± 4.8	20.1 ± 10.6	21.7 ± 6.8
Cr	15.5 ± 6.9	32.6 ± 21.3	12.0 ± 8.6
Cu	77.6 ± 65.3	41.0 ± 19.2	42.9 ± 14.0
Ni	15.1 ± 3.6	49.2 ± 20.7	47.1 ± 3.1
Pb	23.2 ± 7.6	61.8 ± 30.4	47.0 ± 17.4
Zn	88.6 ± 48.6	137.7 ± 51.3	179.6 ± 55.5

3.3.3 Conclusions

Results from this study were used to evaluate transport of specific heavy metals into and through soil from compost based on short-term (2 to 4 months) evaluation of a composts using WGW as a primary feedstock. Study 3 evaluates composting dynamics using WGW in more detail. The results suggest that using WGW, either papered or de-papered, had little impact on the quality of the composts or movement of heavy metals relative to the control compost. Bio-available forms of heavy metals, with the exception of Co, were not greater after addition of WGW. All the final compost treatments met CCME guidelines for Class A compost relative to total heavy metal concentrations, recognizing that the base feedstock for this study was a Class B biosolid. Moreover, the dominant effects in most measured parameters appear to be related to use of the biosolid feedstock rather than the WGW and variable climatic conditions.

3.4 Study 3: Composting Dynamics using Papered WGW

3.4.1 Materials and Methods

A covered composting facility consisting of eight side by side wooden sided bins located at the Bio-Environmental Engineering Centre (BEEC) in Bible Hill, Nova Scotia, Canada (Lat 45.386383, Long -63.242005) were used for this study (Figure 19). The bin dimensions measured 3.66 m in length x 2.18 m in width x 1.63 m high. The bins are walled on three sides to a height of 1.63 m (open above this height), covered with a roof, and open on the north side to allow for equipment access. The bins have a concrete floor that is gently sloped to the rear to allow the run-off of leachate. The leachate is then directed to a collection pit were it can be collected for the individual bins.

Figure 19. Picture of Control Compost and Thermocouples in Covered Bin Study.

Three feedstocks were used to generate compost mixtures for this study: horse bedding, timothy hay, and crushed papered WGW (P-WGW). The horse bedding was obtained from local the Truro Raceway, a standard bred harness racing track located in Bible Hill, Nova Scotia, Canada. The horse bedding was a mixture of horse manure, sawdust, wood shavings and hay. The timothy hay was sourced from a local beef farm. The waste gypsum wallboard (P-WGW) was obtained from Halifax C&D Recycling Ltd. located in Goodwood, Nova Scotia, Canada. This facility receives construction and demolition (C&D) waste from the greater Halifax area, including P-WGW. The P-WGW was a combination of new construction scraps and material from building demolitions and /or home renovations. The P-WGW used for this study was crushed using a plate grinder, screened to < 9 cm and all foreign objects were removed. Another screen sized at < 1.9 cm was employed for further size reduction. Physical and chemical analyses of the feedstocks are presented in Tables 19 and 20.

The experimental design for this study consisted of two treatments (control with no P-WGW and P-WGW at one level) with four replications in a Completely Randomized Design. The compost treatments were assigned to a bin on a randomized basis. Sufficient quantities of feedstock were sourced to produce all compost mixtures from the same batch. All compost treatments were individually produced (a batch process was not used) prior to placement into the appropriate bin. The compost treatment mixtures were designed to have a carbon to nitrogen ratio (C:N) of 28:1 and a moisture content of 52 percent. The compost mixtures were prepared on a wet weight basis. A P-WGW addition rate of 20% on a dry basis was used for the P-WGW treatment. Water was added to each mixture to achieve the desired moisture content. The compost treatments were periodically sampled and checked for moisture content. If the moisture content was 10% below the design moisture of 52%, the treatment was re-mixed with the addition of water to bring the compost back to target moisture content. Once thoroughly mixed, the compost treatment replicate was returned to the bin it came from. Compost treatment replicates stayed in the same bin for the length of the study.

The compost treatments for this study were allowed to process for 353 days from summer 2010 until spring 2011. The compost treatments were turned on days of age as indicated in Table 21. The compost treatments were mixed and prepared using a Supreme Enviro Processor Model 300 Pull Type (Supreme International Limited, Wetaskwin, Alberta, Canada) with a 7.9 m^3 capacity. Compost treatments were all based on a dry weight percentage basis but were prepared using wet weights. The ratios of feedstocks used for each compost treatment replicate are presented in Table 22. Each compost treatment replicate was approximately 7 m^3 in size. The compost was mixed and then placed in the composting bin. Once each compost treatment replicate was placed, type K thermocouples were placed at the 60 cm, 90 cm and 120 cm depths in the compost pile to measure temperature fluctuations over the length of the study. All temperature data was collected and stored using a Campbell Scientific (Campbell Scientific Inc., Logan, Washington, U.S.A.) CR10X data logger. Temperature measurements were taken every fifteen minutes. The ambient temperature was also measured and recorded at the site of the compost bins. Feedstock samples weighing approximately 2 kg were collected as they were received at the research site. Six 2 kg samples were randomly collected from each compost treatment at the time of compost preparation and re-mixing. Samples were placed in plastic bags and tightly sealed.

Statistical Analysis

Data was analyzed using Minitab for descriptive statistics and SAS v. 9.2 (SAS Institute, 1999) PROC GLM ANOVA for Completely Randomized Designs employing the Tukey test for mean comparisons, significant differences were considered at the P<0.05 probability level. The results of the Tukey analysis are reported by two methods. Lower case letters in tables indicate significant differences between samples of the same treatment over the length of the study. Upper case letters in tables indicate significant difference between treatments at specific sampling periods.

3.4.2 Results and Discussion

Hay and horse bedding provided the majority of the carbon and all of the nitrogen to the compost treatments (Table 19). P-WGW provided one tenth of the carbon compared to the other two feedstocks. Hay had a chloride concentration of 880 mg kg $^{-1}$ that was double that of the horse bedding and more than eight times that of the P-WGW. All feedstocks had similar pH and electrical conductivity.

Table 19. Chemical Analysis of Compost Treatment Feedstocks.

Feedstocks	Moisture Content (%)	Total Carbon (%)	Total Nitrogen (%)	C:N Ratio	pH	EC (dS m^{-1})	Cl (mg kg^{-1})
Hay	16.9	39.6	1.22	32	6.5	4.0	880
Horse Bedding	59.7	36.8	0.92	40	7.3	3.4	416
P-WGW	45.4	4.3	0		6.6	2.9	34

Table 20. Compost Feedstock Heavy Metal Concentrations and SEM (n=6).

	Heavy Metal Concentration (Dry basis mg kg^{-1})						
Treatment	Cd	Co	Cr	Cu	Pb	Ni	Zn
Hay	0.3 ± 0.0	1.1 ± 0.6	8.8 ± 2.1	4.6 ± 1.3	0	3.2 ± 1.0	14.8 ± 0.8
Bedding	0.1 ± 0.1	2.3 ± 1.3	43.1 ± 5.4	21.4 ± 2.5	7.9 ± 3.3	10.9 ± 2.1	64 ± 12
P-WGW	5.3 ± 0.6	19.3 ± 1.5	15.2 ± 1.6	28.7 ± 9.2	53.2 ± 9.2	28.2 ± 4.4	33 ± 10

The hay used for this study was not a significant source of any of the heavy metals studied (Table 20). The horse bedding had a chromium concentration almost three times that of the P-WGW and almost five times that of the hay. The zinc concentration in the horse bedding was double that of the P-WGW and over four times that in the hay. P-WGW had a cadmium concentration of 5.3 mg kg $^{-1}$ that was significantly higher than the hay at 0.3 mg kg $^{-1}$ and horse bedding at 0.1 mg kg $^{-1}$. The cobalt concentration in the P-WGW was ten times that in the horse bedding and 20 times that in the hay. The P-WGW in this study was the major source of lead with a concentration of 53.2 mg kg $^{-1}$ compared to 7.9 mg kg $^{-1}$ in the horse bedding and no detectable amounts in the hay.

Compost turning dates were based on a combination of when internal temperatures appeared to begin declining, as well as climatic conditions and availability of equipment and personnel. Table 21 outlines the number of days between compost turnings. After turning on day 353, compost temperatures did not rise much above ambient and composts were measured for maturity.

Table 21. Compost Treatments Age at Day of Turning and Sampling.

	Turning / Sampling				
	1	2	3	4	5
Compost Age (Days)	0	46	123	310	353

The percent ratios of feedstocks in each treatment are presented in Table 22. The control treatment replicates averaged 67% hay and 33% horse bedding. The P-WGW treatment replicates had 18% P-WGW, 55% hay and 27% horse bedding. The two to one ratio of hay to horse bedding in the control treatment was maintained in the P-WGW treatment.

Table 22. Compost Treatment Feedstock Ratios (%) (dry basis).

Treatment	Feedstock Ratio (%)		
	Hay	Bedding	P-WGW
Control	67	33	0
P-WGW	55	27	18

The changes in compost mass over the study period are shown in Tables 23 and 24. The control treatment had greater percent mass loss than the P-WGW treatment in all sampling periods. The percent dry mass loss for the control compost was significantly higher at 49.9% compared to the P-WGW compost treatment at 38.3% at the last sampling of the study. The was no significant difference between the moisture contents of both compost treatments at the five sampling points although the moisture content of the treatments were significantly higher during the later part of the study compared to the first two samplings.

Table 23. Compost Treatments Change in Dry Mass (kg) over the study period.

Treatment	Compost Dry Mass (kg)				
	Day				
	0	46	123	310	353
Control	1002	866	701	538	502
P-WGW	1014	912	744	667	626

Table 24. Compost Treatments Percent Mass Loss over the study period.

Treatment	Compost Mass Loss (%)				
	Day				
	0	46	123	310	353
Control	0	14.6	30.1	47.3	49.9
P-WGW	0	10.1	26.4	34.2	38.3

3.4.2.1 Changes in Chemical Parameters during Composting

The initial carbon to nitrogen ratios of both compost treatments averaged 30:1 at first mixing and dropped significantly over the length of the study. Over all five sampling periods no significant differences in C:N ratios between the two compost treatments were measured (Figure 20). Both compost treatments had similar reductions in the C:N ratios over the length of the study with a 51% and 55% reduction for the control treatment and the P-WGW treatment, respectively.

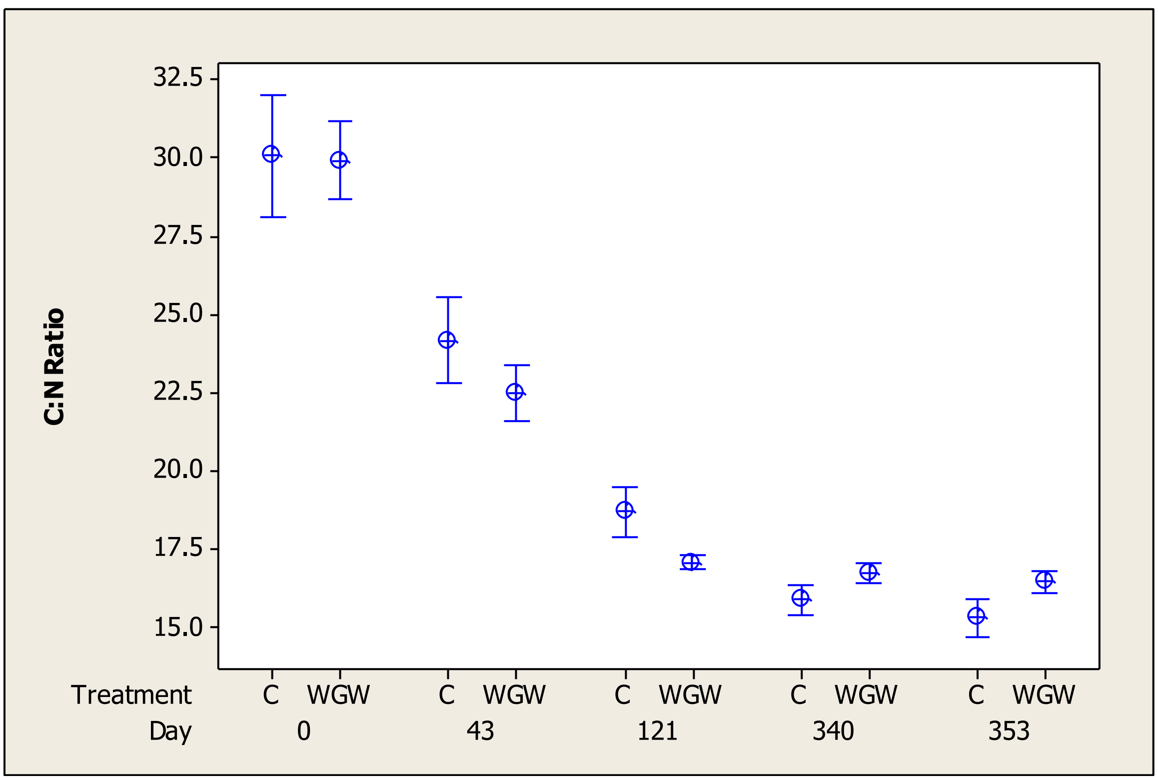

Figure 20. Carbon: Nitrogen ratios of compost treatments (P-WGW vs. Control) over the study period.

Results of pH of the compost treatments are shown in Table 25. The control compost had an initial pH of 6.9 which decreased to 6.2 on the second sampling then increased to 7.3 to 7.5 for the remaining samplings. The final two compost samplings had significantly higher pH than the initial sampling. The P-WGW compost treatment had an increasing pH over the study from an initial pH of 6.4 to a final pH of 7.2. While both treatments had similar pH levels at the initial sampling, the control treatment had a significantly higher pH level at the final sampling compared to the P-WGW treatment. However, the pH was neutral to moderately alkaline and is within the range for an ideal compost pH.

Table 25. pH in Compost Treatments (P-WGW vs. Control) over the study period.

Treatment	pH†				
	Day				
	0	46	123	310	353
Control	6.9 a A	6.2 b B	7.3 ac A	7.5 c A	7.4 c A
P-WGW	6.4 a A	6.9 ab A	7.2 b A	7.0 b B	7.2 b B

†lower case letters are across the row and upper case letters are within each column

Table 26. Electrical Conductivity Content (dS m^{-1}) in Compost Treatments (P-WGW vs. Control) over the study period.

Treatment	Electrical Conductivity dS m^{-1} †				
	Day				
	0	46	123	310	353
Control	5.7 a B	7.1 a B	10.5 b B	9.2 b B	9.8 b A
P-WGW	7.3 a A	9.7 b A	14.1 c A	10.6 b A	10.5 b A

†lower case letters are across the row and upper case letters are within each column

Both compost treatments had increasing EC from the first to the third sampling, both almost doubling from their initial concentrations (Table 26). This is reflected in a concentration of salts as the compost masses and volumes were reduced by approximately 30% during this period. Beyond that sampling, there was significant difference in the control treatment EC while the P-WGW treatment saw a significant reduction in the EC content of the compost possibly due to addition of moisture during the late fall and winter period and leaching during early spring. The EC of the P-WGW treatment was significantly higher than the control treatment at all sampling points except for the final sampling when they were similar.

Table 27. Chloride Concentration Content (mg kg $^{-1}$) in Compost Treatments (P-WGW vs. Control) over the study period.

Treatment	Chloride Concentration mg kg $^{-1}$ †				
	Day				
	0	46	123	310	353
Control	966 a A	949 a A	1661 b A	1608 b A	1600 b A
P-WGW	887 a A	1160 ab A	1426 b A	1063 a B	1032 a B

†lower case letters are across the row and upper case letters are within each column

There was no significant difference in chloride concentration in the control compost the beginning to the second sampling, while there was a significant increase in chloride concentration in the last three samplings (Table 27). An increase in the chlorine concentration was recorded in the P-WGW compost treatment between the first and second sampling which continued into the third sampling. However, this trend was reversed in the final two samplings of the P-WGW compost treatment where the chloride concentration was similar to the initial sampling. Chloride ion concentration in both compost treatments had no significant difference at the time they were prepared. The chloride concentration in the two compost treatments was also similar at the second and third sampling. The chloride concentration in the control compost was over 60% higher in the final two samplings compared to the P-WGW compost treatment.

Total carbon content was measured over the study period in both treatments (Table 28). The control compost had significantly higher carbon content, almost 7%, compared to the P-WGW compost treatment when they were initially prepared. This trend continued throughout the study although the difference increased to 11% by the end of the study. The control however did not have a significant drop in carbon content from the start to the end of the study as the decrease was only from 40.1% to 36.7%. In contrast, the carbon content decreased in the P-WGW compost treatment over the length of the study by 24%, from 33.2% to 25.2%.

Table 28. Total Carbon Content (%) in Compost Treatments (P-WGW vs. Control) over the study period.

Treatment	Total Carbon (%) †				
	Day				
	0	46	123	310	353
Control	40.1 a A	38.9 a A	36.8 a A	36.6 a A	36.7 a A
P-WGW	33.2 a B	30.0 b B	26.8 c B	26.9 c B	25.2 c B

†lower case letters are across the row and upper case letters are within each column

The nitrogen content increased 1.8 times from 1.35% to 2.4% in the control compost (Table 29). The P-WGW compost treatment nitrogen content increased significantly as well but to a lower extent at 1.4 times. The nitrogen content was significantly lower in the P-WGW treatment compared to the control treatment for the length of the study. Both treatments had an increase in total nitrogen content by the end of the study, by almost 1% in the control and 0.5% in the P-WGW treatment.

Table 29. Total Nitrogen Content (%) in Compost Treatments (P-WGW vs. Control) over the study period.

Treatment	Total Nitrogen (%) †				
	Day				
	0	46	123	310	353
Control	1.35 a A	1.62 ab A	1.98 bc A	2.31 c A	2.40 c A
P-WGW	1.11 a B	1.34 b B	1.57 c B	1.61 c B	1.53 c B

†lower case letters are across the row and upper case letters are within each column

The initial sulphur content of the P-WGW compost treatment was higher than the control mainly due to the gypsum (calcium sulphate) in the wallboard (Table 30). At the initial sampling, the sulphur content of the P-WGW compost treatment was 4.5 times that in the control treatment. At the final sampling this difference had increased to the P-WGW compost treatment having 10 times the amount of sulphur than the control compost . The sulphur content in the control treatment increased from 0.38% in the initial compost to 0.71% by the third sampling after which it decreased to 0.26% by the final sampling. The P-WGW compost treatment increased from 1.71% at the initial sampling to 2.39% at the second sampling after no significant change in sulphur content was recorded.

Table 30. Total Sulphur Content (%) in Compost Treatments (P-WGW vs. Control) over the study period.

Treatment	Total Sulphur (%) †				
	Day				
	0	46	123	310	353
Control	0.38 ab B	0.54 bc B	0.71 c B	0.31 ab B	0.26 a B
P-WGW	1.71 a A	2.39 b A	2.76 b A	2.57 b A	2.69 b A

†lower case letters are across the row and upper case letters are within each column

3.4.2.2 Total and Bio-Available Heavy Metals

The initial (start of study) and final (end of study) total and bio-available heavy metal concentrations for the two treatments are shown in Tables 31 and 32. The initial heavy metal concentration was dependent on the feedstocks used to prepare the treatment as indicated previously in the discussion on feedstocks. The P-WGW treatment had a higher initial concentration of cadmium (Cd), cobalt (Co), and lead (Pb). The control compost had a higher initial concentration of chromium (Cr). Copper (Cu), nickel (Ni), and Pb concentrations were similar in two treatments at the initial sampling. These same relationships were also indicated for the two treatments at the final sampling for cadmium, cobalt, chromium, and lead. Copper and zinc (Zn) had higher concentrations in the control treatment than the P-WGW treatment at the final sampling. Nickel had a higher concentration in the P-WGW treatment at the final sampling. As the overall mass of the compost piles decreased over the length of the study, increases in concentration of the heavy metals would be expected. This was evident for cobalt, copper, nickel, and zinc in both treatments. No change in concentration was observed for chromium or lead in either treatment over the length of the study. While there was no change in cadmium concentration from initial to final sampling for the control treatment, as an increase in the P-WGW treatment was measured.

Table 31. Initial and Final Total Heavy Metal Concentrations for Control vs. P-WGW treatment.

	Heavy Metal Concentration (Dry basis mg kg^{-1})[†¥]						
Treatment	Cd	Co	Cr	Cu	Pb	Ni	Zn
Initial							
Control	0.1 bA	1.8 bB	38.4 aA	11.1 aB	3.5 bA	6.0 aB	57.7 aB
P-WGW	0.6 aB	4.5 aB	12.7 bA	9.8 aB	10.9 aA	8.8 aB	45.6 aB
Final							
Control	0.2 bA	3.4 bA	30.1 aA	31.7 aA	4.2 bA	9.3 bA	89.5 aA
P-WGW	0.9 aA	6.6 aA	18.4 bA	24.7 bA	14.3 aA	13.6 aA	67.5 bA
CCME	3	34	210	400	150	62	700

† Dry weight basis

¥ Lower case letters indicate differences between treatment metal concentrations within each sampling period (initial or final) and upper case letters indicate differences between initial and final metal concentrations for each treatment (initial vs. final control or P-WGW)

At the initial sampling, the concentration of bio-available cadmium, cobalt, chromium, lead, and nickel was higher in the P-WGW treatment than the control treatment. Bio-available copper and zinc were similar in both treatments at the initial sampling. The same relationships were indicated at the final sampling for cadmium, cobalt, chromium, lead, and nickel. Bio-available copper concentration was higher the final sample for the P-WGW treatment compared to the control treatment. The reverse was indicated for zinc, were the control treatment concentration was higher than the P-WGW treatment. Bio-available cadmium and zinc increased in both treatments form initial to final sampling. There was no change in the concentration of bio-available chromium, copper, lead and nickel for both treatments. Bio-available cobalt increased in the control treatment but not the P-WGW treatment. Overall, at the final sampling the P-WGW treatment had twice the concentration of bio-available cadmium, cobalt, chromium and nickel compared to the control treatment. Bio-available level concentration in the P-WGW treatment was more than four times that of the control treatment.

Table 32. Initial and Final Bio-available Heavy Metal Concentrations for Control vs. P-WGW treatment.

	Heavy Metal Concentration (Dry basis mg kg^{-1})†¥						
Treatment	Cd	Co	Cr	Cu	Pb	Ni	Zn
Initial							
Control	0.2 bB	0.6 bB	0.4 bA	5.0 aA	0.9 bA	1.2 bA	34.6 aB
P-WGW	0.5 aB	2.1 aA	0.7 aA	5.0 aA	4.3 aA	2.6 aA	32.1 aB
Final							
Control	0.3 bA	0.9 bA	0.4 bA	3.4 bA	0.7 bA	1.0 bA	51.9 aA
P-WGW	0.6 aA	2.2 aA	0.9 aA	4.8 aA	4.2 aA	2.4 aA	41.2 bA

† Dry weight basis

¥ Lower case letters indicate differences between treatment metal concentrations at sampling periods and upper case letters indicate differences between initial and final metal concentrations within treatments

4. Conclusions

Using P-WGW as a compost additive with horse manure and bedding as a base feedstock did not adversely affect the composting process, relative to a non-WGW control compost. The significant effects of using P-WGW as a composting feedstock were a reduction in the amount of total carbon and nitrogen added to the system. Gypsum contributes little to none of either component. On the other hand, total sulphur content was significantly higher in the P-WGW, which was reflected in the compost sulphur composition over the study, and represents a possible concern if the process is not managed properly. High sulphur content in composts under anaerobic conditions can lead to emissions of hydrogen sulphide which requires careful monitoring for the safety of people working with the composts. Therefore, careful monitoring of compost conditions such as aeration, pH, and moisture content will play a role in stabilizing sulphur in the organic matter. Maintaining pH in the neutral range will help offset transformations of sulphate into hydrogen sulphide.

5. Recommendations

The objectives of this project were to broadly characterize waste wallboard gypsum material being received at C&D facilities in Nova Scotia and determine the potential to divert this waste stream into municipal or agricultural composting systems. In particular, a focus of these studies was to examine whether differences would be observed in compost heavy metal concentrations, as a function of using waste wallboard gypsum as a compost feedstock. We examined rates of WGW addition ranging from 20% up to 40% by mass along with commonly available organic waste by-products including: municipal biosolids from Colchester Regional Wastewater Treatment Facility and horse manure/bedding from local farms or racetracks. Results of the studies conducted for this project indicate that addition of WGW in compost systems is feasible and does not significantly alter the decomposition processes or affect the compost quality under current CCME guidelines. Heavy metal concentrations were well below CCME guidelines for Class A composts and bio-availability of heavy metals appeared to be dependent on the specific metal and feedstocks used to make up the compost. Management of compost mixtures where WGW will form an ingredient should focus on maintaining appropriate aeration and bulk density to ensure generation of unwanted gaseous by-products, such as hydrogen sulphide, are minimized. Additionally, determination of chloride and other salts in the final compost should form part of the land application plan in order to ensure adequate plant growth and reduce potential for toxicity as a result of high salt concentrations. Climatic conditions in Nova Scotia provide a loss pathway whereby periodic leaching of the salts and other elements through the soil profile is likely. The concentrations and solubilities of most heavy metals measured in these studies suggest the loss through soil and into water is low, and most of the metals are retained within the compost materials. All of the final compost materials fell within the CCME standards for Class A Compost in terms of total heavy metal concentrations.

Diversion of waste wallboard gypsum from C&D facilities into municipal composting operations or into agricultural sectors is a viable opportunity for Nova Scotia with minimal risks associated with heavy metal contamination. Appropriate on-site management of the composting process, good selection of feedstocks, and incorporation of WGW into the mixture at a ratio <20% by mass will mitigate some of the effects from other components, such as sulphur and salts. Site specific considerations for the management of WGW by operators of municipal landfills or C&D facilities should include:

- Evaluation of WGW material arriving on-site and determining whether they are from new home construction or renovations of older homes;
- Visual determination of drywall covering, e.g. paints, wallpaper, which may be associated with specific contaminants. If visual determination is not possible then discussion with the generator of the waste to identify the source and possible contaminants is suggested;

- New and some older WGW materials should be kept in a covered location with minimal exposure to water in order to reduce production of hydrogen sulphide gases, as well as uncontrolled leaching of metals from the WGW;
- We recommend that WGW be composted at a rate of less than 20% by mass under suitably aerated conditions, along with an adequate turning of the compost piles based on temperature monitoring, in order to optimize the composting processes but also to reduce hazardous gas formation;
- De-papering WGW had a moderate effect on reducing total heavy metal concentrations but the differences were not significant relative to the Papered- WGW.

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