Evaluation of an Aerobic Composting Process for the Management of Specified Risk Materials (SRM)

by

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Abstract

In Atlantic Canada, approximately 8000 tonnes of Specific Risk Materials (SRM) is produced annually. Composting offers a means to partially treat and stabilize SRM. In this project, different types of agricultural residuals and wastes were used to compost with SRM in a pilot scale. The results were discussed based on the change in total carbon and nitrogen, pH, temperature, moisture content and electrical conductivity, which were measured at regular intervals over the study. The temperature for all treatments met the CCME pathogen control guideline. The maturity test showed that the CO_2-C in all the compost was less than 1 mg/g organic matter/day. Straw and other agricultural wastes performed well in the composting SRM, other advantages includes greater availability, lower cost and more easily decomposed carbon compounds.

List of Abbreviations and Symbols Used

BEEC	Bio-Environmental Engineering Centre
BSE	Bovine Spongiform Encephalopathy
CCME	Canadian Council of Ministers of the Environment
CFIA	Canadian Food Inspection Agency
CJD	Creutzfeldt-Jakob disease
CWD	Chronic Wasting Disease
EC	Electrical Conductivity
HB	Horse Bedding
NSAC	Nova Scotia Agricultural College
NSEA	Nova Scotia Environment Act
PrP^c	Prion Protein
SM	Sheep Manure
SRM	Specified Risk Materials
SRMC	Specified Risk Materials Compost
ST	Straw
TC	Total Carbon
TMECC	Test Methods for the Examination of Composting and Compost
TN	Total Nitrogen
TSE	Transmissible Spongiform Encephalopathy

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Chapter One: Introduction

1.1 Background

Canada had a $2.2 billion annual beef export market, mostly to the U.S., Japan, South Korea and Mexico. However, the cattle industry suffered a significant decline in its exports with the first positive Bovine Spongiform Encephalopathy (BSE) test in 2003. BSE is a fatal disease detected in cattle which can affect humans through the food chain. After the first BSE case was confirmed in Alberta in 2003, U.S and other countries closed their borders to shipments of Canadian live cattle and beef products. The beef industry of Canada was financially devastated by a $5.3 billion revenue drop by the end of 2004 (Statistics Canada, 2003). In Nova Scotia, the number of cattle—beef and dairy—declined from 105 thousand head in 2003 to 83 thousand head as of July 1, 2010, which was a 21% downturn. A cow that would have normally sold for $1,300 was selling for $15. The number of farmers also dropped from 1400 to 700 (Forge and Fréchette, 2005; Statistics Canada, 2010). In order to eliminate the potential spread of BSE, the Canadian Food Inspection Agency (CFIA) instituted new regulations for the disposal of Specified Risk Materials (SRM), which are challenging beef producers and slaughterhouse facilities in Nova Scotia. SRM (Figure 1.1) is defined as tissues such as skull, brain, trigeminal ganglia, eyes, tonsils, spinal cord, and dorsal root ganglia from the BSE-infected cows, bovine over 24 months of age, and the distal ilea of cattle of all ages (Health Canada 2003; CFIA, 2007; CFIA, 2009). Several disposal methods, such as high temperature incineration, landfilling and rendering are not acceptable in Nova Scotia due to provincial legislation and economic and environmental concerns (NSEA, 2006; CFIA, 2007). Composting of SRM and its subsequent use as a landscaping soil amendment, may be a viable

containment option for producers and slaughterhouse facilities. The composting process reduces the risk of spreading viruses and pathogens and generates stabilized organic products which can be used as an amendment to help improve soil quality and fertility (Bernal et al., 2009). Composting is not a new technology but it is now gaining interest as a good option for the treatment of SRM. Therefore, information on SRM composting is required.

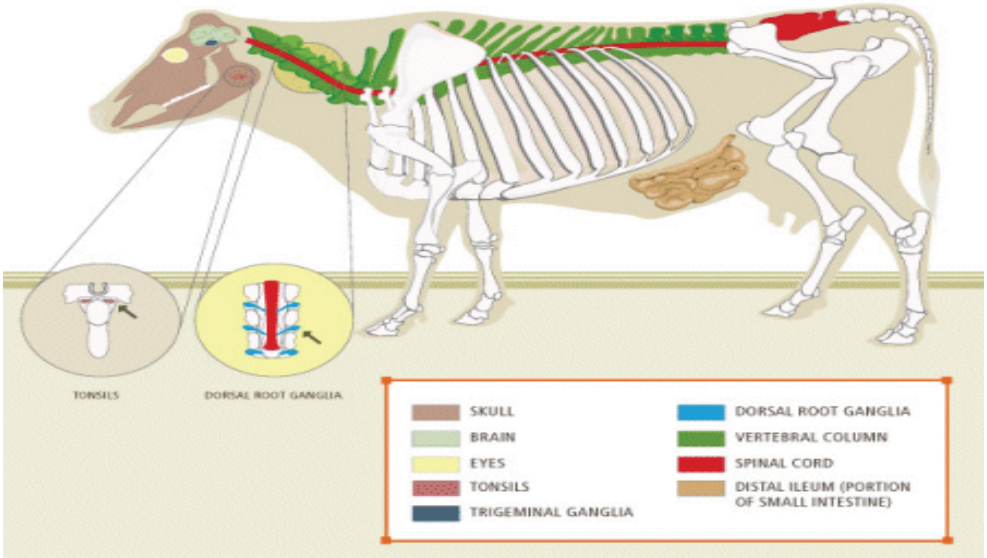

Figure 1.1 Specified Risk Materials (CFIA, 2007)

SRM is a significant source of nitrogen, requiring carbon amendments to sustain the degradation of the SRM tissues. This property is usually described as the carbon to nitrogen ratio (C:N) of the compost mixture. The optimum initial C:N for composting is usually considered to be in a range between 25–30 (Rynk, 1992; Dougherty, 1999; Zhu, 2007). Due to characteristic differences in feedstock, carbon sources with the same C:N may have different influences on the composting process. The organic component in different carbon sources, such as lignin and hemicellulose

will lead to different rates of biodegradability (Tuomela et al., 2000). The aim of this project was to study the influence of carbon composition on the composting process by examining the decomposition dynamics of composting SRM with different carbon sources. In addition, this information would provide specific operational parameters for effective composting of SRM on a pilot scale and deliver research–based recommendations of SRM composting for future study.

1.2 Literature Review

1.2.1 Background History of BSE

Transmissible Spongiform Encephalopathy (TSE) is a fatal disease that causes degradation of animal and human nervous systems (Prusiner, 1998). This disease is caused by the mutation of a prion protein (PrP^c). The mutated prion protein is very resistant to denaturation by chemical and physical agents and this makes the disease untreatable (Prusiner, 1998). Although there are three main hypotheses that scientists believe cause TSE, the "protein only" hypothesis by Prusiner (1985) has been accepted by most scientists (Anne and Haywood, 1997). The hypothesis states that TSE is caused by a particular protein that can replicate itself as an infectious agent in the brain and other tissues of the body (DeArmond and Prusiner, 1995). In the mid-18th century, the first case of TSE, Scrapie in sheep, was discovered in Europe. It is now widespread throughout sheep-breeding countries in Europe, especially the United Kingdom (UK) (Anne and Haywood, 1997; Brown et al., 2001). The rendering of livestock mortalities into meat and bone meal, a protein-rich nutritional supplement, and their subsequent feeding to ruminant and other animals led to disease transmission to cattle (Brown et al., 2001). Nowadays, more types of TSE have been detected, such as BSE in cattle, Chronic Wasting Disease (CWD) in deer and elk, and

Creutzfeldt-Jakob disease (CJD) in humans, which indicate that this disease could be infectious between different species (Johnson and Gibbs, 1998).

BSE, also known as “Mad Cow Disease”, has been detected and became a reportable disease in Canada in 1990 (Becker, 2004; Moens, 2006). In 1993, the first case of BSE was found in a beef cow imported from the UK in 1987. The animal was then destroyed. In May 2003, the first BSE case in a domestic animal was discovered in Alberta. Eighteen cases of BSE have been reported in Canada since then (CFIA, 2010). BSE can degeneratively affect the nervous system in cattle and is considered untreatable. Since it is believed that BSE can be transmitted when the protein from an infected animal is fed to cattle or other ruminants, tissues from BSE-infected cows are defined as SRM. They include the skull, brain, trigeminal ganglia, eyes, tonsils, spinal cord, and dorsal root ganglia of bovine over 24 months old, and the distal ilea of cattle of all ages (Health Canada 2003; Becker, 2004; Moens, 2006; CFIA, 2007).

1.2.2 The Problem

As of 2007, in order to minimize the potential spread of BSE in Canada, the CFIA instituted regulations for the management and disposal of SRM. This regulation requires approval by the CFIA for transporting, accepting and disposing of ruminant slaughterhouse wastes. SRM is also banned from use in animal feed, pet foods and fertilizer in order to reduce exposure to, and transmission of, BSE to ruminant animals (Brown 2006; CFIA, 2007). Nearly 8000 tonnes of SRM are produced annually in Atlantic Canada (Price, 2008). Over the last two decades, many different methods have been used for animal carcass disposal. Methods approved by the CFIA include high temperature incineration (T>850°C), alkaline hydrolysis, thermal hydrolysis, rendering, landfilling, and composting. However, based on the Solid Waste Resource

Management Regulations proposed by the Nova Scotia Environment Act (NSEA), most of these methods are not biologically, economically or environmentally acceptable in Nova Scotia (Ferguson, 2001). Compostable organic material (including cattle carcasses), and leaf and yard waste are banned from landfills and incinerators (NSEA, 2006). Even though rendering is approved by the government, currently only one rendering plant in N.S. is receiving and dealing with SRM. The problem with rendering SRM is that the equipment would need to be cleaned each time the material was handled, reducing the economic benefit to the rendering plant (Price, 2008). Alternative means of SRM disposal in Nova Scotia are therefore required. Composting may be a viable option for the management of SRM.

1.2.3 Composting and Composting Animal Carcasses

Composting is a controlled process to biologically decompose organic matter using natural microorganisms from the environment (Keener et al., 1997). During the composting process, bacteria, fungi and other microorganisms consume oxygen and nutrients to break down materials into a stable organic mass also releasing water, heat and carbon dioxide (Keener et al., 2000). The finished compost, which is similar to humus, can be used as a soil amendment. Composting can be an ideal process to convert organic matter into useable products by: addressing biosecurity concerns around pathogens, being environmentally sound, and providing soil benefits (Haug, 1993; Morse, 2001). Composting to manage animal mortality began with poultry in the 1980s and was then found to be effective for swine and more recently, for cattle (Keener and Elwell, 2003). Proper control of composting can efficiently reduce the volume of the parent material and kill many pathogens (Haug, 1993).

Animal carcasses can be composted in a controlled manner through an adequate

supply of carbon, moisture and other nutrients such as nitrogen (Keener et al., 1997; Keener and Elwell, 2003; Kalbasi et al., 2005; Kalbasi et al., 2006). Composting requires oxygen and water in order to produce thermophilic temperatures (ranging from 40 to 60 °C) (Haug, 1993). Organic constituents caused from animal mortalities containing nitrogen and carbon, are broken down to stable organic forms by bacteria, fungi and other microorganisms. Water, heat and carbon dioxide are released during the process (Keener et al., 2000). Composting can efficiently convert the dead animal from a saturated, dense, highly nitrogenous waste to an unsaturated, porous, moderately nitrogenous product (Kalbasi et al., 2005). Different carcasses and co-composting materials will provide different volume reductions which range from 20% to 65% (Kube, 2002; Fonstad et al., 2003). Conventional pathogens, such as bacteria (*E. coli* and *Salmonella*), viruses and protozoa (*Giardia* and *Cryptosporidium*), will be killed if the proper temperatures are reached in the composting pile. Based on the Canadian Council of Ministers of the Environment (CCME) guidelines, the compost needs to attain a temperature of 55°C or greater for at least 15 days in the windrow composting pile to kill most of the pathogens (CCME, 2005). The finished compost is expected to be stable and easy handled. In Nova Scotia, there are 16 permitted composting facilities but only one is built for the composting of carcasses (Antigonish, NS).

1.2.4 Parameters Affecting Composting

The composting process can occur naturally, but good management will help provide optimum conditions and increase efficiency. Several factors need to be considered in the management of compost (Kalbasi et al., 2006).

1.2.4.1 Carbon

Carbon is the major source that provides energy to microorganisms and almost 50% of microorganism cell content consists of carbon (Pare et al., 1998; Tiquia et al., 2002). By comparison, nitrogen is the other element of note and is an important component of proteins, nucleic acids, amino acids, enzymes and co-enzymes. Cattle remains contain a significant amount of nitrogen (Pare et al., 1998). Composting microorganisms can survive and reproduce in the presence of sufficient carbon and nitrogen (Kalbasi et al., 2005).

A balance of carbon and nitrogen is necessary for healthy microbial activity. This balance is usually described in terms of a carbon to nitrogen ratio (C:N). A C:N reflects the ratio of the weight of total carbon to that of total nitrogen in organic material (Rynk, 1992; Kalbasi et al., 2005). Several residues can be used as carbon amendments, such as wood chips, wood shavings, sawdust, straw, and corn stalks, which all have a high C:N (Michel et al., 2000; Morse, 2001). A proper C:N can also effectively reduce the odour that is generated during the composting process and also provide a proper environment to help microorganisms function efficiently. Normally, a C:N between 25:1 and 40:1 is considered to be satisfactory (Keener et al., 2000). A high C:N (too much carbon) will slow the activity of microorganisms and decrease the compost pile temperature, which leads to a decrease in the decomposition process. A low C:N (too much nitrogen) can cause odor problems during the composting process (Morse, 2001).

According to previous research, the characterization of the carbon source and the biodegradability and compostability of lignocellulosic materials will also influence the composting process (Bernal et al., 1998; Tuomela et al., 2000; Bernal et al., 2009). Different types of carbon compounds have different compositions. Lignin, cellulose

and hemicellulose are the most basic components of the carbon source in plant residues (Sylvia et al., 2005). For instance, wood material is mainly composed of cellulose (40%), hemicellulose (20–30%), and lignin (20–30%) (Tuomela et al., 2000). Straw has a mix of 40–50% cellulose, 30–40% hemicellulose and 10–20% lignin (Antongovanni and Sargentini, 1991). The biodegradability and compostability of these three major carbon components are very different. The carbon in lignin has been proven to be very thermally stable and generally resistant to biodegradation. It is the most difficult carbon source that can be used by microorganisms. Cellulose is moderately resistant to biodegradation, while hemicellulose is the least resistant (Sharma, 1996; Bernal et al., 1998; Tuomela et al., 2000; Marche et al., 2003). Carbon sources composed mostly of cellulose and hemicellulose, such as straw, decompose and release carbon to the microorganisms more easily than material containing larger amount of lignin, such as sawdust and other woody materials (Rynk, 1992).

As a carbon source, sawdust has been proven to perform well on composting carcasses with its high surface area, small particle size and the ability to absorb excess water during the composting process (Murphy et al., 2004; Kalbasi et al., 2005). However, there are some concerns about sawdust composting. Sawdust is now in demand as a biofuel due to rising energy costs. The price of sawdust has soared from $25 per ton to more than $100 per ton since 2006 (Anonymous, 2008; Laumer, 2008). Therefore, research on the effect of the carbon source on the composting of SRM is necessary to find alternative, less expensive sources of carbon.

1.2.4.2 Moisture Content

Microorganisms need water to live and grow. An ideal moisture content of the composting pile allows the microorganisms to perform their metabolic activities (Richard et al., 2002). Water acts as a medium for nutrient transport and chemical exchange. Proper water content in the mixture can help to encourage the microorganisms' activity and increase the rate of decomposition (Keener et al., 2000). Microorganisms could not survive if there is not enough moisture in the compost; the degradation slows when the moisture level decreases to 40% or less (Morse, 2001). In contrast, too much moisture can inhibit microbial activity by reducing the free pore space in the pile, slowing, or even inhibiting, the flow of oxygen. To reach an optimum state of biodegradation, the most suitable moisture content in the compost pile is approximately 40 to 70% of the mass (Dougherty, 1999; Richard et al., 2002).

1.2.4.3 Oxygen

Along with moisture, oxygen is another key factor in the composting process. Aerobic microorganisms need oxygen to survive and degrade the organic matter. Oxygen usually enters the pile through the air flow and helps raise the temperature in the compost. Too little oxygen will inhibit or even stop the composting process and produce odours. An oxygen concentration of 5% or less will be considered inadequate for microorganisms (Morse, 2001). Odours and slow degradation will occur under these conditions (Dougherty, 1999; Keener et al., 2000; Kalbasi et al., 2005). A common method that people use to aerate the compost pile is by turning it. Materials need to be completely relocated to allow fresh air to flow in and carbon dioxide to escape (Morse, 2001). Turning the pile can be done weekly or monthly, depending on the size of the composting material and how quickly a product is desired. Temperature

of the compost is not affected by the oxygen content alone, but also by the aeration frequency and duration (Keener et al., 2000; Kalbasi et al., 2005). Turning the pile too frequently would not allow the compost pile time to heat up. Materials within the compost pile can also affect the air flow.

1.2.4.4 Temperature

While microorganisms work, heat is produced during the degradation process leading to an increase in the temperature of the compost pile (Wilkinson, 2007). The temperature of the compost pile indicates and affects the microorganisms' activity. Microorganisms need a proper temperature to work; low temperatures will slow the decomposition rate and some pathogens will not be killed completely (Morse, 2001). Usually, an environment with a high (over 70°C) temperature is optimal for microorganisms to decompose the material rapidly (Nakasaki et al., 1985). Research shows that composting includes two major temperature phases: mesophilic and thermophilic. In the mesophilic phase, the temperature starts to rise and usually ranges from 25°C to 40°C, while in the thermophilic phase, the temperature rises to over 45°C. The optimal temperature for composting is around 55°C to 66°C; at this temperature the highest decomposition rate occurs and most of the pathogens are killed (Nakasaki et al., 1985; Storm, 1985; Keener et al., 2000; Ekinci et al., 2001; Morse, 2001). Based on the CCME guidelines, the composting pile needs to attain a temperature of 55°C or greater for at least 15 days to kill most of the pathogens in a windrow composting pile. Pathogens, such as infectious bursal disease virus, salmonella, and coliform bacteria, are killed at this high temperature (CCME, 2005).

1.2.4.5 Surface Area

Because microbial decomposition occurs on the surface of organic wastes, a large surface area of composting material in the carcass pile can also help the process (Kalbasi et al., 2005). Grinding and mixing provide well mixed and smaller pieces of composting material, therefore increasing the surface area. This also reduces the number of times required to turn the pile and decreases the composting time (Kube, 2002).

1.2.4.6 pH

The pH range for the composting process is between 6.5 and 7.2 (Carr et al. 1998). Too alkaline or too acidic environments do not have many positive effects (Kalbasi et al., 2005). The environment for growing bacteria normally keeps pH in the range of 6.5 to 9.0. Fungi will compete with the bacteria when the pH is below 6.5; all metabolic activity will be retarded when the pH exceeds 9.0.

1.2.5 Bin Composting

Three composting systems—static windrow, bin and in-vessel— are commonly used for the composting of carcasses. The type of facility is selected based on the body size, the quantity and the financial resources available.

Bin composting of animal waste occurs in an enclosure which is built with a concrete floor, three-sided wood or concrete walls, and a roof constructed with water-repelling materials which help to prevent the composting pile from getting excessive moisture from precipitation (Morse, 2001; Keener and Elwell, 2003). The roof can also help eliminate weather problems such as the rainfall and snow, which may affect the moisture content of the compost.

1.2.6 Grinding and Mixing

In animal mortality composting, particle size of carcasses and co-composting materials will influence the composting process as well. Small pieces of material can increase the surface area, accelerate the composting process and reduce the composting time (Looper, 2002; Kalbasi et al., 2006). Some researchers showed that grinding and mixing the carcass with co-composting material prior to composting can help provide this condition. With grinding, the number of compost turnings can be reduced from three to one and the composting time can be decreased from twelve to six months (Cawthon, 2000; Kube, 2002; Kalbasi et al., 2006). The Colorado Governor's Office of Energy Management and Conservation (2003) also found that with grinding and composting, the time can be reduced by between 30 to 60%. Grinding and mixing can also homogenize carcass and co-composting material so that the carbon source is more efficiently used by the microorganisms and the moisture can be adjusted more easily (Price, 2008).

1.2.7 Gases and Odours

During the degradation process, microorganisms decompose organic compound but only use 30–40% of the carbon as their cellular components, the remaining 60–70% of the carbon is released as carbon dioxide to the atmosphere (Barrington et al., 2002). Large amounts of carbon dioxide are generated by these carbon losses. The knowledge of nitrous oxide release from composting is still limited. Recent studies showed that nitrous oxide could be generated, not only by the incomplete anaerobic denitrification of the nitrogen source, but also through incomplete ammonium oxidation. The composting process is usually aerobic, however, with microbial consumption, the oxygen level is reduced and may lead to an anaerobic environment

which generates methane (Lou and Nair, 2009). Even in well managed, aerated composting systems, considerable methane emissions were still detected (Zeman et al., 2002; Amlinger et al., 2008). Although most methan is oxidized to carbon dioxide, it is still a high risk GHG because of its long lifetime and high global warming potential—25 times greater than carbon dioxide (Zeman et al., 2002; Brown and Leonard, 2004).

1.2.8 Biofilter Cover

A layer of carbon-rich material is usually used to cover the composting pile. The cap can work as a biofilter which helps prevent the odour problem by deodorizing the gases released from the pile (Kalbasi et al., 2005). Also, it can reduce the loss of heat, conserve the energy and keep the pile under a thermophilic condition. In mortality composting, the carbon cap can prevent animals from reaching the carcass tissues.

1.2.9 Compost Maturity and Utilization

Compost maturity is established as an indicator of the completion of the composting process. Mature compost is usually considered to have the optimum quality to support plant growth with few phytotoxic compounds (Bueno et al., 2009). Based on the CCME guideline, mature compost should have either: an oxygen uptake of less than 400 mg O_2/kg organic matter/ hour; or produce less than 4 mg CO_2-C/g organic matter/day; or the temperature rise of the compost above ambient temperature is less than 8 °C (CCME, 2005). Mature compost is usually utilized as a soil amendment or fertilizer to agronomic crops due to its nutrient content. Wong et al. (1999), Yermiyahu et al. (2001) and Sullivan et al. (2002) reported that mature compost applied to the soil had a beneficial effect on plant growth and gave a higher

yield. Another option may be using mature compost in more composting process. It is believed that the mature compost contains a certain amount of microbes because of the degradation of the organic matter. Applying mature compost to the composting process for microbial inoculation is considered to reduce the composting period.

1.3 Objectives

The overall objective of this project was to deliver research-based recommendations on SRM composting for future studies. In order to achieve this overall goal, the following objectives were completed:

1. The decomposition dynamics of composting SRM with different carbon sources was examined;
2. Composting parameters were measured and evaluated during the composting process;
3. The influences of seasonal variation on SRM composting were studied;
4. The physical and chemical characteristics of the resulting compost were evaluated for its use as a potential soil amendment in agriculture.

Chapter Two: Evaluation of Straw and Sawdust as Carbon Sources for Composting Specified Risk Materials (SRM)

2.1 Introduction

BSE is currently a worldwide issue. Canadian cattle industry has suffered a negative effect since 2003 when the first domestic BSE case was reported in Alberta. In Nova Scotia (N.S.), the number of cattle—beef and dairy—dropped from 105 thousand head in 2003 to 83 thousand head as of July 1, 2010, which was a 21% decline. The number of farmers also dropped from 1400 to 700 (Statistics Canada, 2010). The beef industry of Canada also has been financially devastated by a $5.3 billion loss by the end of 2004 (Statistics Canada, 2006). BSE can degeneratively affect the nervous system in cattle and is considered untreatable. It is believed that the disease is transmitted when the protein from an infected animal are fed to cattle or others (Becker, 2004; Moens, 2006; CFIA, 2007). Therefore, tissues from the BSE-infected cows are defined as SRM. It includes 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 (Health Canada, 2003; CFIA, 2007).

Recent federal legislation regulating the disposal of materials believed to harbor this disease agent requires special permits from the CFIA for transport, storage and disposal of SRM. To minimize the potential spread of BSE, the CFIA now tracks and controls the disposal of SRM. Disposal of SRM must follow the methods approved by the CFIA which include high temperature incineration (T>850˚C), alkaline hydrolysis, thermal hydrolysis, rendering, landfilling, and composting (CFIA, 2007). Based on current environmental legislation and high economic cost, most of these methods are not viable options in Nova Scotia (Ferguson, 2001). Composting of SRM, and subsequent use of the finished compost, may be a viable containment option for

producers and abattoir facilities in the province. However, there are 16 organic composting facilities in NS but only one is built for ruminant mortality composting; the information on mortality composting is limited.

Composting is an increasingly popular management tool for animal mortalities, widely used in the poultry industry through the 1980s and later adapted to swine, cattle, sheep, exotic animals and even road kill (Keener and Elwell, 2003; Kalbasi et al., 2005). This process is an ideal method to convert raw organic matter into a useable end product while mitigating biosecurity concerns, and providing environmental benefits (Haug, 1993; Morse, 2001). Composting is the process of using microorganisms in the environment to biologically decompose animal carcasses (Keener et al., 1997). It is a special waste management technique requiring oxygen and water, generating thermophilic temperatures mediated by microbial activity (Haug, 1993). During the process, bacteria, fungi and other microorganisms consume oxygen and nutrients to break down organic materials into a stable mixture called compost, while also releasing water, heat and carbon dioxide (Keener et al., 2000). The process reduces the risk of spreading of viruses and pathogens and generates stabilized organic products which be used as the amendment to help improve soil quality and fertility (Bernal et al., 2009). Composting is not a new technology but it is now gaining interest as a good option for SRM disposal. Therefore, information on SRM composting is required.

SRM is a significant source of nitrogen requiring carbon amendments to sustain the degradation of the SRM tissues. This property is usually described as the carbon to nitrogen ratio of the compost mixture. The optimum initial C:N for composting is usually considered at the range between 25:1 to 30:1 (Rynk, 1992; Dougherty, 1999; Zhu, 2006). However, due to the characteristic differences, carbon sources with the

same C:N may have different influences on the composting process. The organic component in different carbon sources, such as lignin and hemicellulose will lead to different levels of biodegradability of the material (Tuomela et al., 2000). Several materials can be used as carbon sources, such as wood chips, sawdust, straw, and corn stalks, which all have a extremely high C:N (Michael et al., 2000; Morse, 2001). Research shows that sawdust performs well on mortality composting due to its high surface area, small particle size and its ability to absorb excess water during the composting process (Murphy et al., 2004; Kalbasi et al., 2005). However, the high lignin content in sawdust (usually 40%) makes it difficult to be degraded by the microorganisms. The carbon in lignin has been shown to be very thermal stable and generally resistant to biodegradation (Huang et al., 2010).

In addition, 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 (Anonymous, 2008; Laumer, 2008). Therefore, finding alternative sources of carbon to compost SRM is necessary to maintain the economic viability of the livestock industry. Wheat straw is a mix of 40–50% cellulose, 30–40% hemicellulose, which is less resistant to biodegradation, and 10–20% lignin, and is less expensive and generally available within the farming community (Antongovanni and Sargentini, 1991). In this study, the decomposition dynamics of composting SRM with sawdust and wheat straw were compared. A compost system for the management of SRM was developed by testing the changes in chemical, biological, and physical parameters during the composting process. The information provided specific operational parameters for effective composting of SRM and deliver research-based recommendation of SRM composting for the future study.

2.2 Materials and Methods

2.2.1 Research Site

From September 24, 2008 to July 28, 2009, an SRM composting study was conducted at NSAC's Bio-Environmental Engineering Centre (BEEC), Bible Hill, NS, Canada (45°23' N, 63°14' W). Eight compost bins with three sidewalls constructed on a concrete base, measuring 4 m × 2.4 m × 3 m, were used in this study. Each bin was roofed (Figure 2.1).

Figure 2.1 Composting bins at BEEC.

2.2.2 Compost Feedstocks

Hay was donated by the NSAC farm. The fresh wheat straw was bought from a local farm. The hardwood sawdust was provided by the Evergreen Forest Inc., Glenholme, NS. The SRM was obtained from a local abattoir, and the NS Pathology Laboratory, Truro, NS.

2.2.3 Experimental Design

The study was set up as a completely randomized design with two treatments, wheat straw and hardwood sawdust. Each treatment was composed of a mixture of SRM and hay with four replicates. Each replicate was randomly assigned a compost bin and samples were collected randomly from different locations in each pile. The SRM was delivered in barrels separated as heads, intestines, and spinal cords (Figure 2.2). The SRM barrels were assigned to each treatment and pile to ensure even distribution of heterogeneous material across all replicates. A Supreme Enviro Processor 400 compost grinder attached to a weighing scale was used to weigh, grind and mix the composting materials. The straw/sawdust and hay were first added to the grinder to be fully ground (Figure 2.3). SRM was then loaded into the grinder for grinding and mixing together with the carbon source (Figure 2.4). Water was added to the initial mixture to obtain a moisture content of approximately 60%. Once the compost was in the bin, 90 kg of straw and sawdust were taken from each replicate, respectively, to use as a biofilter cap. The cap was then mixed with the compost pile contents at the first turning period. However, after the first turning, a layer of sawdust was used as a biofilter cap over the pile in order to reduce odours and vector migration. A horticultural shade cloth was placed between the cap and the composting pile to prevent the sawdust in the cap from mixing with the composting materials.

Figure 2.2 SRM particles in barrels.

Figure 2.3 Adding wheat straw to grinder.

Figure 2.4 Loading SRM into grinder.

2.2.4 SRM Compost Recipe Preparation

The moisture content of the straw, sawdust and hay was measured before the experiment. Fresh samples of raw materials were weighed and dried in a drying oven at 70 ^{o}C for 48 hours until a constant weight was achieved, the moisture content was calculated based on the difference between the weight of fresh and dry sample. The carbon and nitrogen content of straw, sawdust and hay was measured using a LECO 2000 CN analyzer (LECO Corporation, St. Joseph, MI). The moisture content and the total carbon and total nitrogen content of slaughterhouse wastes were obtained from the literature (Rynk, 1992). The chemical characteristics of the raw composting materials are listed in Table 2.1.

Table 2.1 Chemical characteristics of raw composting materials.

Ingredient	Moisture (%)	%C (DW[a])	%N (DW)
Straw	37	45	0.4
Sawdust	48	43	0.16
Hay	39	42	2.1
SRM[b]	70	15	3

a: Dry Weight
b: estimated values for carcasses (Rynk, 1992)

A recipe (Table 2.2 and 2.3) was developed to obtain an initial C:N close to 30 :1 and a moisture content of 60%. Based on the compost recipe calculations (Rynk, 1992), six units of sawdust or wheat straw, one unit of hay and 4 units of SRM were mixed for each pile by mass.

Calculation for moisture content

$$Moisture\ content = \frac{weight\ of\ water\ in\ sample\ a + weight\ of\ water\ in\ sample\ b + weight\ of\ water\ in\ sample\ c}{total\ weight\ of\ all\ ingredient}$$

$$= \frac{(a \times m_a) + (b \times m_b) + (c \times m_c)}{a + b + c}$$

a : total weight (wet basis) of sample a
b : total weight (wet basis) of sample b
c : total weight (wet basis) of sample b
m_a : moisture content of sample a
m_b : moisture content of sample b
m_c moisture content of sample c

Calculation for C:N

$$C:N = \frac{weight\ of\ C\ in\ sample\ a + weight\ of\ C\ in\ sample\ b + weight\ of\ C\ in\ sample\ c}{weight\ of\ N\ in\ sample\ a + weight\ of\ N\ in\ sample\ b + weight\ of\ N\ in\ sample\ c}$$

$$= \frac{[\%C_a \times a \times (1 - m_a)] + [\%C_b \times b \times (1 - m_b)] + [\%C_c \times c \times (1 - m_c)]}{[\%N_a \times a \times (1 - m_a)] + [\%N_b \times b \times (1 - m_b)] + [\%N_c \times c \times (1 - m_c)]}$$

a : total weight (wet basis) of sample a
b : total weight (wet basis) of sample b
c : total weight (wet basis) of sample b
m_a : moisture content of sample a
m_b : moisture content of sample b
m_c : moisture content of sample c
$\%N_a a$: nitrogen content of sample a
$\%N_b$: nitrogen content of sample b
$\%N_c$: nitrogen content of sample c
$\%C_a$: carbon content of sample a
$\%C_b$: carbon content of sample b
$\%C_c$: carbon content of sample c

Table 2.2 Recipe of the Straw:SRM composting treatment for each bin.

Target Moisture Content: 60% Target C:N: 30:1						
Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Straw	37	63	45	0.4	112	340
SRM[e]	70	30	15	3	5	227
Hay	39	61	42	2.1	20	57
						624
Recipe Moisture Content: 49% Recipe C:N: 33.43:1 Water needed (kg): 168.6						

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

Table 2.3 Recipe of the Sawdust:SRM composting treatment for each bin.

Target Moisture Content: 60% Target C:N: 30:1						
Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Sawdust	48	52	43	0.16	269	340
SRM[e]	70	30	15	3	5	227
Hay	39	61	42	2.1	20	57
						624
Recipe Moisture Content: 55% Recipe C:N: 33.04:1 Water needed (kg): 75.1						

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

2.2.5 Monitoring and Sampling

The temperature of each pile was measured at regular intervals using thermocouples linked to a Campbell Scientific CR23X datalogger with an AMT25 multiplexer. A single probe containing three thermocouples at two, three and four foot lengths was inserted into each pile to measure temperature at the depths of one, two and three feet from the top of the composting pile, reflecting top, center and bottom

temperatures of the pile, respectively (Figure 2.5). In total, 24 thermocouples were used with temperatures recorded every 15 minutes. The temperature data was downloaded from the data logger on a weekly basis. The compost piles were turned when the temperature of compost pile decreased to ambient temperature. Therefore the compost piles were turned on days 37, 51, 71 and 266 to aerate the composting pile and homogenize the material. A squeeze test was conducted to evaluate the moisture content of the compost pile before each turning period. A sample of compost was squeezed by hand to estimate the moisture content. A sample that formed small balls and dripped a small amount of water by squeezing was considered to have a moisture content of 50 to 60%.

The moisture content was estimated based on this qualitative approach and water was then added in an attempt to achieve a moisture content of 60%. Twelve samples were collected from each pile during each mixing period, resulting in a 27 kg mass loss in each replicate during each turning event. The sample was then frozen at a temperature of -10°C for analysis of total carbon and total nitrogen, moisture content, pH and electric conductivity (EC) at a later date. The total weight of each pile was measured at the beginning of the study and at every turning, as well as at the end of the study. The overall compost pile was loaded into the Supreme Enviro Processor 400 and weighed by a scale attached to the grinder. The mass reduction of each compost pile was calculated as the difference between the original mass and the mass at each sampling time.

Electrical conductivity and pH were measured as an aqueous extract. This aqueous extract was obtained by following a method based on the Test Methods for the Examination of Composting and Compost (TMECC) (USDA and CCREF, 2002[1]; USDA and CCREF, 2002[2]). A 10 g fresh compost sample was mechanically shaken

with deionized water at a solid to water ratio of 1:10 (w/v) for 20 min at room temperature. The suspension was filtered and the liquid was measured for pH and EC using an Accumet XL50 dual channel pH/Ion/Conductivity meter.

An experiment for the maturity test was conducted in July 2009 based on the compost respirometry test from TMECC (USDA and CCREF, 2002[3]). The samples were collected on day 266. Three 25 g of as-received moist compost subsamples from each bin were collected and a total of 27 1-L Mason jars were used (24 for the sample, 3 for the blank). The TMECC method recommends adjusting the moisture content to 70 to 80% of the water holding capacity to maintain the sample in an unsaturated state. However, during the preparation of the sample, the moisture content was adjusted in error to 75%, well above the recommended moisture content. The samples were pre-incubated at room temperature (around 25°C) for 48 hours to allow microorganisms in the compost to adapt to the mesophilic environment. After the pre-incubation, the samples were transferred to the sealed Mason jars and incubated at 32°C for 5 days. Carbon dioxide evolution was measured by extracting 20 mL of headspace air each day at the same time. 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.

The content of organic matter was measured based on the loss on ignition method from TMECC (USDA and CCREF, 2001). Twenty-four (3 subsamples for each pile) 10 g compost samples were oven-dried at 70°C over 48 hours until a constant sample weigh was achieved. The samples were then placed in a muffle furnace. The temperature of the furnace was slowly ramped to 550°C and the samples were combusted at 550°C for 2 h. After that, the temperature of the furnace was slowly ramped down to approximately 200°C. The ashed samples were then removed from

the furnace and transferred to desiccators to cool to the ambient laboratory temperature. The content of organic matter was then calculated based on the weight of dry sample and ash.

The compost was tested for maturity based on CCME guidelines requiring the CO_2-C respiration of the mature compost to be less than 4 mg/g organic matter/day (CCME, 2005).

Figure 2.5 Measurement of temperature at three depths in compost pile.

2.2.6 Statistical Analysis

Data in this study were tested for normality of data distribution and constant variance using Minitab v15. Independence was assumed through randomization of treatments. After assumptions were validated, analysis of variance (ANOVA) was used to test the significance within the treatment for initial and final pH and EC mean values using Minitab v15. Least Squares Means (LSmeans) method was conducted using Proc Mixed in SAS 9.2 for means comparison if a significant difference was found. Nonlinear regression analysis was conducted using 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 (SAS Institute Inc. 2008). A $p<0.05$ probability level of significance was tested for all the data analysis in this study.

2.3 Results and Discussion

2.3.1 Temperature Profiles

The two treatments had different composting temperature profiles throughout the study before the winter period (Figure 2.6 and Figure 2.7). The data was averaged over four replications to show the temperature at three depths for each treatment. The trends of temperature at three depths were similar in both treatments. Discussion focused on the center temperature, which was considered to be less affected by the ambient temperature (Figure 2.8).

The temperature increased rapidly within the first 24 hours, which is similar to many other composting systems (Tiquia et al., 1997; Sivakumar, et al., 2008; Roca-Pérez et al., 2009). The straw treatment only stayed in the mesophilic phase ($T<40°C$) for one day and reached 55°C in 3 days, while the sawdust treatment took 7 days to reach this temperature. Both treatments met the CCME guidelines for pathogen kill attaining a temperature of 55°C or greater for at least 15 days (CCME, 2005). Temperatures in the straw treatment stayed above 55°C for approximately 20 days before declining, while the sawdust treatment maintained a temperature between 55 and 65°C for 37 days, likely the result of large particle sizes in straw, which makes the pile unable to hold the heat generated by microbial activity. Also, the differences may be explained by the different carbon compounds between the straw and sawdust. Sawdust contains more recalcitrant pools of carbon (lignin) which requires high temperature conditions to degrade. As a highly branched polymer, lignin has a

different degradation path than cellulose or hemicellulose (Petric et al., 2009). The most effective composting condition for lignin degradation is at a temperature between 40 and 50°C, while 50–70 % of lignin could be degraded by thermophilic fungi (Tomati et al., 1995; Tuomela et al., 2000).

Both treatments had temperature increases after turning events except the sawdust turning at day 71, likely the result of exposing available carbon surfaces to the microbes and adding water, as well as the replenishment of the oxygen. However, despite the fact that temperatures increased quickly over a short term they dropped quickly. This is possibly because the available carbon sources were consumed. Another reason for this may be the insufficient oxygen which inhibited the microbe's activity.

Four temperature peaks occurred during the composting process in both treatments. In the straw treatment, an initial peak of 70°C occurred at day 7 while in the sawdust treatment, a maximum peak of 60°C occurred at day 12. Maximum peaks occurred quickly after each turning and the maximum temperature reached nearly 80°C for both treatments. Petric et al. (2009) mentioned that a microbial inhibition could occur when temperatures rise above 65°C. At a temperature greater than 65°C, microorganisms such as actinomycetes and fungi are inactive, leaving only spore-forming bacteria (Gray et al., 1971). However, these maximum temperatures only remained for a short time (one to two days).

During the winter period, the temperature in the sawdust and straw treatments dropped quickly to around 0°C or lower, mirroring ambient conditions. The temperatures increased again after the last turning in early spring, day 266, which was likely due to the compost not being fully mature and the microorganisms re-activating in early spring.

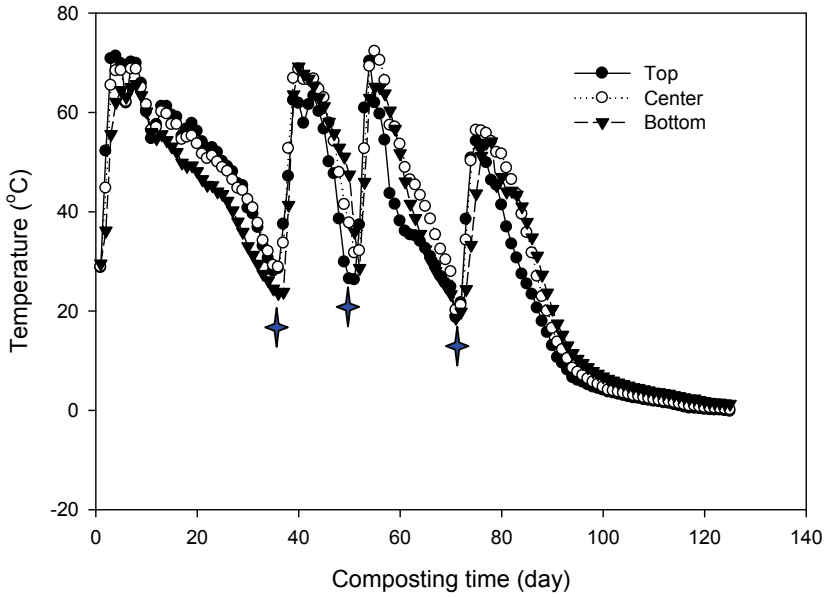

Figure 2.6 Daily change of temperature in Straw:SRM treatment at three depths before the winter period. (✦Turning point)

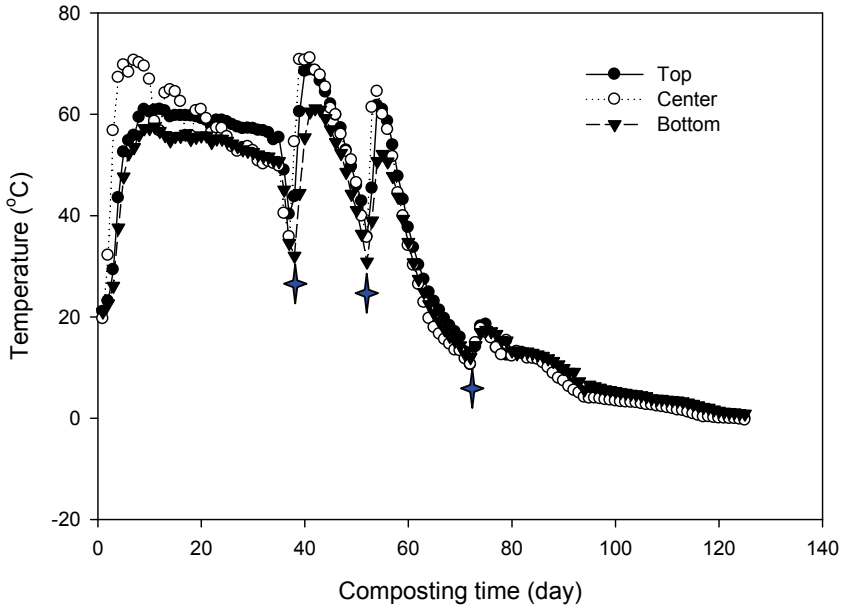

Figure 2.7 Daily change of temperature in Sawdust:SRM treatment at three depths before the winter period. (✦Turning point)

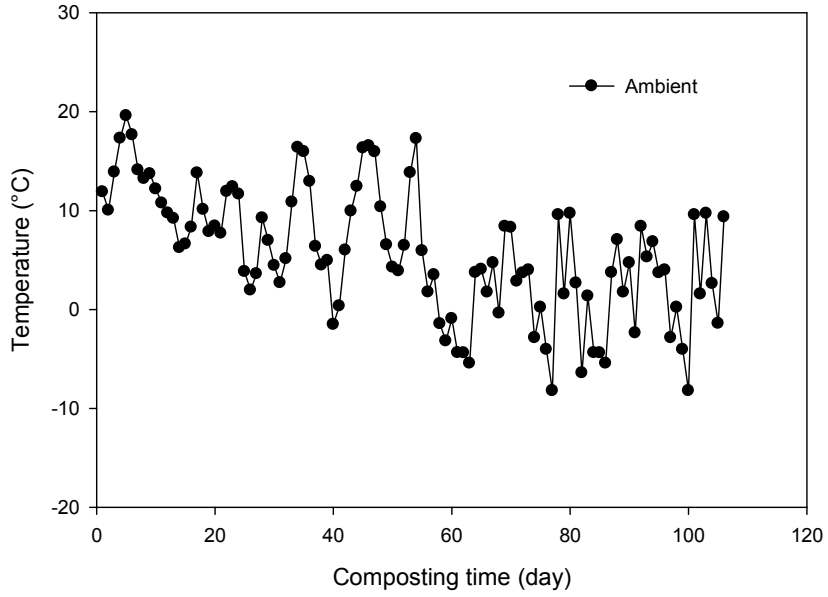

Figure 2.8 Daily change of ambient temperature before winter period.

2.3.2 pH and Electrical Conductivity

The pH data were averaged from four replications for each treatment. The pH of both treatments increased at the beginning of the composting process (Figure 2.9). The increase may be attributed to the initial microbial activity, producing ammonium during ammonification and mineralization of organic nitrogen (Huang et al., 2004; Petric et al., 2009). At the early stage of composting, Tuomela et al. (2000) found that microorganisms degrade proteins to liberate ammonium and increase the pH. Also, according to Sundberg and Jönsson (2008), at the start of the composting process, high microbial activity occurs due to the sufficient carbon source and the presence of water and oxygen, increasing decomposition rates and raising the pH. However, pH for both treatments decreased after day 71. This decrease is probably due to the release of H^+ and volatilization of ammoniacal nitrogen through the microbial nitrification process (Eklind and Kirchmann, 2000; Huang et al., 2004).

No significant difference was detected in pH values between treatments ($p<0.05$). The pH of the sawdust treatment at the end of the composting process was 6.6, while the value of the straw treatment was 6.4 which were within the optimum range of 6 to 8 for finished compost.

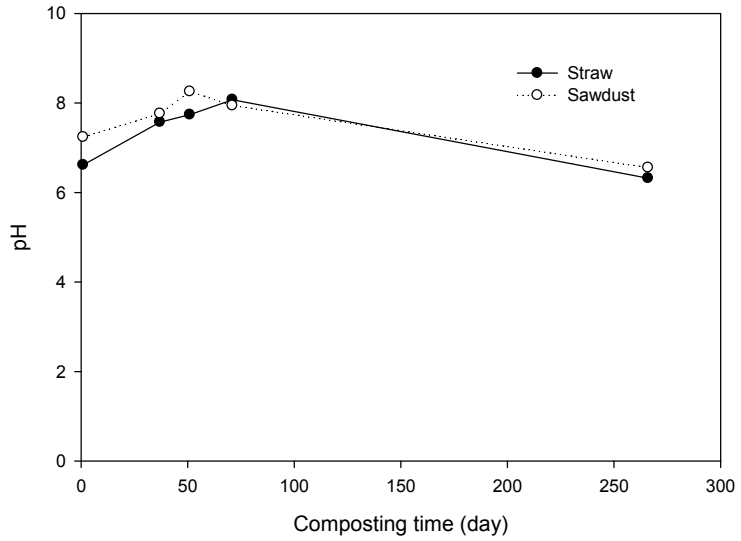

Figure 2.9 Changes in pH during the composting process for each treatment

The electrical conductivity (EC) data was averaged over four replications for each treatment (Figure 2.10). The EC of the two treatments increased in the first 40 days, then began to decrease thereafter. The increase in EC may be caused by the decomposition of organic substances, which releases mineral salts such as ammonium ions (Abid and Sayadi, 2006), while the volatilization of these mineral salts and ammonia decreased the EC at the later phase of composting (Wong et al., 1995). By agricultural standards, soils with an EC greater than 4 dS/m are considered saline (Dougherty, 1999). The EC in both treatments were less than 4 dS/m, which is considered appropriate for use in crop production. No significant difference in EC was detected for the initial and final data within each treatment ($P < 0.05$).

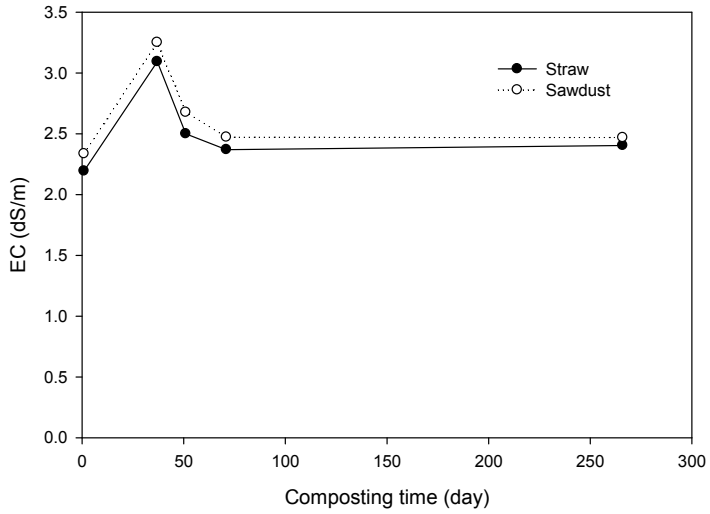

Figure 2.10 Changes in EC during the composting process for each treatment.

2.3.3 Compost Treatment Changes in Mass and Moisture Content

Table 2.4 shows the change in total mass on a dry basis for both treatments over the composting period, reflecting directly on the rate of decomposition of organic matter by the microorganisms (Sivakumar, et al., 2008). The data was an average of four replications. Ninety kg of straw/sawdust was taken from each replicate, respectively to be used as a biofilter cap and mixed with the compost at day 37. Twenty-seven kg of sample were taken at each period from each replicate. This value was added to the total mass at each period. Reductions in total dry mass in both treatments were similar. For the straw treatment, the overall mass reduction was 41% while the sawdust treatment showed a mass loss of 34%. These results were similar to, or even exceed, some of the reported values. Petric et al. (2009) reported a weight loss of 25.1–38.5% in wheat straw/poultry manure composting. A large reduction (18%) in dry mass for both treatments was observed at the start of the study, indicating a large consumption of the organic matter by the microorganisms.

The reduction in mass of the sawdust decreased to only 1% by day 71, which is much smaller than that of the straw treatment (11%). However, a large reduction in mass (15%) of the sawdust treatment was observed again in late spring 2009 (day 266).

Table 2.4 Changes in total mass (dry basis) of the two treatments

Day	Straw		Sawdust	
	DW (kg)	RD%	DW (kg)	RD%
1	309	---	207	---
37	252 (342*)	18	170 (260*)	18
51	288	16	234	10
71	256	11	231	1
266	236	9	196	15
Total	---	41	---	34

* 90 kg of straw/sawdust was added to each replicate, respectively
DW: Dry Weight. RD: reduction

During the turning process, a squeeze test was used to estimate the moisture content before mixing and water was added to each compost pile to adjust the moisture content close to approximately 60%. Figure 2.11 shows the average moisture content of both treatments. The measured moisture contents indicated that the squeeze test estimates for moisture content were not sufficient in the first two turnings to achieve the 60% target.

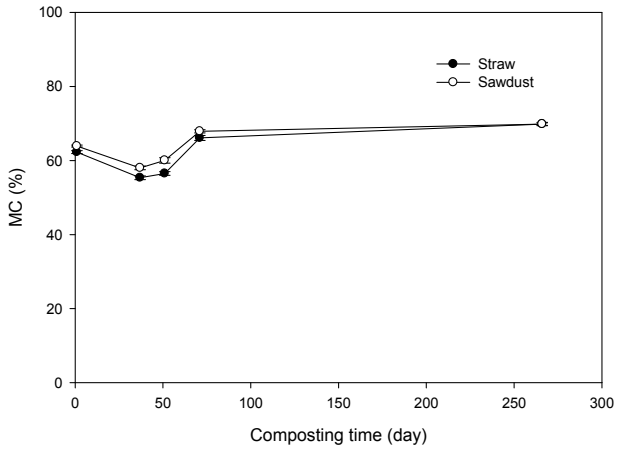

Figure 2.11 Change in moisture content during composting in each treatment

2.3.4 Total Carbon and Nitrogen

The relationships described by the regression equations over the composting study were significant ($p<0.05$). The R^2, calculated by using the equation from Kvalseth (1985), $R^2 = \frac{sum\ of\ squares\ (error)}{sum\ of\ squares\ (total)}$ of both treatments suggests that the relationships are adequately described by the regression equation. The regression pattern does not cover all the points (average of each treatment from four replications) which may be caused by the variables of the original data.

Figure 2.12 is the profile of total carbon change in both treatments. The regression relations of the two treatments were significant ($p<0.05$).

$TC_{straw} = 52.469 + 91.19 * e^{-(0.0209 * day)}$, $R^2 = 0.87$;

$TC_{sawdust} = 30.5402 + 71.9411 * e^{-(0.0216 * day)}$, $R^2 = 0.96$;

Large reductions in total carbon were observed in the straw treatment and sawdust treatment between the commencement of the study and day 37 (22.61% and 31.31%) and between days 37 and 51 (26.90% and 27.43%), indicating a reproductive

and flourishing microbial community utilizing the available carbon sources. The total carbon in the straw treatment decreased gradually until the winter period (day 71). This is because of the action of microorganisms in the presence of sufficient, easily biodegradable carbon sources (likely cellulose and hemicellulose). However, the degradation of total carbon in the sawdust treatment slowed after day 51; only 1.92% of the carbon reduction was observed between days 51 and 71. The reason for this can be the lack of an easily-degraded and available carbon source in sawdust that slows or even stops the action of microorganisms. Petric et al. (2009) also reported an exhaustion of easily degradable organic matter in the wheat straw composting with poultry manure, resulting in less carbon dioxide emissions. A greater carbon reduction (35.46%) was found in the sawdust treatment during the winter and spring period (days 71–266) compared to that of the straw treatment (14.24%), which may indicate that available carbon was degraded in this period. Li and Zhang (2000), Solano et al. (2001) and Zhu et al. (2007) all mentioned that lignin would be degraded gradually in the curing phase. Significant differences were found between the two treatments ($p<0.05$). A larger amount of carbon reduction was observed in the sawdust treatment. The overall reduction of total carbon in the straw treatment was 60% while the sawdust treatment had a nearly 70% reduction.

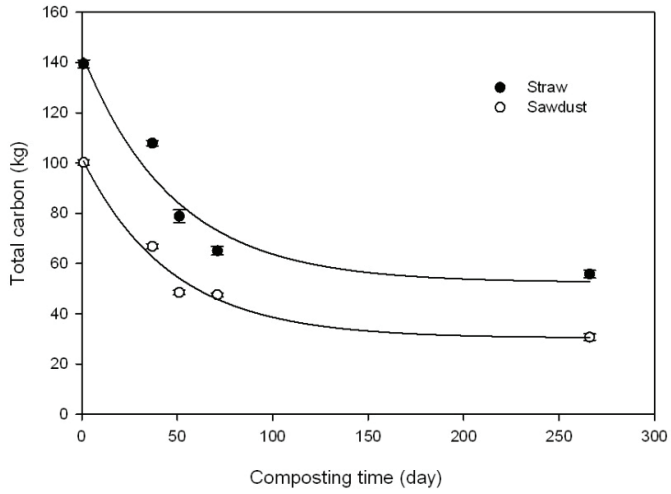

Figure 2.12 Change in total carbon in dry mass in each treatment
(Standard errors were shown in error bars)

The overall relationships in total nitrogen between the two treatments over the study period are shown in Figure 2.13. The data were shown as an average of four replicates. The regression relationships in both treatments were significant ($P < 0.05$).

$TN_{straw} = 2.1298 + 1.2374 * e^{-(0.0311 * day)}$, $R^2 = 0.97$;

$TN_{sawdust} = 0.8352 + 3.2793 * e^{-(0.0271 * day)}$, $R^2 = 0.97$;

The concentration of total nitrogen in the compost decreased at the beginning of the composting process in both treatments. However, this concentration increased after the first turning period (day 37) in the straw treatment and reached a stable status by day 71. This can be explained by the total mass of nitrogen in the straw treatment plateauing after day 37 while the total mass of the straw treatment continue to decrease during the composting process, increasing the nitrogen concentration. A gradual reduction in nitrogen concentration was observed in the sawdust treatment. This may be due to high temperature and high pH values in the sawdust treatment, causing the nitrogen loss. Michel et al. (2004) and Petric et al. (2009) reported that high temperature and alkaline pH can increase nitrogen volatilization and lead to

higher nitrogen loss and ammonia odours.

The reduction in total nitrogen in the straw treatment was 23.51% by day 37, while in the sawdust treatment it was 43.32%. The total nitrogen losses reported in the literature in animal manure/carcass composting in a range from 21 to 77% (Martins and Dewes, 1992; Tiquia et al., 2000). However, the rate of decline in total nitrogen in the straw treatment was much lower during the rest of composting period, while the reduced rate of decline in total nitrogen occurred between days 51 and 71 in the sawdust treatment. The reason for this can probably be the higher release of nitrogen as NH_4^+ in the sawdust, increasing the pH of the compost and inhibiting the action of the microorganisms. A higher reduction in total nitrogen was observed in the sawdust treatment.

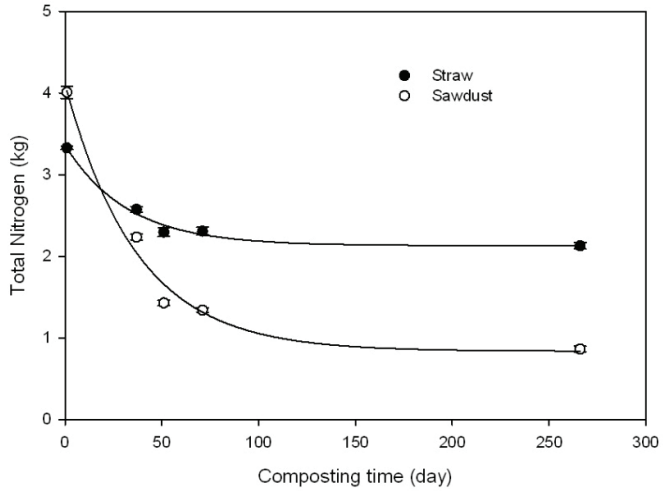

Figure 2.13 Change in total nitrogen in dry mass in each treatment
(Standard errors were shown in error bars)

The change in C:N of the two treatments were different (Figure 2.14) and the actual, initial C:N for both treatments were different from the calculated recipe. The straw treatment started at a ratio of 36:1 and decreased continuously after the first turning to reach to a ratio of 26:1 by day 266. The actual initial C:N of the straw

treatment was probably higher than the recipe due to a higher carbon content in the SRM compared to the literature value used in the study. The sawdust treatment had a lower actual initial C:N of 25:1. This is due to the 90 kg of sawdust used as cap which was originally withheld from the initial mix and only added after the first turning, this reduced the carbon content of the initial mixture affecting the starting C:N ratio. The C:N of the sawdust treatment was increased during the composting process, ending at 35:1. This is because proportionately more nitrogen was lost from the sawdust than carbon as vigorous NH_3 volatilization. The increase of C:N value had also been reported by Morisaki et al. (1989) and Tiquia et al. (2000) during composting process as well.

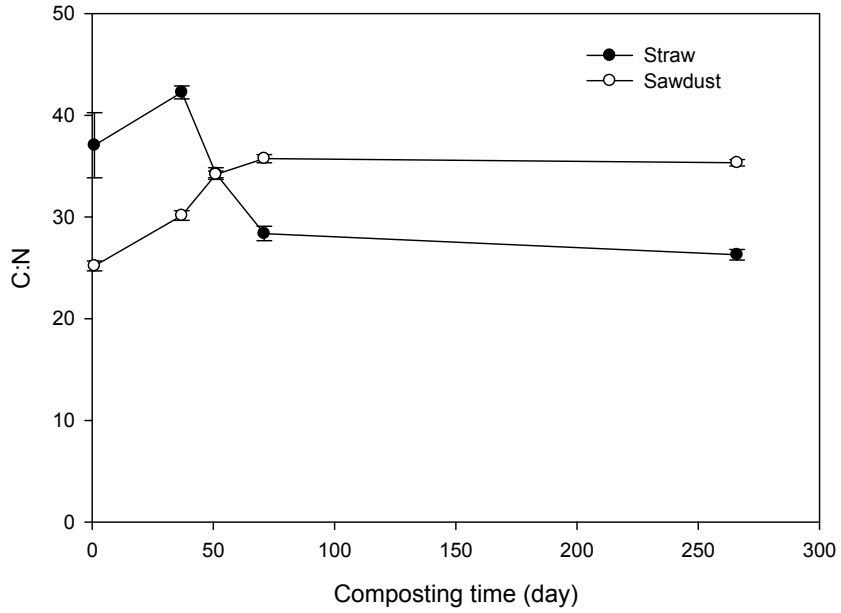

Figure 2.14 Changes in C:N during the composting process in each treatment (Standard errors were shown in error bars)

2.3.5 Maturity Test

The maturity tests indicated that the averaged daily release of CO_2-C in the straw and sawdust compost: 0.199 and 0.167 mg CO_2-C g^{-1} organic matter d^{-1} over a 5-day incubation period, which meets the CCME guidelines for mature compost (CCME, 2005). The values of produced CO_2-C for both treatments were possibly lower than expected since a 75% moisture content of the incubation sample may have suppressed aerobic activity. However, the production of methane during the incubation period was low, which may indicate aerobic conditions.

2.4 Conclusions

The temperature for both treatments met the CCME pathogen control guideline and significant temperature increases were detected in both treatments shortly after mixing. The straw treatment had a similar reduction in total mass, as well as total carbon, compared to the sawdust treatment. A lower reduction in total nitrogen was observed in the straw treatment, indicating less nitrogen losses. The maturity test showed the CO_2-C in the compost was less than 1 mg CO_2-C g^{-1} organic matter day^{-1} by day 266, which was under the CCME regulation. Straw performed as well as sawdust as a carbon source in SRM composting.

Chapter Three: Comparison of Straw and Three Agricultural Wastes for Composting Specified Risk Materials (SRM)

3.1 Introduction

In order to eliminate the potential for cross-contamination of BSE in Canada, the CFIA has issued the enhanced feed ban regulations to completely remove SRM from animal feed, pet food and fertilizer. Based on this regulation, SRM must be fully contained or destroyed following methods approved by the CFIA including: high temperature incineration (T>850˚C), alkaline hydrolysis, thermal hydrolysis, rendering, landfilling, and composting (CFIA, 2007).

In Nova Scotia, an estimated 2700 tonnes of mixed animal slaughter waste containing SRM is produced annually. As a result of environmental legislation, as well as economic concerns, composting has been identified as a suitable method of SRM containment in NS. Composting of SRM is an ideal option for livestock producers and abattoir facilities to convert raw organic matter into a more uniform and easily transportable end product, which may have some potential use as a soil amendment or landfill cap material. Composting is a process of using microorganisms to biologically decompose animal carcasses. Composting is a waste management technique requiring oxygen and water mediated by microbial activity to generate thermophilic temperatures aimed at degrading organic materials (Haug, 1993; Morse, 2001; Keener and Elwell, 2003; Kalbasi et al., 2005). During the process, bacteria, fungi and other microorganisms consume oxygen and nutrients to break down organic material into a stable mixture called compost, while also releasing water, heat and carbon dioxide (Keener et al., 2000). Advantages of composting SRM include mitigating biosecurity concerns as the hazardous materials can be well-contained and the risk of spread of the prion protein is reduced.

One of the most important factors affecting the composting process is the carbon source. It is a major source of energy for microorganisms and almost 50% of the microorganism's cells consist of carbon (Pare et al., 1998; Tiquia et al., 2002). During the composting process, a balance of carbon and nitrogen is necessary to promote microbial activity. This balance of carbon to nitrogen in organic residuals, the C:N, reflects the ratio of the weight of total carbon to that of total nitrogen. Normally, a C:N between 25:1 and 30:1 is considered to be satisfactory for a final compost (Rynk, 1992; Keener et al., 2000; Kalbasi et al., 2005). Since SRM is a nitrogen-rich material, additional carbon sources become necessary to adjust the C:N value of the compost. A variety of materials can be used as carbon sources, including wood chips, sawdust, straw, and corn stalks, which all have high C:N (Michel et al., 2000; Morse, 2001). However, some of these carbon sources are agricultural residues and can be more worthwhile to use in other agricultural production, for example, animal feeds and beddings. Agriculture waste, such as horse bedding and SRM compost may be another carbon source option.

In this study, SRM was composted with four different carbon sources, including agricultural residue (wheat straw) and agriculture waste (horse bedding, SRM compost, and sheep manure). The objectives of this portion of the study were to:

1. Compare the decomposition dynamics of an agricultural residue (straw) and agricultural wastes (bedding, manure and SRM compost) during the composting of SRM
2. Measure and evaluate changes in chemical, biological, and physical parameters during the composting process.

3.2 Materials and Methods

3.2.1 Research Site

The study began on July 29, 2009 and finished on June 17, 2010. Sixteen roofed compost bins with three sidewalls constructed on a concrete base, measuring 4 m × 2.4 m × 3 m, were set up at BEEC, Bible Hill, N.S., Canada (45°23' N, 63°14' W).

3.2.2 Original Materials

Hay and sheep manure were acquired from the NSAC farm and fresh wheat straw and fresh horse bedding were bought from a local farm to be incorporated in the SRM compost recipe. SRM was obtained from an abattoir in Brookside, NS, and the NS Pathology Laboratory, Truro, NS. SRM compost was obtained from the straw composting pile conducted in 2008.

3.2.3 Recipe Preparation

The moisture content of the straw, horse bedding, sheep manure and SRM compost and hay was measured before the experiment. Samples of the original material were weighed fresh and dried at 70^{o}C for 48 hours to calculate the moisture content. Total carbon and nitrogen of straw, and hay was measured using a LECO 2000 CN analyzer (LECO Corporation, St. Joseph, MI). Moisture content and chemical parameters of slaughterhouse wastes were obtained from the literature (Rynk, 1992). The chemical characteristics of the raw composting materials are listed in Table 3.1. Recipes (Tables 3.2, 3.3, 3.4 and 3.5) were developed to calculate a target C:N of 30 and a moisture content of 60% for each replication (Rynk, 1992).

Calculation for moisture content

$$Moisture\ content = \frac{weight\ of\ water\ in\ sample\ a + weight\ of\ water\ in\ sample\ b + weight\ of\ water\ in\ sample\ c}{total\ weight\ of\ all\ ingredient}$$
$$= \frac{(a \times m_a) + (b \times m_b) + (c \times m_c)}{a + b + c}$$

a : total weight (wet basis) of sample a
b : total weight (wet basis) of sample b
c : total weight (wet basis) of sample b
m_a : moisture content of sample a
m_b : moisture content of sample b
m_c moisture content of sample c

Calculation for C:N

$$C:N = \frac{weight\ of\ C\ in\ sample\ a + weight\ of\ C\ in\ sample\ b + weight\ of\ C\ in\ sample\ c}{weight\ of\ N\ in\ sample\ a + weight\ of\ N\ in\ sample\ b + weight\ of\ N\ in\ sample\ c}$$
$$= \frac{[\%C_a \times a \times (1 - m_a)] + [\%C_b \times b \times (1 - m_b)] + [\%C_c \times c \times (1 - m_c)]}{[\%N_a \times a \times (1 - m_a)] + [\%N_b \times b \times (1 - m_b)] + [\%N_c \times c \times (1 - m_c)]}$$

a : total weight (wet basis) of sample a
b : total weight (wet basis) of sample b
c : total weight (wet basis) of sample b
m_a : moisture content of sample a
m_b : moisture content of sample b
m_c : moisture content of sample c
$\%N_a a$: nitrogen content of sample a
$\%N_b$: nitrogen content of sample b
$\%N_c$: nitrogen content of sample c
$\%C_a$: carbon content of sample a
$\%C_b$: carbon content of sample b
$\%C_c$: carbon content of sample c

Table 3.1 Chemical characteristics of raw composting materials

Ingredient	Moisture (%)	%C (DW[a])	%N (DW)
Straw	37	45	0.4
Hay	39	42	2.1
Horse Bedding	46	43	0.71
Sheep Manure	68	32	1.22
SRM compost	71	38	1.48
SRM[b]	70	15	3

a: Dry Weight
b: estimated values for carcasses (Rynk, 1992)

Table 3.2 Recipe of the Straw:SRM treatment (ST)

Target Moisture Content: 60%
Target C:N: 30:1

Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Straw	37	63	45	0.4	112	340
SRM[e]	70	30	15	3	5	227
Hay	39	61	42	2.1	20	57
						624

Recipe Moisture Content: 49%
Recipe C:N: 33.43:1
Additional Water Required to Reach 60% (kg): 168.6

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

Table 3.3 Recipe of Horse Bedding: SRM treatment (HB)

Target Moisture Content: 60%
Target C:N: 30:1

Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Horse Bedding	46	54	43	0.71	61	272
SRM[e]	70	30	15	3	5	136
						408

Recipe Moisture Content: 54%
Recipe C:N: 30.56:1
Additional Water Required to Reach 60% (kg): 61.4

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

Table 3.4 Recipe of Horse Bedding/Sheep Manure:SRM treatment (HBSM)

Target Moisture Content: 60%
Target C:N: 30:1

Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Horse Bedding	46	54	43	0.71	61	136
SRM[e]	70	30	15	3	5	136
Sheep Manure	68	32	32	1.22	26	136
						408

Recipe Moisture Content: 61%
Recipe C:N: 22.62:1
Additional Water Required to Reach 60% (kg): 0

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

Table 3.5 Recipe of Horse Bedding/SRM Compost: SRM treatment (HBSRMC)

Target Moisture Content: 60%
Target C:N: 30:1

Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Horse Bedding	46	54	43	0.71	61	136
SRM[e]	70	30	15	3	5	136
SRM Compost	71	29	38	1.48	26	136
						408

Recipe Moisture Content: 62%
Recipe C:N: 22.68:1
Additional Water Required to Reach 60% (kg): 0

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

3.2.4 Experimental Design

The study consisted of a completely randomized design with four treatments (fresh wheat straw, horse bedding, horse bedding/sheep manure, and horse bedding/SRM compost). Each treatment had four replications. The composting materials for each replicate were weighed, ground and mixed by a Supreme Enviro Processor 400 compost grinder attached with a scale and randomly assigned a compost bin. Four samples were collected randomly from different locations in each pile, resulting in a 9 kg mass loss in each pile. For each replicate, the carbon source was first added to the grinder to be fully ground, followed by the loading of SRM. The SRM was chopped into large pieces and delivered in barrels (Figure 2.2). Selective SRM pieces were assigned to each treatment to make sure each pile contained equal and similar SRM. Water was added to the initial mixture to obtain a moisture content of 60%. In order to reduce odours and vector migration, a layer of sawdust over the top of a horticultural shade cloth was used as a biofilter cap once the compost was loaded into the bin.

3.2.5 Monitoring and Sampling

The compost treatments were turned on days 42, 78, 110 and 286 after initiation of the study to provide aeration and mixing. The turning date was determined when the temperature in the pile fell to close to ambient conditions. The total weight of each pile was measured at the beginning of the study and at every turning, as well as at the end of the study. The entire compost pile for each replicate was loaded into the Supreme Enviro Processor 400 and weighed by a scale attached to the grinder. A mass reduction of each compost treatment was calculated as the difference between the original mass and the mass at each sampling time. The temperature of each pile was

measured at regular intervals using thermocouples linked to a Campbell Scientific CR23X datalogger with an AMT25 multiplexer on a weekly basis. A single probe containing three thermocouples placed at one, two and three foot depths were inserted into each pile to measure the top, center and bottom temperatures of the pile. In total, 48 thermocouples were used. Temperature data was collected every 15 minutes.

Samples collected from each period were stored at -10°C until they were prepared for total carbon and total nitrogen, moisture content, pH and electrical conductivity (EC) analysis. Electrical conductivity and pH were measured as an aqueous extract. This aqueous extract was obtained by following the method outlined in the TMECC (USDA and CCREF, 2002[1]; USDA and CCREF, 2002[2]). A 10 g fresh compost sample was mechanically shaken with deionized water at a solid to water ratio of 1:10 (w/v) for 20 min at room temperature. The suspension was filtered and the liquid was measured for pH and EC using an Accumet XL50 dual channel pH/Ion/Conductivity meter.

A maturity test was conducted in June 2010 using samples collected on day 286 of the study. The compost respirometry test from TMECC was used (USDA and CCREF, 2002[3]). Two 25 g as-received moist compost subsamples from each bin were collected and a total of 34 1 L Mason jars were used (32 for the samples, 2 for the blank). The TMECC method recommends adjusting the moisture content to a water holding capacity of 70 to 80%. However, during the preparation of the sample, the moisture content was adjusted in error to 75%. The samples were pre-incubated at room temperature (approximately 25°C) for 48 hours to allow the microorganisms in the compost to adapt. After the pre-incubation, the samples were transferred to the Mason jars and incubated in an environmentally controlled chamber at 32°C for 5 days. Carbon dioxide evolution was measured by extracting 20 mL of headspace air

each day at the same time after which the headspace was purged and the jar resealed.

The content of organic matter was measured based on the loss on ignition method from TMECC (USDA and CCREF, 2001). Thirty two (2 subsamples for each pile) 10 g compost samples were oven-dried at 70 over 48 hours until a constant sample weigh was achieved. The samples were then placed in a muffle furnace. The temperature of furnace was slowly ramped to 550°C and the samples were combusted at 550°C for 2 h. After that, the temperature of furnace was slowly ramped down to approximately 200°C. The ashed samples were then removed from the furnace and transferred to desiccators to cool to ambient laboratory temperature. The content of organic matter was then calculated based on the weight of dry sample and ash.

The compost was tested for maturity based on CCME guidelines requiring the CO_2-C respiration of the mature compost to be less than 4 mg/g organic matter/day (CCME, 2005).

3.2.6 Statistical Analysis

Data in this study were tested for normality of data distribution and constant variance using Minitab v15. Independence was assumed through randomization of treatments. After assumptions were validated, analysis of variance (ANOVA) was used to test the significance within the treatment for initial and final pH and EC mean values using Minitab v15. Least Squares Means (LSmeans) method was conducted using Proc Mixed in SAS 9.2 for means comparison if a significant difference was found. Nonlinear regression analysis was conducted using 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 (SAS Institute Inc. 2008). A $p<0.05$ probability level of significance was tested for all the data analysis in this study.

3.3 Results and Discussion

3.3.1 Temperature Profile

Figure 3.1, 3.2, 3.3 and 3.4 show the temperature profile of the 4 treatments. The data was averaged over four replications to show the temperature at three depths for each treatment. The trends of temperature at three depths were similar in each treatment. Discussion focused on the center temperature, which was considered to be less affected by the ambient temperature (Figure 3.5).

The temperature increased quickly at the beginning of the composting process and reached 55°C within 5 days for all treatments, meeting the CCME guidelines for pathogen kill attaining a temperature of 55°C or greater for at least 15 days for windrow composting (CCME, 2005). This temperature stayed at this level for approximately 20 days before declining in the ST while the other three treatments maintained a temperature between 55 to 60°C for 36 days. These differences may be explained by the large composition of sawdust in the horse bedding substrate which had a small particle size and held the heat generated by microbial activity.

After the first turning period (day 42), significant temperature increases were recorded in most of the treatments. Temperatures increased rapidly to 55°C, with the exception being the HB. However, after the second and third turning periods, only the ST treatment had a significant temperature increase, likely the result of less available carbon in the three other treatments. Despite the fact that temperatures in the ST treatment increased quickly over a short term, they dropped quickly after the available carbon sources were consumed.

During the winter period, the thermocouples were removed due to the low ambient temperature. The treatments were turned again in early spring, day 266. However, no temperature increases above ambient were observed.

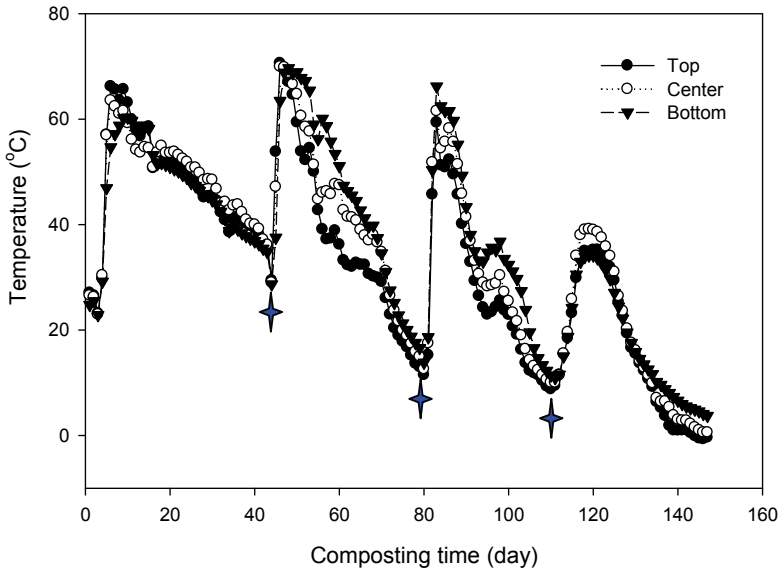

Figure 3.1 Daily change of temperature in ST at three depths before the winter period. (✦ Turning point)

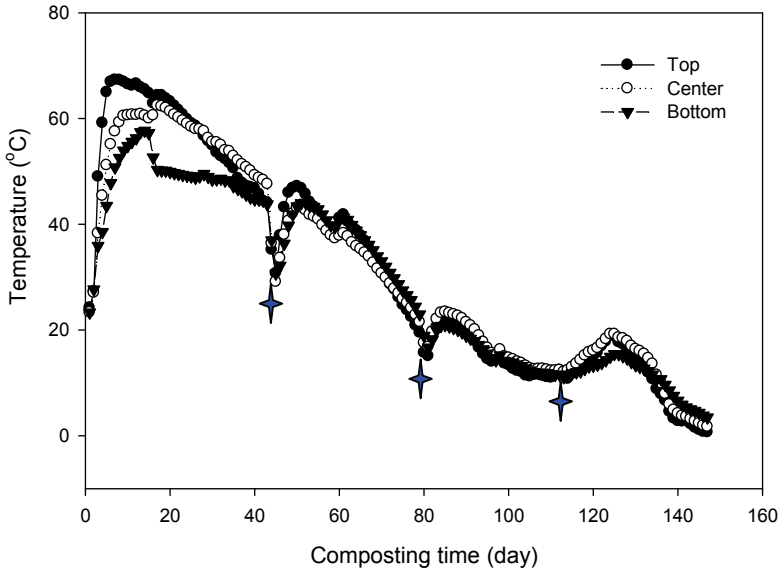

Figure 3.2 Daily change of temperature in HB at three depths before the winter period. (✦ Turning point)

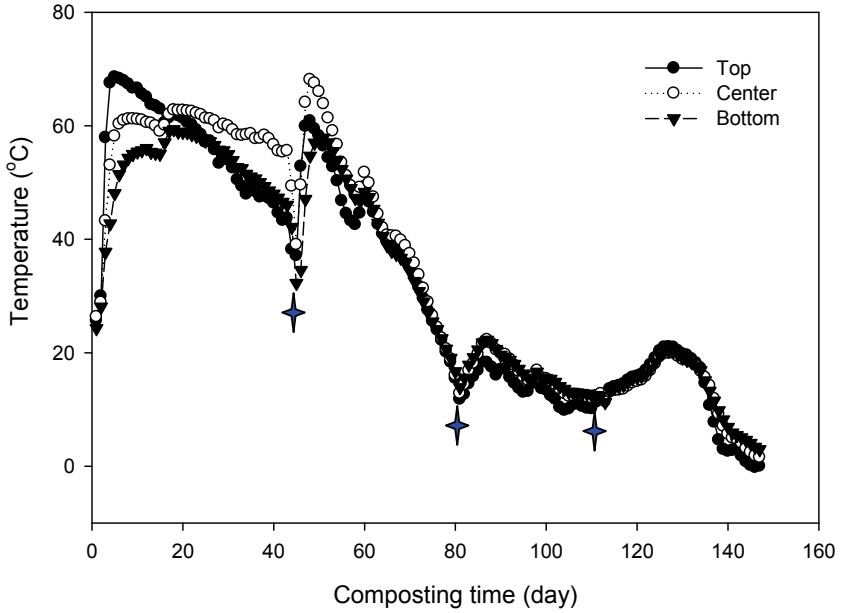

Figure 3.3 Daily change of temperature in HBSM at three depths before the winter period. (✦ Turning point)

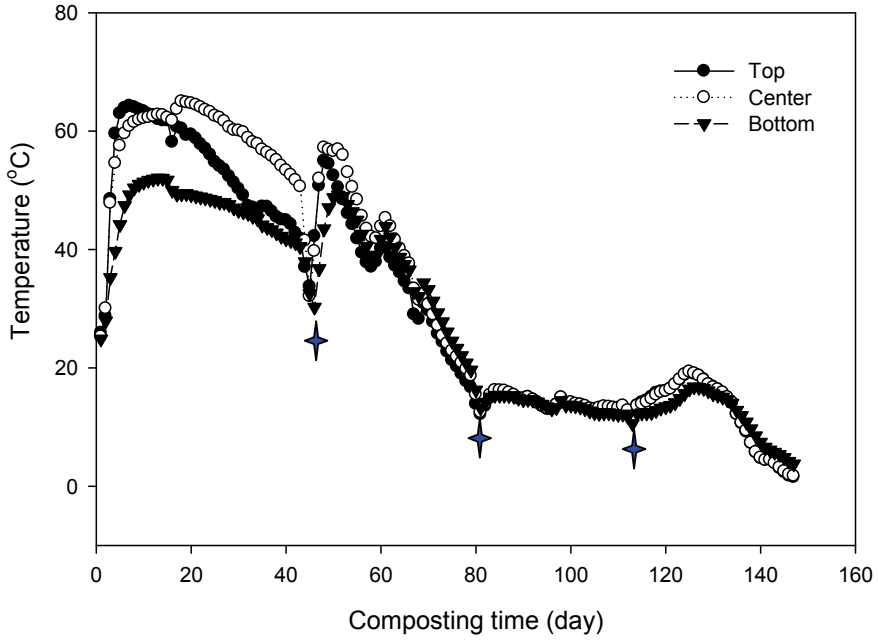

Figure 3.4 Daily change of temperature in HBSRMC at three depths before the winter period. (✦ Turning point)

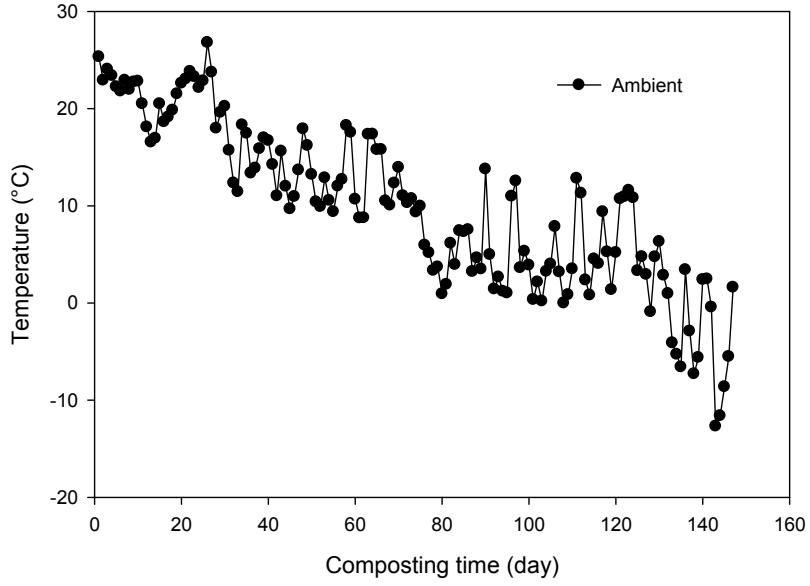

Figure 3.5 Daily change of ambient temperature before winter period.

3.3.2 pH and Electrical Conductivity

Figure 3.6 shows the changes in pH of each treatment over the composting period. pH data were averaged from four replications for each treatment. pH of HB and HBSM stayed at approximately 7 during the entire composting process while the value of HBSRMC remained between 6 and 7. A significant difference was found in ST between day 1 and day 286. The pH of ST started at 5.5 and increased to 6.5 at the end of the composting period. This can be explained by the high microbial activity that occurred due to a sufficient carbon source and the presence of water and oxygen, which increases the decomposition rate and raises the pH value (Sundberg and Jönsson, 2008; Petric et al., 2009). pH of all the treatments are within the optimum composting pH range of 6 to 8.

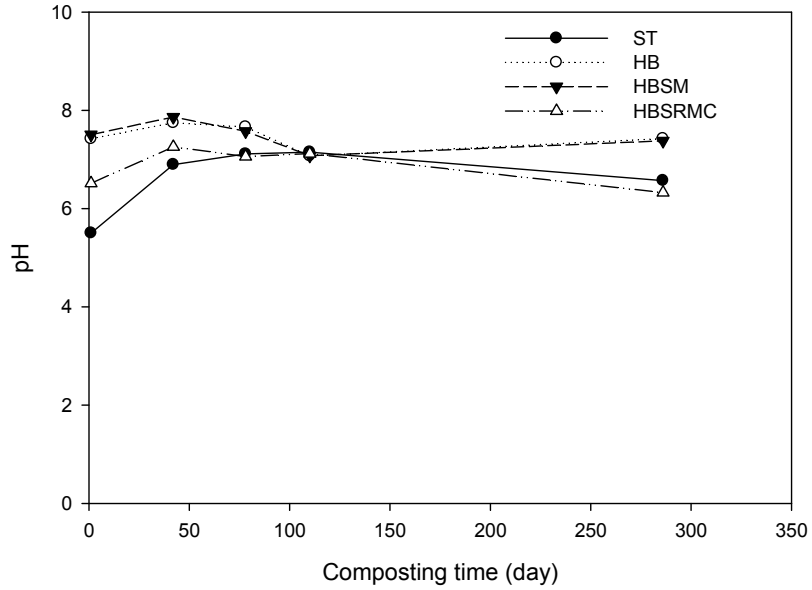

Figure 3.6 Changes in pH during the composting process for each treatment.

The electrical conductivity (EC) data is shown in Figure 3.7, which was averaged over four replications for each treatment. No difference was found in the EC within ST between day 1 and day 286, as well as HBSM. However, the EC of ST stayed at approximately 4 dS/m or lower at each sampling time while the value of HBSM increased to over 5 dS/m at day 42 and day 78 before falling below 5 dS/m during the latter stages of the study. This significant increase was also observed in HB, HBSM and HBSRMC by day 42. The reason for this may be the high original EC value in the horse bedding and sheep manure, as well as decomposition of the organic substances, which release mineral salts such as ammonium ions (Abid and Sayadi, 2006). The EC of the finished compost in most of the treatments (excepting HBSM) was less than 4 dS/m, which is considered appropriate for plant growth.

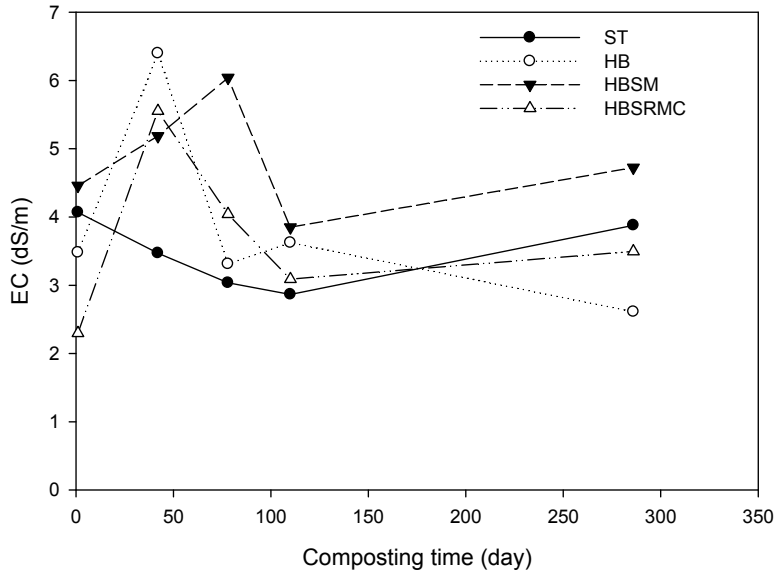

Figure 3.7 Changes in EC during the composting process for each treatment.

3.3.3 Mass Change and Moisture Content

During the turning process, the moisture content was estimate using a squeeze test before mixing and water was added to each compost pile to adjust the moisture content close to 60% Figure 3.8 shows the moisture contents of each treatment which were averaged over four replications. The actual initial mixtures only contained 40% to 50% moisture. This is likely due to the lower original moisture content in SRM compared to the recipe. The moisture level later on was a little bit higher than 60% as a result of additional water. This is caused by the inaccurate squeeze test before adding the water.

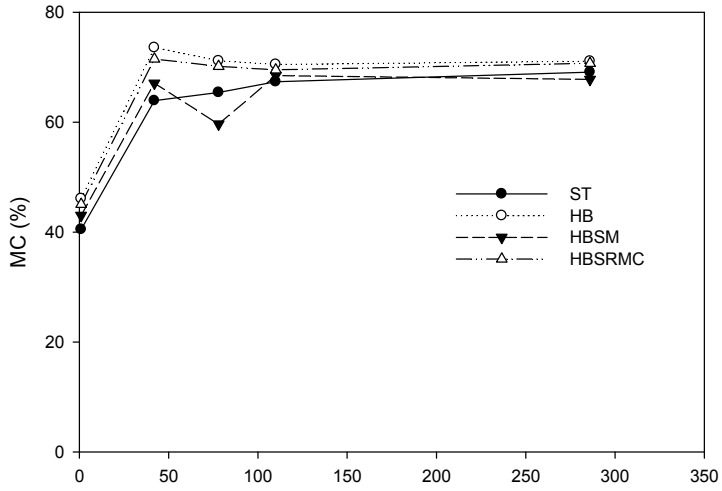

Figure 3.8 Moisture changes during composting for each treatment

Table 3.6 shows the mass change in all treatments in a dry weight basis over the study period and the percent mass reduction in the treatments between each turning period. The data was an average of four replications. Nine kilograms of samples were taken at each period from each replicate. This value had to be added to the total mass at each period. HB had the largest overall mass reduction, at approximately 61% over the study period. This was followed by HBSM and HBSRMC, which had mass reductions of 56% and 54%, respectively. ST had the lowest mass reduction at approximately 51%. In HB, HBSM and HBSRMC, a large reduction (42–49%) in dry mass occurred between days 1 and day 42, indicating a larger consumption of the organic matter by the microorganisms during this period. On the other hand, the most significant mass change in ST occurred between days 1 and 78, with a two–stage mass change of 26% and 30% over this period. The reason for the low mass reduction in ST in the first stage could be the unexpected low initial moisture content (40%). The insufficient moisture reduced the microorganisms' activity and slowed the degradation of the organic material. The reduction of ST increased to 30% after the

first turning (between day 42 and 78), while the reduction of the other three treatments decreased to 7%–18%. This can be due to more available carbon in ST during the turning process, as well as the additional water re-activating the microorganisms.

Over the winter period, a large reduction was observed in HBSRMC (10%) while in late spring 2010 HBSM had only a 1% reduction (day 286).

Table 3.6 Mass changes (dry basis) of each treatment over the study period.

	ST		HB		HBSM		HBSRMC	
Day	DW(kg)	RD %	DW (kg)	RD%	DW (kg)	RD%	DW (kg)	RD%
1	275	---	303	---	281	---	243	---
42	203	26	154	49	163	42	138	43
78	142	30	132	14	134	18	127	7
110	140	1	129	2	130	2	124	2
286	135	3	119	7	129	1	106	10
Total	---	51	---	61	---	54	---	56

DW: Dry Mass. RD: Reduction

3.3.4 Total Carbon and Total Nitrogen

The relationships described by the regression equations over the composting study were significant ($p<0.05$). The R^2, calculated by using the equation from Kvalseth (1985), $R^2 = \frac{sum\ of\ squares\ (error)}{sum\ of\ squares\ (total)}$ of each treatment suggests that the relationships are adequately described by the regression equation. The regression pattern does not cover all the points (average of each treatment from four replications) which may be caused by the variables of the original data.

During the composting process, the treatments with horse bedding exhibited similar carbon decomposition relationships (Figure 3.9). The regression relationship

of each treatment was significant ($p<0.05$).

ST: $TC=48.4042+77.4714* e^{(-0.0221*day)}$, $R^2=0.87$;

HB: $TC=44.3962+81.0393* e^{(-0.048*day)}$, $R^2=0.94$;

HBSM: $TC=44.9315+67.4420* e^{(-0.0482*day)}$, $R^2=0.93$;

HBSRMC: $TC=40.9326+71.5174* e^{(-0.0502*day)}$, $R^2=0.94$;

The regression relationships for HB, HBSM and HBSRMC followed the same trend. No differences were found among these three treatments. Significant degradation was observed by the first turning point (day 42). Approximately 50% of total carbon source was consumed. This is caused by the consumption of carbon by the microorganisms for their action and reproduction, which was nicely correlated to the high temperature observed during this period. After day 42, the degradation of these three treatments started to slow and was reduced to about 10% by day 78, then reached to a stable state. The reason for the low decomposition rate at day 78 can be attributed to a lack of available carbon sources in the mixtures. For the straw treatment, the degradation of carbon was rapid (28%) by the first turning period but not as great as the three horse bedding-based treatments (49.1%). The consumption of available carbon by microorganisms increased the temperature after the turning period.

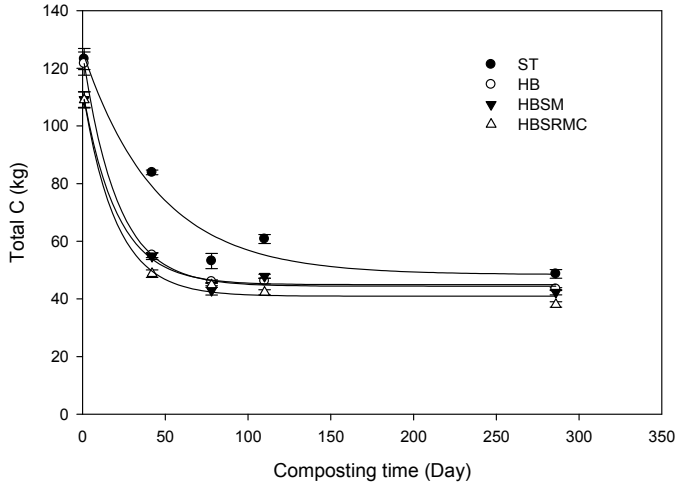

Figure 3.9 Change in total carbon during the composting period for each treatment (Standard errors were shown in error bars)

The total nitrogen data were shown as an average of four replicates (Figure 3.10). During composting, the change of total nitrogen of HB, HBSM and HBSRMC underwent similar patterns. A great loss of total nitrogen was found by the first turning point (day 42), from then on, the change of total nitrogen became small, reaching to a steady state. The regression relations of these three treatments are significant ($p<0.05$).

ST: TN=2.6, Not Significant (NS)

HB: $TN=1.8340+3.7004* e^{(-0.3836*day)}$, $R^2=0.79$;

HBSM: $TN=2.4071+4.8073* e^{(-0.6251*day)}$, $R^2=0.83$;

HBSRMC: $TN=1.9863+8.1287* e^{(-0.7028*day)}$, $R^2=0.86$;

The loss of total nitrogen in HB, HBSM and HBSRMC were between 20–70%. Nitrogen in HB decreased about 22% from day 1 to day 286 while HBSM decreased 50% and HBSRMC decreased 66%. The reason for the high nitrogen loss in HBSM

and HBSRMC can be due to the low initial C:N of these two mixtures. The properties of the initial material, in particular, the C:N can affect the degree of nitrogen loss, low initial C:N (<20:1) would contribute to losses of nitrogen through NH_3 volatilization (Bishop and Godfrey, 1983; Tiquia and Tam, 2000).

However, no significant difference was found in the change of total nitrogen in ST since the initial nitrogen content of ST was much lower than that of the other three treatments to begin with. A reason for this may be because the organic nitrogen in SRM was lost with the leachate. SRM for ST was held at the field for two days before mixing, maggots were found in the material due to the hot weather, which may have released the organic nitrogen and mix into the liquid. Only about 10% of total nitrogen loss was found at the end of composting (day 286).

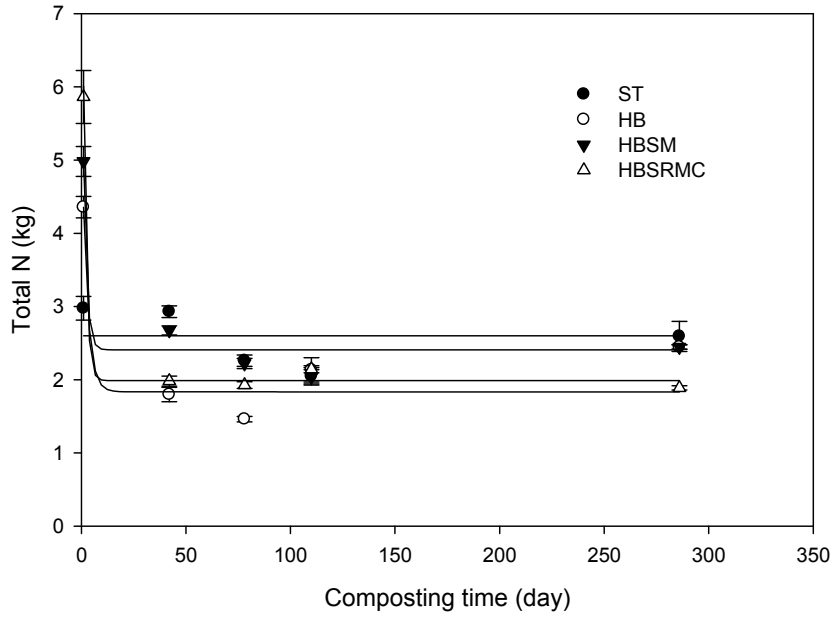

Figure 3.10 Change in total nitrogen during the composting period for each treatment (Standard errors were shown in error bars)

The change in C:N of the four treatments were different (Figure 3.11). ST had a initial C:N of 41:1 which may be due to a higher carbon content in the treatment than originally estimated. The value decreased continuously to reach a ratio of 18:1 at day 286, reflecting the reduction in total carbon. The initial C:N in HB, HBSM and HBSMRC were 27:1, 21:1 and 18:1, respectively, which were much closer to the recipe. The C:N of HB decreased slightly while no significant difference was found between the initial and final C:N within the HBSM, as well as HBSRMC. No significant difference was found in final C:N of the four treatments.

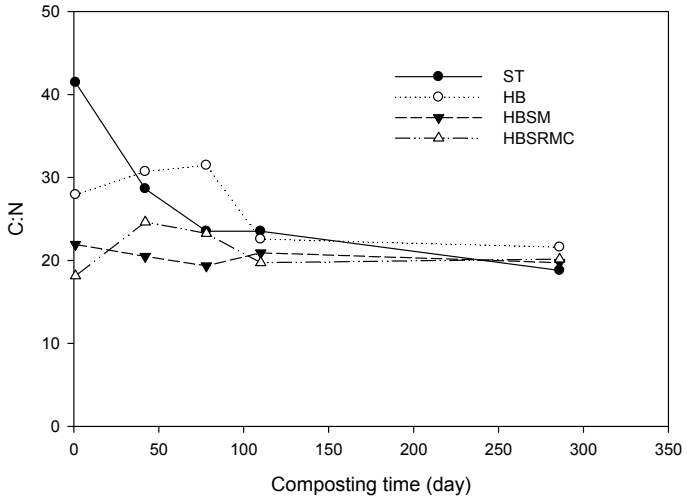

Figure 3.11 Change in C:N during the composting period for each treatment

3.3.5 Maturity Test

The maturity tests indicated that the averaged daily release of CO_2-C in ST, HB, HBSM and HBSRMC was 0.099, 0.127, 0.137 and 0.103 mg CO_2-C g^{-1} organic matter day^{-1}, respectively, which all meet the CCME guidelines for mature compost (CCME, 2005). A 75% moisture content of the incubation sample may have created anaerobic conditions; however, the production of methane during the incubation period was low, which may indicate aerobic conditions.

3.4 Conclusions

The temperature of all treatments met the CCME pathogen control guideline and significant temperature increases were detected in straw treatments shortly after mixing. All of the four treatments experienced similar mass reductions. Although ST showed a different pattern of total carbon and total nitrogen reduction from the other three treatments, the final products all reached a similar state. The maturity test showed the CO_2-C in the compost was less than 4 mg CO_2-C g^{-1} organic matter day^{-1} by day 286, which was under the CCME regulation. The results suggested that agricultural wastes such as horse bedding and compost can be used as a carbon source in the composting of SRM as agricultural residuals. Also, during composting, the change in temperature, total carbon and total nitrogen in HBSM and HBSRMC were observed to be similar. HBSRMC had a larger loss (19.11%) of dry mass during the winter and spring period, compared to HBSM. The final pH and EC of HBSM are higher than HBSRMC, which is due to the higher pH and EC of the original sheep manure.

Chapter Four: Seasonal Comparison of Composting Specified Risk Materials with Wheat Straw

4.1 Introduction

In Nova Scotia approximately 2700 tonnes of SRM is produced annually. Based on the current federal and provincial environmental legislation and safety regulations, as well as economic concerns, composting has been identified as a suitable method of SRM containment (NSEA, 2006; CFIA, 2007; CFIA, 2009). Although the finished product will still be considered SRM, composting is an ideal option for the livestock producers and abattoir facilities to convert raw organic matter into a more uniform and easily transportable end product, which may also have the potential to be used as a soil amendment.

Composting is a process of using microorganisms in the natural environment to biologically decompose the animal carcasses in the presence of oxygen and water. It is a special waste management technique with thermophilic temperatures ranging from 40 to 60˚C to support microbial activity (Haug, 1993; Morse, 2001; Keener and Elwell, 2003; Kalbasi et al., 2005; Sivakumar, et al., 2006). During the process, bacteria, fungi and other microorganisms (such as actinomycetes) consume oxygen and nutrients to break down organic materials into a stable mixture called compost, while also releasing water, carbon dioxide and heat (Keener et al., 2000). Temperature is an important factor to the composting process by affecting the microorganism's activity. Usually, an environment with a high temperature (>45˚C) is optimal for microorganisms to decompose the material rapidly (Nakasaki et al., 1985). In this study, SRM with hay were composted with wheat straw in mid summer and early fall to evaluate seasonal effects on the composting process.

4.2 Materials and Methods

4.2.1 Research Field

The study was set up at BEEC, Bible Hill, NS, Canada (45°23' N, 63°14' W).The fall treatment was commenced on September 24, 2008 and ended on July 28, 2009, while the summer treatment was from July 29, 2009 to June 17, 2010. Four roofed compost bins with three sidewalls constructed on a concrete base, measuring 4 m × 2.4 m × 3 m, were used for each trail.

4.2.2 Compost Materials

The fresh wheat straw was purchased from a NS farm. Hay was donated by the NSAC farm and was incorporated into the SRM compost recipe. The SRM was provided by a local abattoir from Brookside, NS, and the NS Pathology Laboratory, Truro, NS.

4.2.3 Experimental Design

The study was set up as a completely randomized design. Each treatment had four replicates. Each replicate was randomly assigned a compost bin and samples were collected randomly from different locations in each pile. Since the SRM was chopped into large pieces and delivered in barrels, selective samples of SRM were assigned to each bin to make sure each pile contained an equal and varied feedstocks. A Supreme Enviro Processor 400 compost grinder attached with a scale was used to weigh, grind and mix the composting materials. Wheat straw and hay were first added into the grinder to be fully ground, followed by the SRM. The moisture content was adjusted to 60% by adding water. For the fall treatment, 90 kg of straw was taken from each replicate to use as a biofilter cap, then the cap was mixed into the compost pile during

the first turning period. A layer of sawdust over the top of a horticultural shade cloth was used as a biofilter cap in the summer treatment. The piles begun in the fall were turned on days 37, 51, 71 and 266 while the summer piles were turned on days 42, 78, 110 and 286, both of which were based on when the compost pile temperature approached the ambient temperature.

4.2.4 SRM Compost Recipe Preparation

The moisture content of the straw and hay was measured before the experiment. Samples were weighed fresh and dried at 70˚C for 48 hours until a constant weight was achieved, the moisture content was calculated based on the difference between the weight of fresh and dry sample. The carbon and nitrogen level of straw and hay was measured using a LECO 2000 CN analyzer (LECO Corporation, St. Joseph, MI). Moisture of slaughterhouse wastes and the total carbon and total nitrogen level of the slaughterhouse waste was obtained from the literature (Rynk, 1992). The chemical characteristics of the raw composting materials are listed in Table 4.1. A recipe (Table 4.2) was developed to obtain a final C:N of 30 and a moisture content of 60% (Rynk, 1992).

Calculation for moisture content

$$Moisture\ content = \frac{weight\ of\ water\ in\ sample\ a + weight\ of\ water\ in\ sample\ b + weight\ of\ water\ in\ sample\ c}{total\ weight\ of\ all\ ingredient}$$

$$= \frac{(a \times m_a) + (b \times m_b) + (c \times m_c)}{a + b + c}$$

a : total weight (wet basis) of sample a
b : total weight (wet basis) of sample b
c : total weight (wet basis) of sample b
m_a : moisture content of sample a
m_b : moisture content of sample b
m_c moisture content of sample c

Calculation for C:N

$$C:N = \frac{weight\ of\ C\ in\ sample\ a + weight\ of\ C\ in\ sample\ b + weight\ of\ C\ in\ sample\ c}{weight\ of\ N\ in\ sample\ a + weight\ of\ N\ in\ sample\ b + weight\ of\ N\ in\ sample\ c}$$
$$= \frac{[\%C_a \times a \times (1-m_a)] + [\%C_b \times b \times (1-m_b)] + [\%C_c \times c \times (1-m_c)]}{[\%N_a \times a \times (1-m_a)] + [\%N_b \times b \times (1-m_b)] + [\%N_c \times c \times (1-m_c)]}$$

a : total weight (wet basis) of sample a
b : total weight (wet basis) of sample b
c : total weight (wet basis) of sample b
m_a : moisture content of sample a
m_b : moisture content of sample b
m_c : moisture content of sample c
$\%N_a a$: nitrogen content of sample a
$\%N_b$: nitrogen content of sample b
$\%N_c$: nitrogen content of sample c
$\%C_a$: carbon content of sample a
$\%C_b$: carbon content of sample b
$\%C_c$: carbon content of sample c

Table 4.1 Chemical characteristics of raw composting materials

Ingredient	Moisture (%)	%C (DW[a])	%N (DW)
Straw	37	45	0.4
Hay	39	42	2.1
SRM[b]	70	15	3

a: Dry Weight
b: estimated values for carcasses (Rynk, 1992)

Table 4.2 Recipe of the Straw:SRM treatment

Target Moisture Content: 60%
Target C:N: 30:1

Ingredient	MC[a] (%)	TS[b] (%)	%C (DW[c])	%N (DW)	C:N (DW)	WM[d] (kg)
Straw	37	63	45	0.4	112	340
SRM[e]	70	30	15	3	5	227
Hay	39	61	42	2.1	20	57
						624

Recipe Moisture Content: 49%
Recipe C:N: 33.43:1
Water needed (kg): 168.6

a: Moisture Content
b: Total Solids
c: Dry Weight
d: Wet Mass
e: estimated values for carcasses (Rynk, 1992)

4.2.5 Monitoring and Sampling

A single probe containing three thermocouples at one, two and three foot depths was inserted into each pile to measure temperature at one, two and three foot depths from the top of the composting pile, reflecting top, center and bottom temperatures of the pile, respectively. These thermocouples were linked to a Campbell Scientific CR23X datalogger with an AMT25 multiplexer to collect the temperature every 15 minutes. The total weight of each pile was measured at the beginning of the study and at every turning, as well as at the end of the study. The overall compost pile was loaded into the Supreme Enviro Processor 400 and weighed by a scale attached to the grinder. The mass reduction of each compost pile was calculated as the difference between the original mass and the mass at each sampling time.

Samples (12 for the fall treatment and 4 for the summer treatment) were collected from random spots in each pile during each mixing period and frozen at a temperature of -10°C for measurement of total carbon and total nitrogen, moisture content, pH and electrical conductivity (EC). EC and pH were measured as an aqueous extract. This aqueous extract was obtained by following a method published by the TMECC (USDA and CCREF, 2002[1]; USDA and CCREF, 2002[2]). A 10 g fresh compost sample was mechanically shaken with deionized water at a solid to water ratio of 1:10 (w/v) for 20 minutes at room temperature. The suspension was filtered and the liquid was measured for pH and EC using an Accumet XL50 dual channel pH/Ion/Conductivity meter.

A maturity test was conducted for each treatment based on the compost respirometry test from TMECC (USDA and CCREF, 2002[3]). Twenty-five grams of as-received moist compost subsamples (3 for the fall treatment, 2 for the summer treatment) from each bin were collected and 1-L Mason jars were used. The TMECC

method recommends adjusting the moisture content to 70 to 80% of the water holding capacity to maintain the sample in an unsaturated state. However, during the preparation of the sample, the moisture content was adjusted in error to 75%, well above the moisture content. The samples were pre-incubated at room temperature (around 25°C) for 48 hours to allow microorganisms in the compost to adapt to the mesophilic environment. After the pre-incubation, the samples were transferred to the Mason jars and incubated at 32°C for 5 days. Carbon dioxide evolution was measured by extracting 20 mL of headspace air each day at the same time. 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.

The organic matter was measured based on the loss on ignition method from TMECC (USDA and CCREF, 2001). Twelve (3 replications for each pile) 10 g compost samples from each treatment were oven dried at 70^{o}C over 48 hours until a constant sample weight was achieved. The samples were then placed in a muffle furnace. The temperature of the furnace was slowly ramped to 550°C and the samples were combusted at 550°C for 2 h. After that, the temperature of the furnace was slowly ramped down to approximately 200°C. The ashed samples were then removed from the furnace and transferred to desiccators to cool to ambient laboratory temperature. The content of organic matter was then calculated based on the weight of dry sample and ash.

The compost was tested for maturity based on CCME guidelines requiring the CO_2-C respiration of the mature compost to be less than 4 mg/g organic matter/day (CCME, 2005).

4.2.6 Statistical Analysis

Data in this study were tested for normality of data distribution and constant variance using Minitab v15. Independence was assumed through randomization of treatments. After assumptions were validated, analysis of variance (ANOVA) was used to test the significance within the treatment for initial and final pH and EC mean values using Minitab v15. Least Squares Means (LSmeans) method was conducted using Proc Mixed in SAS 9.2 for means comparison if a significant difference was found. Nonlinear regression analysis was conducted using 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 (SAS Institute Inc. 2008). A $p<0.05$ probability level of significance was tested for all the data analysis in this study.

4.3 Results and Discussions

4.3.1 Temperature Profile

Figure 4.1 and Figure 4.2 are temperature profile of the two treatments. The data was averaged over four replications to show the temperature at three depths for each treatment. The trends of temperature at three depths were similar in both treatments. Discussion focused on the center temperature, which was considered to be less affected by the ambient temperature (Figure 4.3).

The overall temperature trends of the two different periods of straw treatments are similar. The temperatures from three depths were averaged to a daily temperature for each pile. The temperatures increased quickly at the beginning of the composting period, and were sustained over 55°C for about 20 days before starting to decrease. However, the temperature of the fall treatment stayed at >40°C for 30 days while that

of the summer treatment stayed for 35 days, indicating a longer thermophilic phase (T>40°C), which is a major period of organic material decomposition (Tang et al., 2007).

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 the available carbon sources were consumed. Longer thermophilic phases were detected in the summer treatment after the first turning period, temperatures in the summer treatment increased to over 40°C for 20 days while the fall treatment only remained over 40°C for 12 days. After the second turning period, both treatments re-heated and held the thermophilic phase for 10 days. The average ambient temperatures during the composting period for the summer treatment (August to October) ranged from 20 to30°C, which was about 15 to 20°C higher than the fall treatment (September to November). This is likely the reason for a prolonged thermophilic phase during the summer treatment composting period (Sivakumar et al., 2007). Only the fall treatment reached a thermophilic phase again after the third turning while the summer treatment began its curing phase.

After the winter period, the composting piles were turned again for both treatments. The fall treatment showed a temperature increase but did not reach the thermophilic phase. The temperature of the summer treatment stayed close to the ambient temperature, indicating that both treatments reached the curing phase.

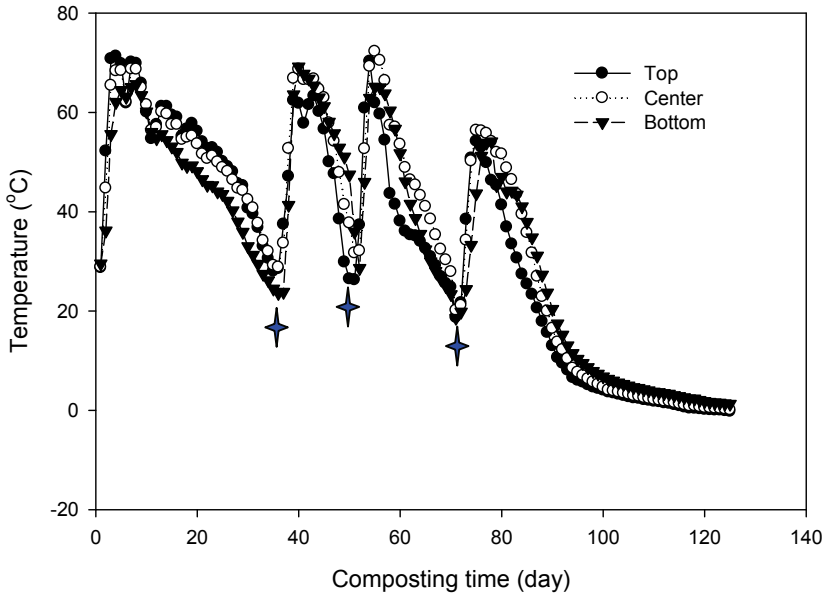

Figure 4.1 Daily change of temperature in the fall treatment at three depths before the winter period. (✦ Turning point)

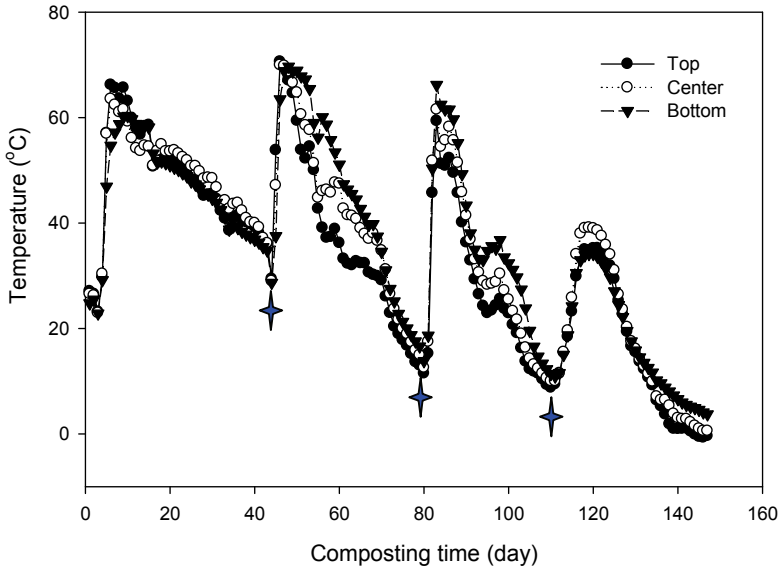

Figure 4.2 Daily change of temperature in the summer treatment at three depths before the winter period. (✦ Turning point)

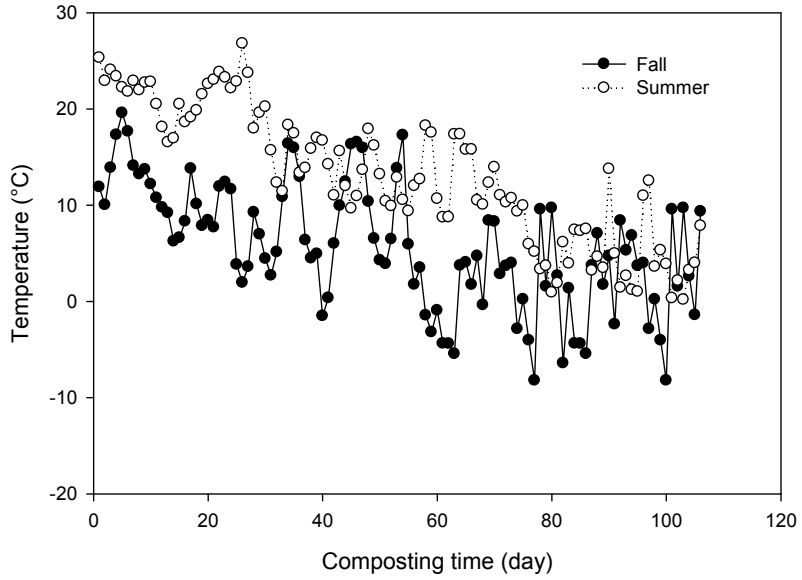

Figure 4.3 Daily change of ambient temperature before winter period of both treatments

4.3.2 Mass Reduction and Moisture Control

Table 4.3 shows the reduction of dry mass in both treatments over the study period. For the fall treatment, 90 kg of straw was taken from each replicate to be used as a biofilter cap and mixed with the compost on day 37. The summer treatment (51%) had a larger total dry mass reduction rate than the fall treatment (41%). A large reduction (26–30%) in dry mass was observed in summer in the first two months, indicating a major decomposition period with a high consumption of the organic matter by the microorganisms and a heavy loss of moisture. The mass change was small after the second turning period. For the fall treatment, the mass reduction appeared to be more consistent. Significant mass reductions were found at each turning period and ranged from 9 to 16%, showing a longer period of active composting.

Table 4.3 Changes in total mass (dry basis) of the two treatments

Sampling time	Fall		Summer	
	DW (kg)	RD %	DW (kg)	RD%
1	309	---	275	---
2	252 (342*)	18	203	26
3	288	16	142	30
4	256	11	140	1
5	236	9	135	3
Total	---	41	---	51

* 90 kg of straw had been added to each pile

During the turning process, a squeeze test was used to estimate the moisture content before mixing and water was added to each compost pile to adjust the moisture content close to 60% based on the estimated moisture content. Figure 4.4 shows the moisture content of both treatments which were averaged over four replications. The moisture content did not stay at 60% during the process, which could be due to the inaccurate estimate of moisture content before mixing. For the summer treatment, initial mixtures only contained 40% moisture. This is likely due to the lower original moisture content in the raw material compared to the recipe.

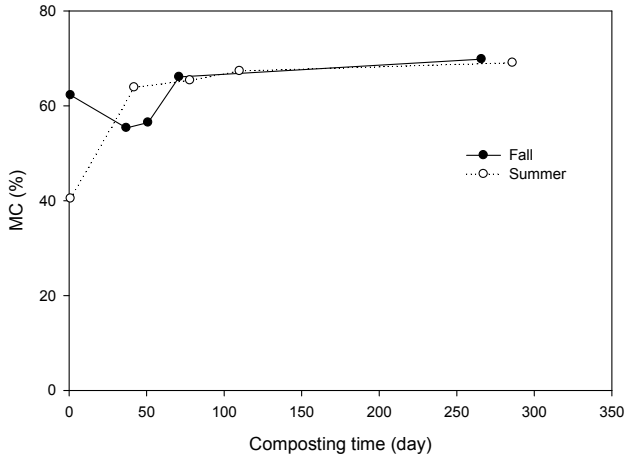

Figure 4.4 Moisture content of both treatments

4.3.3 pH and EC

The pH and EC data are shown in Figures 4.5 and 4.6. The data were averaged from four replications for each treatment. The pH of both treatments increased at the beginning of the composting process to an alkaline state. This is likely due to the high microbial activity and fast decomposition rate which raises the pH value (Sundberg and Jönsson, 2008). Significant differences were found between two treatments over time ($p<0.05$). Significant differences were found in EC between the two treatments ($p<0.05$). The summer treatment reached a higher EC (3~4 dS/m) value than the fall treatment (2~3 dS/m) over time. However, the EC value of both treatments was less than 4 dS/m, which is considered appropriate for use for plant growth (Abid and Sayadi, 2006). No significant difference was found between the initial and final samples within each treatment.

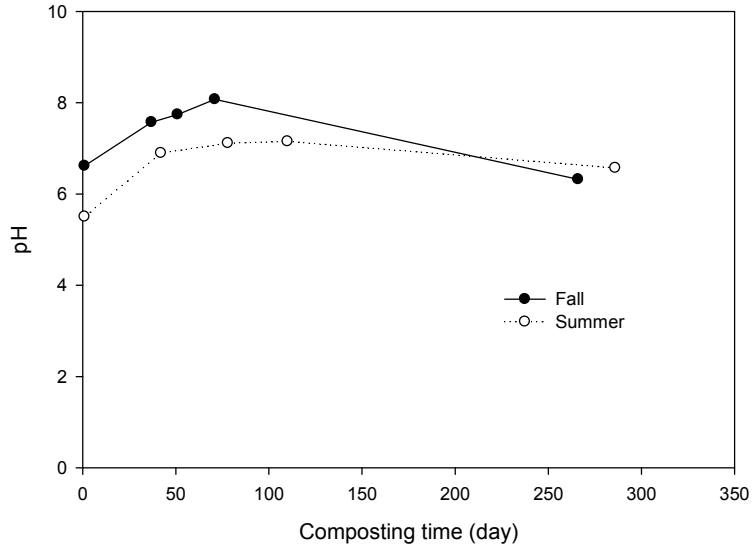

Figure 4.5 Changes in pH of both treatments during the composting process.

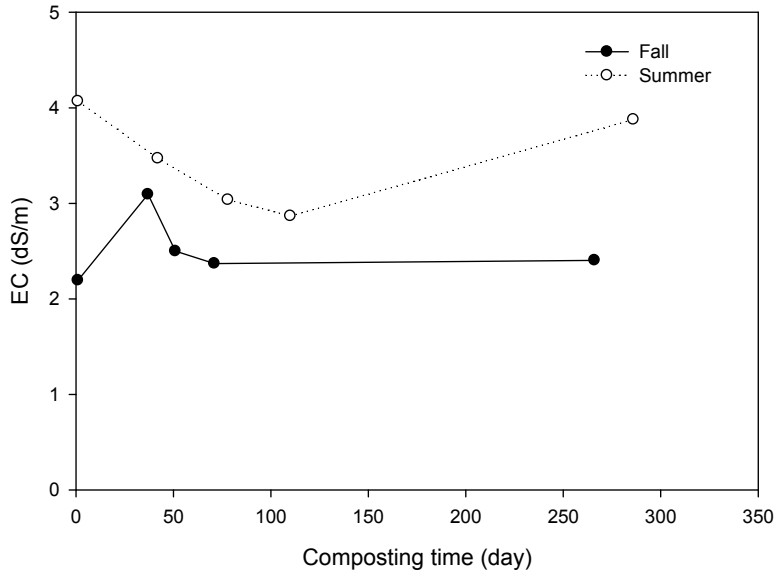

Figure 4.6 Changes in EC of both treatments during the composting process.

4.3.4 Total Carbon and Total Nitrogen

The relationships described by the regression equations over the composting study were significant ($p<0.05$). The R^2, calculated by using the equation from Kvalseth (1985), $R^2 = \frac{sum\ of\ squares\ (error)}{sum\ of\ squares\ (total)}$ of both treatments suggests that the relationships are adequately described by the regression equation. The regression pattern does not cover all the points (average of each treatment from four replications) which may be caused by the variables of the original data.

Figures 4.7, 4.8 and 4.9 include the change in total carbon and nitrogen during the composting process. The overall total carbon in fall and summer decreased from 44% and 46% to 38% and 37%, respectively at the end of the composting process. The mass reductions of total carbon in both treatments are similar. The regression relationships for both treatments are significant:

$TC_{fall} = 52.469 + 91.19 * e^{-(0.0209 * day)}$, $R^2 = 0.87$;

$TC_{summer} = 48.4042 + 77.4714 * e^{(-0.0221 * day)}$, $R^2 = 0.87$.

Nearly 50% of total carbon mass was decomposed or lost as CO_2 for both treatments. However, for the fall treatment, the mass reduction was consistent at each sampling time before the winter period while the reduction in the summer treatment was mostly in the first and second sampling period. This can be due to the warm ambient temperature in the summer that accelerated the decomposition rate and reduced the composting time. The initial total nitrogen for the summer treatment was 30% lower than the fall treatment and increased the initial C:N in the summer treatment. The initial C:N in the summer treatment was about 41:1, which was greater than the common range of initial C:N (20:1 to 40:1). No difference in total nitrogen was found between the initial and final compost in the summer treatment. The regression relations for the fall treatments is,

$TN_{fall} = 2.1298 + 1.2374 * e^{-(0.0311 * day)}$, $R^2 = 0.97$.

$TN_{summer} = 2.6$, Not Significant (NS)

These great differences can be due to the low initial nitrogen content in the summer treatment. SRM for the summer treatment was held at the field for two days before mixing; maggots were found in the material due to the hot weather which may have impacted the nitrogen content. Approximately 40% of the total nitrogen loss was found in the fall treatment while only about 10% of overall loss was found in the summer treatment. A reason for this can be the high pH value in the fall treatment. The pH of the fall treatment increased to over 8 during the composting process. These high pH values can increase nitrogen losses and ammonia odours by favoring nitrogen volatilization (Michel et al., 1993; Sundberg and Jönsson, 2008). The finished C:N in the fall treatment and the summer treatment fell to 26:1 and 20:1 respectively.

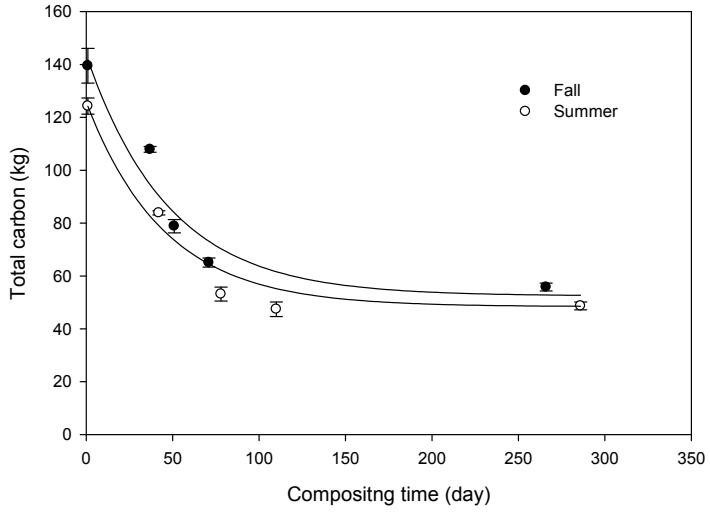

Figure 4.7 Change in total carbon during composting process for each treatment (Standard errors were shown in error bars)

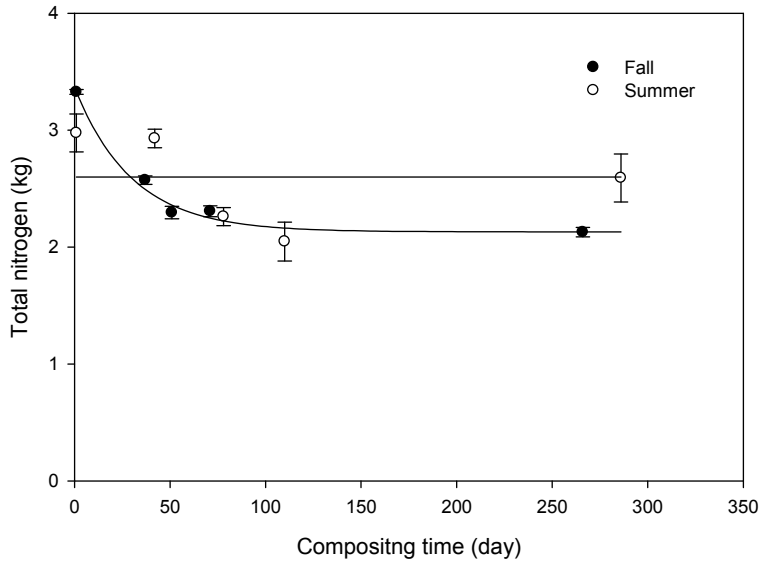

Figure 4.8 Change in total nitrogen during composting process for each treatment (Standard errors were shown in error bars)

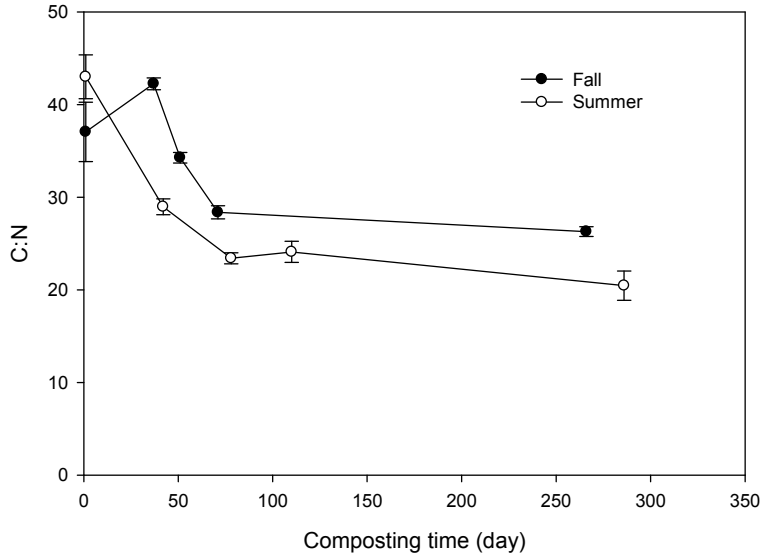

Figure 4.9 Change in C:N during composting process for each treatment (Standard errors were shown in error bars)

4.3.5 Maturity Test

The maturity tests indicated that the average daily release of CO_2-C in the fall treatment and the summer treatment were 0.099 and 0.995 mg CO_2-C/g organic matter/day, respectively, which meet the CCME guidelines for mature compost (CCME, 2005). The values of produced CO_2-C for both treatments were considered to be small since a 75% moisture content of the incubation sample may have created anaerobic conditions; however, the production of methane during the incubation period was low. The composts may be considered mature.

4.4 Conclusions

Composting of SRM with straw can be done in either the summer or fall season. Warm ambient conditions (summer) can prolong the thermophilic decomposition period and reduce the time for compost to reach the curing phase. The pH value of the

treatment in the summer season was lower than that in the fall, which reduced the nitrogen losses. The temperature profile of both treatments was found to meet the CCME guidelines and favor elimination of pathogenic microorganisms. The finished composts still contained available carbon, which has the potential to be reused as a carbon source for more SRM composting.

Chapter Five: Conclusions and Recommendations for Future Research

The study showed that straw and other agricultural wastes such as horse bedding and SRM compost can perform as well as sawdust in SRM composting processes. The temperature for all treatments held at 55°C over 15 days and met the CCME pathogen control guideline, which suggested effective pathogen reduction. Significant temperature increases were detected in most of the treatments shortly after each mixing, indicating the mixing and turning process helped reactivate the compost pile.

For the first study, the straw treatment had a similar reduction in total mass, as well as total carbon, compared to the sawdust treatment. Nitrogen losses were found in both treatments but straw treatments seemed to have a smaller ratio of losses. To deal with the problem, additional bulking agent such as rice husk, wood ash, or squeezed grapefruit peels can be used (Morisaki et al., 1989; Raviv et al., 1999; Wan et al., 1999; Tiquia et al., 2000). No difference was found in pH/ EC between the two treatments. The pH of the final compost for both treatments was between 6 and 7 while the EC was less than 4 dS/m, suggesting that the compost is suitable as a soil amendment. The final compost from both treatments was tested for maturity at day 266 and degraded to small and fine particles and easily contained material.

All of the four treatments in the second study had a similar amount of mass reduction. The straw treatment showed a different pattern of total carbon and total nitrogen reduction from the other three treatments because of the different consistency of the carbon compounds. Based on the results, agricultural wastes such as horse bedding, sheep manure and SRM compost can be used as the agricultural residuals with the composting of SRM. The two materials, sheep manure and SRM compost,

were found to have the same C:N but different carbon compounds. The change in temperature, total carbon and total nitrogen during composting in HBSM and HBSRMC were observed to be similar. Fewer odours were generated during the composting process in HBSRMC compared to HBSN. HBSRMC had a larger degradation (19.11%) of dry mass during the winter and spring period, compared to HBSM, which suggested that SC contains a larger pool of lignin, which provides more sustainable energy to the microorganisms. This lignin can be from the remains of the straw from the first study and suggests the reuse of SRM compost in composting process for a sustainable environment. The final pH and EC of HBSM are higher than HBSRMC, as well as the optimum range for soil, which is due to the higher pH and EC of the original sheep manure.

Seasonal variation seems not to be an issue for SRM composting. Composting of SRM with straw performed well in both the summer and fall season. The temperature profile of both treatments was found to meet the CCME guidelines and favor elimination of pathogenic microorganisms. However, summer will be suggested as the better composting season. Warm ambient conditions can prolong the thermophilic decomposition period and reduce the time for compost to reach its curing phase. Less nitrogen loss occurred in summer due to the lower pH value.

In general, composting is a good option for the management of SRM in Nova Scotia since the SRM disposal methods are either prohibited in the province by the government regulation (landfilling and incineration) or refused by the abattoirs due to the high economic cost (thermal hydrolysis and rendering). Composting SRM can provide a stable and easily handled final product with other advantages such as easy operation, low economic cost and less environmental impact. This study provides different kinds of carbon sources which all can be used in SRM composting.

Composting SRM can be easily done in this province since most of these carbon sources can be easily obtained by abattoirs, and the materials are less expensive. Appropriate management needs to be incorporated in order to produce successful compost. The final product is easier for storage or transport compared to the cattle carcass. Also, this final product can be used as a carbon source for additional SRM composts, reducing the total amount of SRM compost generated in the province. In the province, abattoirs typically compost on-site due to the restrictions on transport of SRM and cost. The next stage for the SRM composting study can be separated into two parts. First, since the finished compost is still considered SRM and restricted as an agricultural soil amendment, a suitable way to deal with this compost needs to be found. One of the options may be reusing the SRM compost in the composting process as an additional carbon source, which performed well in this project. Another option may be gasification as a means of destroying the prions and using the compost as an energy source. The second part for a future SRM composting study is to study the degradation of the protein in the compost, especially the prion protein. The optimum use for compost is as a soil amendment or fertilizer; if the prion protein in the compost is found to be degraded or separated, there would be no obstacles for applying the SRM compost in soil.

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