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Evaluation of an aerobic composting process for the management of Specified Risk Materials (SRM)

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ABSTRACT

In Nova Scotia (NS), approximately 2700 tonnes of Specified Risk Materials (SRM) are produced annually. SRM disposal is a serious concern for abattoirs and the beef industry. Composting offers a low risk and simple means to transform raw SRM into a more stable and easily managed material. In this project, wheat straw and sawdust were used to compost with SRM on a pilot scale. The study evaluated changes over time in total carbon, total nitrogen, pH, temperature, moisture content and electrical conductivity. Compost temperatures in all treatments met the Canadian Council of Ministers of the Environment (CCME) guidelines for pathogen kill. The compost maturity tests showed that the evolution of CO_2–C in all the final compost products was less than 1 mg g^{-1} organic matter day^{-1}. Wheat straw performed well as a composting feedstock for raw SRM as sawdust. While the wheat straw has advantages including greater availability, lower cost and easily decomposable carbon compounds more management is required to maintain adequate compost temperatures. The influences of seasonal variations due to temperate climatic conditions on SRM composting were also studied with wheat straw. The results suggest no significant differences in composting effectiveness between the two seasons.

1. Introduction

Bovine Spongiform Encephalopathy (BSE), also known as ‘Mad Cow’ Disease, is a global concern. In Canada, the beef industry has suffered severe economic repercussions since the first domestic BSE case was reported in 2003. It has been estimated that the beef industry in Canada lost $5.3 billion by the end of 2004 as a result of trade sanctions due to two positive BSE cases in Alberta [1]. In Nova Scotia (NS), the number of beef and dairy cattle dropped from 105,000 head in 2003 to 83,000 head as of July 1, 2010, a 21% decline. The number of cattle farmers in NS also dropped from 1400 to 700 in that same time period [2].

BSE has a degenerative effect on the nervous system in cattle and is considered a terminal disease. It is believed that the disease is transmitted through meat and bone meal feed contaminated with infective prion proteins from rendered slaughterhouse wastes [3–5]. Specifically, the nervous tissues in cattle, including the skull, brain, trigeminal ganglia, eyes, tonsils, spinal cord, and dorsal root ganglia of bovine over 24 months old, and the distal ileum of cattle of all ages, are classified as Specified Risk Materials (SRM) [5,6].

Recent Canadian legislation, which requires special permits for transport, storage and disposal from the Canadian Food Inspection Agency, was introduced to regulate the disposal of SRM. To minimize the potential spread of BSE, disposal of SRM must follow approved methods, including high temperature incineration ($T > 850\,^{\circ}$C), alkaline hydrolysis, thermal hydrolysis, and landfilling, while rendering and composting are considered containment options only [5]. In Nova Scotia, approximately 2700 tonnes of SRM are produced annually. However, current environmental legislation prohibits incineration or burial of organic waste, while other approved technologies bear a high economic cost to the industry.

Composting of SRM may be a viable on-site containment option for producers and abattoir facilities in Canada. Composting is an increasingly popular management tool for animal mortalities and has been widely used in the poultry industry [7,8]. This technology is an ideal process to convert raw organic matter into a useable end-product while mitigating some biosecurity concerns and providing environmental benefits [9]. The process reduces the risk of spreading conventional pathogens but to date has not been shown to destroy prion proteins [10,11]. Composting is not a new technology but is now momentous as an effective and economical option for SRM management. Currently, one composting facility in NS has been designed to receive and manage SRM.

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SRM is a significant source of nitrogen, requiring the addition of carbon amendments to sustain the degradation of the SRM tissues. This relationship is usually described as the carbon to nitrogen ratio of the compost mixture. The optimum initial C:N for composting ranges between 25:1 and 30:1 [12–14]. Traditionally, materials used as carbon sources included sawdust and other woody residuals, manures, straw, and corn stalks, which all have a higher C:N ratio. Several studies have demonstrated the effectiveness of using sawdust to compost animal mortalities due to the small particle size, high surface area, and its ability to absorb excess water during the composting process [8,16]. However, growing energy costs have led to a diversion of sawdust toward energy production causing the price of sawdust to soar from $25 a ton to more than $100 since 2006 [17,18]. In contrast, wheat straw, which has a good proportion of available carbon compounds, is less expensive and generally available within the farming community [19]. Therefore, evaluating alternative sources of carbon to compost SRM is necessary to ensure the viability of the cattle livestock industry in Canada.

The objective of this study was to compare the decomposition dynamics of composting SRM with sawdust or wheat straw. Biochemical and physical parameters of the composts were measured periodically over the study. Seasonal variations were also evaluated with the wheat straw treatment since temperature is an important factor in the composting process [20].

2. Materials and methods

2.1. Research site

A composting study with SRM was conducted at Nova Scotia Agricultural College's Bio-Environmental Engineering Centre (BEEC), Bible Hill, NS, Canada (45°23′N, 63°14′W). Eight roofed compost bins with three sidewalls constructed on a concrete base, measuring 4 m × 2.4 m × 3 m, were used in this study.

2.2. Compost feedstocks

Hay and fresh wheat straw were acquired from the NSAC farm. The softwood sawdust was purchased from Evergreen Forest Inc., Glenholme, NS and SRM was obtained from a local abattoir, Brookside Abattoir Co-Op Ltd. and the NS Department of Agriculture Pathology Laboratory, Truro, NS.

2.3. Experimental design

The study was set up as a completely randomized design with three treatments, wheat straw (summer and fall) and sawdust. An initial study including a wheat straw-SRM treatment (WS_{Fall}) and a sawdust-SRM treatment (SD_{Fall}) was initiated in September, 2008 as a representative Fall period. A secondary study with wheat straw-SRM (WS_{Sum}) treatment was initiated in July, 2009, and considered as the summer period. Each feedstock treatment was mixed with specific ratios of SRM and hay and replicated four times. The SRM was delivered in barrels separated as heads, intestines, and spinal cords. Each SRM barrel was distributed to ensure all treatments received equal amounts of the various SRM components and to create a homogeneous compost mixture. A Supreme Enviro Processor 400 compost grinder (Supreme International Ltd., Alberta, Canada) attached to an electronic scale was used to weigh, grind and mix the composting feedstocks. Wheat straw or sawdust was added first, followed by the hay, and finally the SRM. The Enviro Processor was run for approximately 15–20 min once all the materials were introduced to ensure complete mixing of the feedstocks. Water was added to each mixture to obtain a moisture content of approximately 60%. The total mass of the composts were 2496 kg and 1632 kg for the $WS_{Fall\ \&\ Summer}$ and SD_{Fall} treatments, respectively, which were subsequently divided into four replicates. The approximate volume of the composts in each bin was 8.4 m^3 for the wheat straw-SRM treatments and 10.1 m^3 for the sawdust-SRM treatment. In the WS_{Fall} and SD_{Fall} study, 90 kg of sawdust or straw was used as a biofilter cap over each replicate in order to reduce odours and vector migration. This was subsequently incorporated into each compost, as part of the original recipe, at the first turning interval and removed from the surface of the WS_{Fall} treatment. During the WS_{Summer} study, a horticultural shade cloth was placed between a sawdust biofilter cap and the compost pile to prevent any sawdust in the cap from mixing with the compost treatment.

2.4. SRM compost recipe preparation

The chemical characteristics of the raw composting materials, with the exception of the SRM due to the heterogeneous nature of the components, were determined prior to initiation of the study and are shown in Table 1. Fresh samples of raw materials were weighed and dried in a drying oven at 70 °C for 48 h until a constant weight was achieved to determine gravimetric moisture contents. Total carbon and nitrogen contents of the wheat straw, sawdust and hay were determined using a LECO 2000 CN analyzer (LECO Corporation, St. Joseph, MI). Moisture contents, total carbon, and total nitrogen of the SRM were obtained from the literature (Rynk, 1992). A compost recipe was developed using a ratio of 6:4:1 (wheat straw or sawdust:SRM:hay) on a mass basis (Table 1). The C:N ratio was calculated using the equation for multiple compost feedstocks [12], to be 33.2:1 for two straw treatments and 33.4 for the sawdust treatment.

2.5. Monitoring and sampling

The temperature within each compost pile was measured at regular intervals using thermocouples linked to a Campbell Scientific CR23X datalogger with an AMT25 multiplexer. Three temperature probes were inserted at depths of approximately 30 cm, 60 cm and 90 cm from the top of the composting pile, reflecting the surface, center and bottom temperatures of the compost, respectively. In total, 24 thermocouples were used to record compost temperatures every 15 min which were collected from the datalogger on a weekly basis. The compost piles were turned when the compost temperatures decreased to ambient levels. Composts were turned four times in both studies (Fall study: on days 37, 51, 71 and 266 from the start; Summer study: on day 42, 78, 110, 286 from the start) during the composting process to mix and aerate each pile. The mean ambient temperatures at days 71 and 110 in the Fall and Summer study respectively, were beginning to reach 0 °C and the piles were allowed to overwinter. In early spring, when ambient temperatures began to increase the piles were mixed again, at day 266 and 286 for the Fall and Summer study, respectively, and allowed to re-activate for a two week period. In both studies, temperatures did not increase (data not shown) and composts were considered to be mature. At each turning, the moisture contents of the composts were estimated qualitatively, using a squeeze test, and water was added in an attempt to achieve the target moisture content of 60%. During each turning period, twelve samples were collected from each pile and frozen for analysis at a later date. Each sample was analyzed for total carbon and total nitrogen, gravimetric moisture content, pH and electrical conductivity (EC). Moisture content in the WS_{Fall} and WS_{Sum} treatments at the start of the studies were found to be different, at 62% and 43%, respectively. The moisture content in the WS_{Sum} treatment was corrected at the first turning.

The mass of each pile was measured at the beginning of the study, at every turning, and at the end of the study period using the

Table 1
Chemical characteristics of composting feedstocks and mass (kg fresh) of compost treatments in each bin.

Ingredient	Moisture content (%)	Total C (%)[a]	Total N (%)[a]	Fresh mass (kg) $WS_{Fall\ \&\ Summer}$	Fresh mass (kg) SD_{Fall}
Straw	37	45	0.4	340	–
Sawdust	48	43	0.16	–	340
Hay	39	42	2.1	57	57
SRM[b]	70	15	3.0	227	227

[a] Dry mass.
[b] Literature values for slaughterhouse wastes [12].

Supreme Enviro Processor 400. The difference between the original mass and the mass at each sampling time was related to the total mass reduction for each treatment. Electrical conductivity and pH were measured as an aqueous extract following a method based on the Test Methods for the Examination of Composting and Compost (TMECC) [21,22]. A 10 g fresh compost sample was mechanically shaken with deionized water for 20 min at room temperature. A solid to water ratio of 1:10 (w/v) was used, instead of an original 1:5 ratio from the method in order to obtain filter liquid from the wheat straw treatment. This was due to the water absorptive capacity of the wheat straw. An Accumet XL50 dual channel pH/Ion/Conductivity meter was used to measure the extract for pH and EC. Fresh compost samples were weighed and subsequently dried in a drying oven at 70 °C for 48 h to determine gravimetric moisture contents. Total carbon and nitrogen contents of the treatments were measured using a LECO 2000 CN analyzer (LECO Corporation, St. Joseph, MI). Samples collected on day 266 were tested for maturity based on the TMECC compost respirometry method [23]. Three 1-L glass jars with 25 g of as-received composites from each compost treatment replicate, as well as three blank jars, were set up in an environmentally controlled chamber at 32 °C. Each sample was adjusted to a moisture content of 75% in error and which is higher than indicated by the method. Therefore, measurements of methane and nitrous oxide were also taken from each subsample to determine whether anaerobic conditions were present during the maturity test period. Prior to the maturity test, the subsamples were pre-incubated at room temperature (approximately 25 °C) for 48 h to allow microorganisms in the compost to acclimate, and then transferred to the sealed glass jars and incubated at 32 °C for 5 days. A volume of 20 mL of headspace air was extracted each day using a syringe through a septum on the jar caps. Once the sample was taken, the headspace was purged with ambient air and the bottles were resealed and the process repeated for each of the remaining test days. Each sample was measured for measure carbon dioxide, methane, and nitrous oxide using a Varian CP-3800 Gas Chromatograph. Organic matter content was measured using a loss on ignition method [24]. Twenty-four 10 g oven-dried compost samples were placed in a muffle furnace and combusted at 550 °C for 2 h. The ashed sample was then cooled and used to calculate the content of organic matter. The Canadian Council of Ministers of the Environment composting guidelines require CO_2–C evolution of a compost to be less than 4 mg g^{-1} organic matter day^{-1} in order to be considered mature [25].

2.6. Statistical analysis

Data in this study were tested for normality of data distribution and constant variance using Minitab ver. 15. Independence was assumed through randomization of treatments. Analysis of variance and least squares means (LSmeans) was conducted using Proc Mixed in SAS 9.2 for comparison of initial and final pH, EC, total carbon, and total nitrogen of the treatments. Nonlinear regression analysis was conducted using the PROC NLIN procedure to analyze the variables for total carbon and total nitrogen data in SAS 9.2 with the Gauss-Newton method of iteration [26]. A $p < 0.05$ probability level was used as the threshold for identifying significant differences between treatments.

3. Results and discussion

3.1. Temperature profiles

Fig. 1 shows the temperature profiles of the compost treatments at three depths and Fig. 2 provides the mean daily ambient temperatures during the study periods. Different composting temperature profiles were observed between the WS_{Fall} and SD_{Fall} compost treatments. The temperatures of both treatments increased rapidly over the initial 24 h period, which has been demonstrated in many other composting studies for highly volatile feedstocks [27,28]. However, the WS_{Fall} treatment only remained in the mesophilic phase ($T < 45$ °C) for one day and reached thermophilic temperatures, 55 °C, within 3 days. In contrast, the SD_{Fall} treatment took 7 days to reach thermophilic temperatures. Temperatures in the WS_{Fall} treatment remained above 55 °C for approximately 20 days before declining, while the SD_{Fall} treatment maintained a temperature between 55 °C and 65 °C for 37 days, likely the result of smaller particle size and greater surface area. Sustained higher temperatures and promotion of thermophilic fungi in the SD_{Fall} treatment may have contributed toward enhanced lignin degradation prolonging the degradative period [29,30]. Sawdust contains more recalcitrant pools of carbon such as lignin, a highly branched polymer with a different degradation pathway than cellulose or hemicelluloses, requiring higher temperature conditions to degrade [31]. Four temperature peaks occurred during the composting process in both treatments. In the WS_{Fall} treatment, an initial peak of 70 °C occurred at day 7 while in the SD_{Fall} treatment, a maximum peak of 60 °C occurred at day 12. Maximum peaks occurred quickly after each turning and the maximum temperature was over 70 °C for both treatments. Petric et al. [31] suggested that microbial inhibition could occur when temperatures rise above 65 °C and subsequent rapid temperature declines were also observed in our study. At a temperature greater than 65 °C, microorganisms such as actinomycetes and fungi are inactive, leaving only spore-forming bacteria [32]. However, these maximum temperatures only remained for a short time (one to two days). Temperatures in both treatments increased after each turning event except in the SD_{Fall} treatment after day 71 which may have been due to complete consumption of the more labile carbon sources. In the WS_{Fall} treatment, thermophilic temperatures were not sustained after each turning and declined quickly over a short period of time. This is possibly due to rapid consumption of the available carbon sources or as a function of the large particle size of the wheat straw preventing access to labile carbon bound within the structural components.

The overall temperature trends of the wheat straw treatments over two different seasons are similar, although initial moisture contents were different. The initial WS_{Sum} treatment moisture content was approximately 43% which was lower than the target. This may have lead to slightly slower rate of increase to thermophilic temperatures relative to the WS_{Fall} treatment. Despite differences

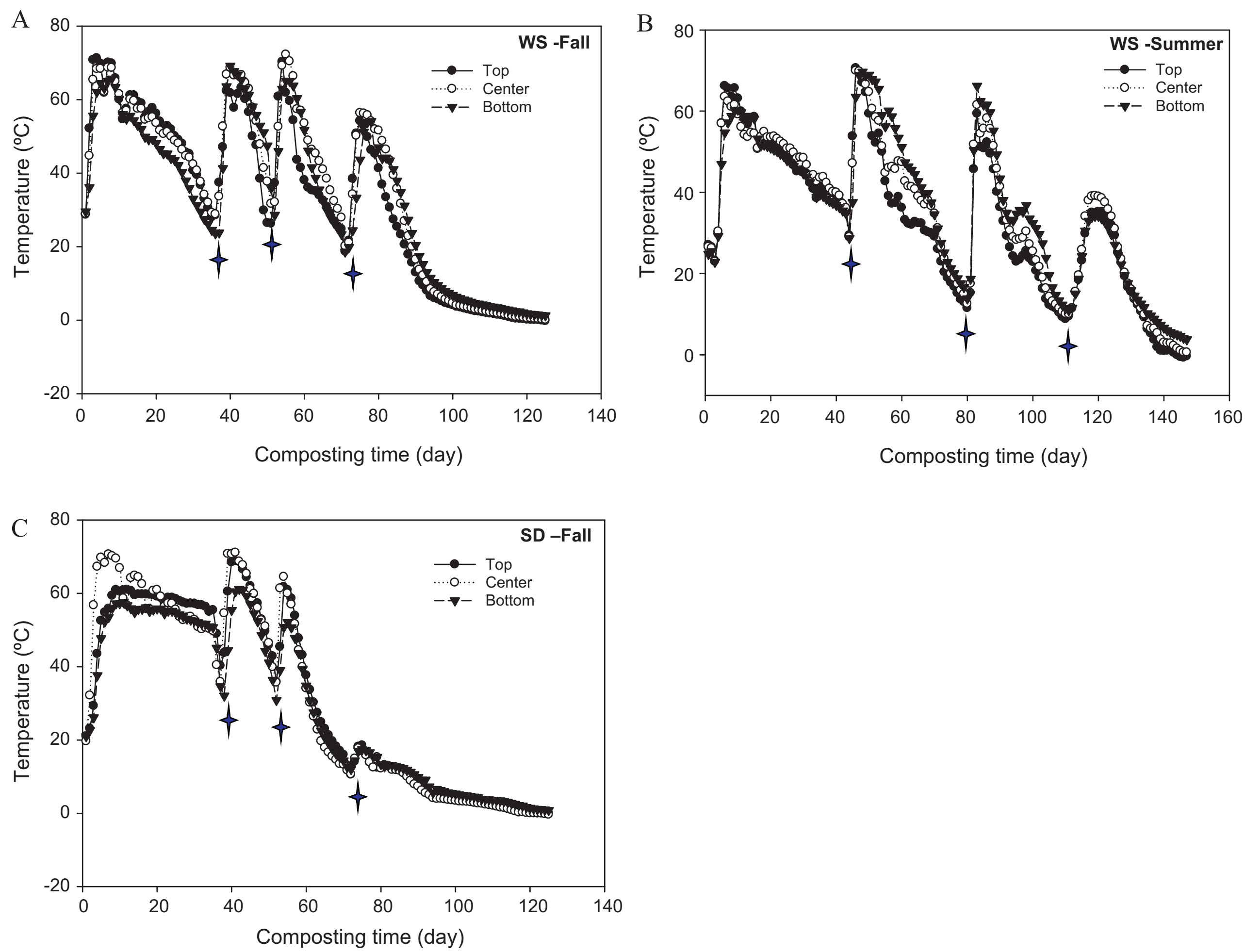

Fig. 1. Mean temperature fluctuations (°C) at three depths in compost treatments (A. WS_{Fall}, B. WS_{Sum}, C. SD_{Fall}) over the Fall and Summer study periods. Compost turning is indicated by the ✦.

in moisture, temperatures increased rapidly at the beginning of the composting period, and were sustained over 55 °C for approximately 10–15 days. Over the entire study period, temperatures in the WS_{Fall} treatment remained >40 °C for 30 days while that of the WS_{Sum} treatment was maintained at this level for 35 days, indicating a longer thermophilic phase [33]. Both treatments had temperature increases after turning, likely the result of exposing available carbon surfaces to the microbes and adding water, as well as the replenishment of oxygen. Despite the fact that temperatures increased quickly over a short term, they dropped quickly after easily accessible sources of carbon were consumed. After the second turning period, both treatments re-heated and maintained a

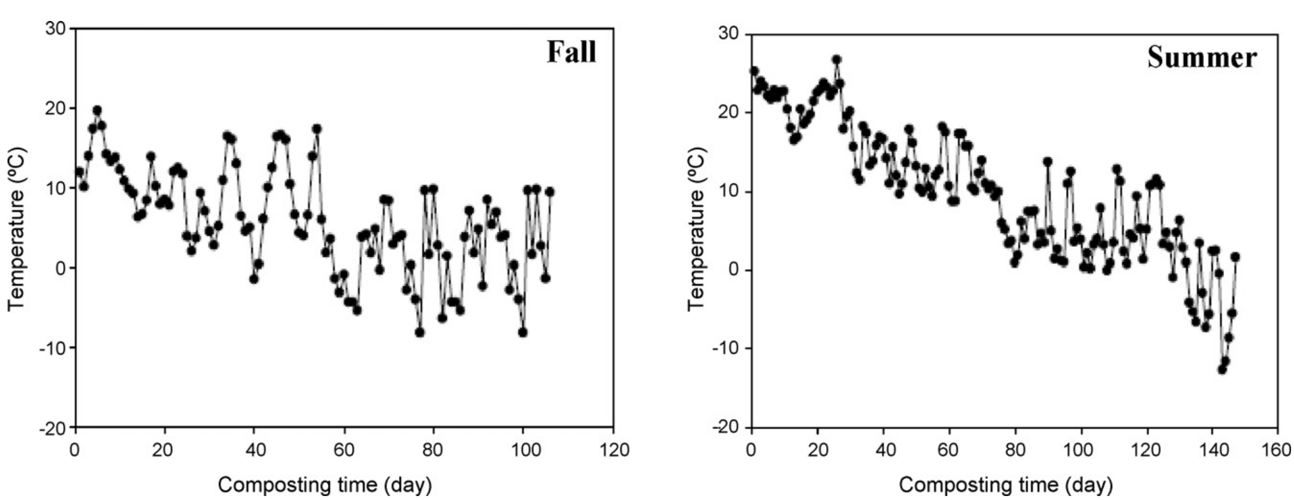

Fig. 2. Mean ambient temperature fluctuations (°C) over the two composting studies conducted during the Fall and Summer.

Table 2
pH and electrical conductivity (EC) (data ± standard errors) of treatments (WS-Fall, SD and WS-Sum) over the study period.

	Sampling time	Treatments		
		WS_{Fall}	SD_{Fall}	WS_{Sum}
pH	1	6.6 ± 0.3[a]	7.2 ± 0.1[a]	5.2 ± 0.0[b]
	2	7.5 ± 0.0[a]	7.7 ± 0.1[a]	6.8 ± 0.2[b]
	3	7.7 ± 0.1[b]	8.2 ± 0.1[a]	7.1 ± 0.1[b]
	4	8.0 ± 0.1[a]	7.9 ± 0.1[a]	7.1 ± 0.1[b]
	5	6.3 ± 0.1[a]	6.5 ± 0.1[a]	6.5 ± 0.1[a]
EC	1	2.1 ± 0.1[a]	2.3 ± 0.0[a]	4.0 ± 0.1[b]
	2	3.0 ± 0.1[a]	3.2 ± 0.2[a]	3.4 ± 0.2[b]
	3	2.5 ± 0.0[b]	2.6 ± 0.1[a]	3.0 ± 0.2[b]
	4	2.3 ± 0.0[a]	2.4 ± 0.1[a]	2.8 ± 0.1[b]
	5	2.4 ± 0.1[a]	2.4 ± 0.1[a]	3.8 ± 0.2[b]

Different letters within rows represent significant differences ($p < 0.05$).

thermophilic phase for 10 days. The average ambient temperatures during the major composting period for WS_{Sum} (August–October) ranged from 20 to 30 °C, which was about 15–20 °C higher than the fall treatments (September–November). This is likely the reason for a prolonged thermophilic phase during WS_{Sum} composting period and similar studies have reported variable temperatures in composts due to changes in ambient conditions [28]. Only the WS_{Fall} treatment reached a thermophilic phase after the third turning.

During the winter period, the temperature in all treatments dropped quickly to 0 °C or lower, mirroring ambient conditions. After the winter period, on days 266 and 286, the WS_{Fall} and WS_{Sum} compost treatments were turned again and the WS_{Fall} treatment responded with a small temperature increase which did not reach a thermophilic range. The temperature of WS_{Sum} was maintained at close to ambient conditions after turning indicating a cured or mature product. All treatments met the CCME guidelines for pathogen kill attaining a temperature of 55 °C or greater for at least 15 days [25].

3.2. pH and electrical conductivity

The pH and EC results are shown in Table 2. The pH in all SRM compost treatments increased during the initial phases of the composting process which is attributable to initial microbial activity, producing ammonium ions during ammonification and mineralization of organic nitrogen [31,34]. During the early stages of composting, Tuomela et al. [30] found that microorganisms degrade proteins to liberate ammonium and increase the pH. Sundberg and Jönsson [35] also reported high microbial activity at the start of the composting process in the presence of sufficient carbon, water, and oxygen, thereby increasing decomposition rates and raising the pH. After the second compost turning, the pH in all treatments decreased, possibly as a result of the release of H^+ ions and volatilization of ammoniacal nitrogen through nitrification [34,36]. No significant differences were detected in pH values between the two fall season treatments, while significant differences were found between the two wheat straw treatments over different seasons ($p < 0.05$). WS_{Sum} had a lower pH value than WS_{Fall}, which is likely due to lower initial nitrogen content in the wheat straw for the summer treatment. Optimum pH values for finished composts range from 6 to 8 and all treatment in this study were between 6.3 and 6.5.

EC of the two fall season compost treatments increased within the first 40 days and decreased to approximately 2.4 dS m^{-1} through to the end of the study. The increase in EC may have been caused through the decomposition of organic substances [36], while the volatilization of ammonia–nitrogen may have resulted in reduced EC values at later stages of the composting process [37]. No significant differences were detected in EC values between the two fall season treatments, but a higher EC value was measured in the WS_{Sum} treatment compared to those treatments ($p < 0.05$). The EC of the WS_{Sum} treatment was still below 4 dS m^{-1}, which is considered acceptable for use in crop production [13].

3.3. Compost mass reduction

Substantial compost mass reductions were observed in all the treatments by the end of both studies. Changes in compost mass typically reflect decomposition of organic matter and water loss [28]. Total mass reductions on a dry basis for the WS_{Fall}, SD_{Fall} and WS_{Sum} treatments were 49%, 43% and 51%, respectively. Petric et al. [31] reported a mass loss of 25.1–38.5% after composting wheat straw and poultry manure. The SRM in the present study was largely degraded by the third turning and mass reductions at this stage were 43%, 29%, and 48% for the WS_{Fall}, SD_{Fall} and WS_{Sum} treatments, respectively. An additional 18% reduction in mass was recorded in SD_{Fall} after the winter period, indicating a decline in the rate of decomposition. With respect to composting of SRM, this suggests that in an optimized system, i.e. increased surface area and regular compost turning, degradation of tissues can occur within a 3 month period. Xu et al. [32] reported dry mass reductions of cattle mortalities in an enclosed biosecure composting system in the range of 35% and degradation of full carcasses in a 5 month period.

3.4. Total carbon and nitrogen dynamics

The relationships of total carbon and total nitrogen content, by dry mass, in the composting treatments over the study period are shown in Fig. 3. The responses were fit using a first order exponential decay model which appeared to provide the best fit. The high R^2 in all the treatments suggests that the relationships are adequately described by the equations. Significant decreases in the mass of carbon in each compost treatment were observed ($p < 0.05$). The strongest fit to the mean values from the data was for the SD_{Fall} treatment. Total carbon content at the intercept points was lower in the SD_{Fall} and WS_{Sum} than the WS_{Fall} treatment. The carbon content in the SD_{Fall} treatment by the end of the study was lower than both the wheat straw treatments but not different between the two wheat straw treatments. Over the studies, total carbon was reduced by 68%, 74%, and 58% in the treatment WS_{Fall}, SD_{Fall}, and WS_{Sum} treatments, respectively. Xu et al. [38] registered large carbon dioxide and methane fluxes during co-composting of cattle mortalities with manure, up to a total of 77.9 kg C Mg^{-1} and 3.16 kg C Mg^{-1}, respectively, over 310 days, but with a reduction in total carbon of approximately 25%. With respect to mortality composting, the feedstock composition plays an important role in the rate of degradation and may have additional impacts on greenhouse gas emissions.

The rate of decay was not different between the two fall season compost treatments (WS_{Fall} and SD_{Fall}). The largest reductions in total carbon were observed in WS_{Fall} and SD_{Fall} between days 1 and day 37 (34% and 44%, respectively) and between days 37 and 51 (26% and 27%, respectively), indicating a reproductive and flourishing microbial community utilizing the labile carbon sources. This is suggestive of rapid decomposition and supports other studies reporting mechanisms to enhance the process of stabilization of mortalities in composting systems [28,31,32]. Petric et al. [31] reported an exhaustion of easily degradable organic matter in wheat straw composting with poultry manure after a similar period. In the spring, total carbon in the SD_{Fall} treatment was reduced a further 35.46% due to weathering and increasingly optimal conditions for microbiota to attack the newly labile carbon pools. Gradual degradation of resistant carbon pools, including lignin, has been shown to occur during the compost curing phase, with interspersed bursts of activity as adapted microbial species

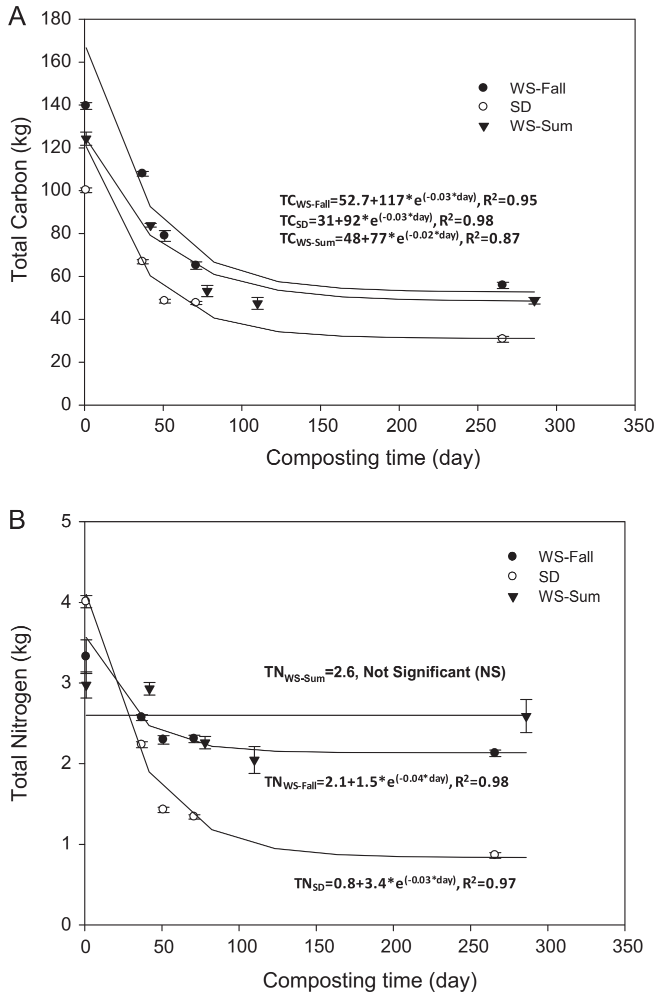

Fig. 3. Changes in A. Total carbon and B. Total nitrogen content (kg) in all compost treatments (WS_{Fall}, SD_{Fall} and WS_{Sum}) over the study period.

colonize and break down the organic matter [39,40]. Carbon reductions in the two straw treatments were initially similar at 35% and 33% for WS_{Sum} and WS_{Fall} after the first turning, respectively. However, from that point forward carbon content was reduced by 56% in the WS_{Sum} treatment and by 43% in the WS_{Fall} treatment. After the winter period, a reduction of 14% was detected in the WS_{Fall} treatment while less than 1% was measured in the WS_{Sum} treatment. This was due to the higher ambient temperatures in the summer promoting conditions of greater microbial decomposition of the treatment.

Significant first order decay relationships ($p < 0.05$) were also observed in total nitrogen content for the two fall season treatments over the study period. Total nitrogen changes in the WS_{Sum} treatment were not significant. In the two fall season treatments, the reduction in total nitrogen was 23.51% in WS_{Fall} by day 37 and 43.32% in the SD_{Fall} treatment. Total nitrogen losses reported in the literature for animal manure/carcasses compost ranges from 21 to 77% [32,41,42]. A reduction in total nitrogen content was observed in the SD_{Fall} treatment over the latter half of the study period. This may be due to the higher sustained temperatures and higher pH values in SD_{Fall}, causing nitrogen loss through volatilization. Michel et al. [15] and Petric et al. [31] reported that high temperature and alkaline pH can increase nitrogen losses and ammonia odours by favoring nitrogen volatilization. The initial total carbon and nitrogen contents in WS_{Sum} were lower than the WS_{Fall} treatment due to some decomposition of the wheat straw prior to start of the summer period.

Table 3
Changes (data ± standard errors) in carbon to nitrogen ratios (C:N) in each treatment (WS-Fall, SD and WS-Sum) over the study period.

	Sampling time	Treatments		
		WS_{Fall}	SD_{Fall}	WS_{Sum}
C:N	1	37.1 ± 3.2	25.2 ± 0.5	43.0 ± 2.4
	2	42.2 ± 0.6	30.1 ± 0.5	29.0 ± 0.9
	3	34.3 ± 0.6	34.2 ± 0.3	23.4 ± 0.6
	4	28.4 ± 0.7	35.7 ± 0.4	24.1 ± 1.1
	5	26.3 ± 0.5	35.3 ± 0.3	20.5 ± 1.6

Table 3 shows the changes of carbon to nitrogen ratio (C:N) of all treatments. The actual measured C:N ratios of the WS_{Fall}, WS_{Sum}, and SD treatments at the beginning of the study were 37:1, 43:1, and 25:1, respectively. These C:N ratios were different than the values calculated based on measuring all the feedstocks, with the exception of the SRM. This suggests the SRM biochemical values from the literature were not appropriate. The C:N ratios dropped to 26:1 and 20:1 by the end of the composting process in the two wheat straw treatments (WS_{Fall} and WS_{Sum}). In contrast, the SD treatment had a lower initial C:N of 25:1 which increased over the study period to 35:1. This is due to high nitrogen losses from the SD treatment which we attribute to the higher pH and increased ammonia loss. An increase in the C:N ratio in some composts has also been reported by Tiquia and Tam [42] and Morisaki et al. [43].

The results presented support previous studies which show the effectiveness of using agricultural feedstocks to compost SRM and livestock mortalities [16,28,32,38]. The rate of carbon degradation and percent mass loss from the two wheat straw studies are comparable with a sawdust carbon source. The use of wheat straw with SRM reduces the cost of on-farm management substantially given current pricing trends relative to purchasing of sawdust or woody residuals. The temperature profiles indicate that thermophilic temperatures are reached for a sufficient time period to deal with most conventional pathogens.

3.5. Maturity test

The average daily release of CO_2–C in finished compost for WS_{Fall}, SD_{Fall}, and WS_{Sum} were 0.199, 0.167, and 0.995 mg CO_2–C g^{-1} of organic matter d^{-1}, respectively, over a 5-day incubation period [44]. These values are well below the current CCME guidelines for a mature compost of <4 mg CO_2–C g^{-1} of organic matter d^{-1} [25]. The high initial moisture content of the samples may have had an impact on CO_2–C evolution through suppression of aerobic microbial activity. However, methane and nitrous oxide evolution, as measures of anaerobic microbial activity, were measured to be 2 and 0.9 $\mu l\ L^{-1}$ gas, respectively.

4. Conclusions

The wheat straw performed well as a carbon source substitute for woody residuals, such as sawdust, in SRM composting. Composting of SRM with wheat straw was effective in either the summer or fall season resulting in maximum dry mass and total carbon loss within a 3 month period. Warm ambient conditions (summer) prolonged the thermophilic decomposition period and reduced the time for the compost to reach a curing phase. The temperatures in all treatments met the CCME pathogen kill guidelines and significant temperature increases were detected in all treatments shortly after mixing. The results of this study also indicated that SRM can be degraded into a stable, homogenous material within a short-time frame and can be performed on an agricultural site using inexpensive, easily accessible feedstocks. Wheat straw required an additional turning cycle to maintain thermophilic temperatures for enough time to meet CCME guidelines for pathogen control.

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