EFFECT OF DIVERSE COMPOST PRODUCTS ON POTATO PRODUCTIVITY AND SOIL QUALITY

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
June 2017

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ABSTRACT

Quality and productivity of potato fields in New Brunswick, Canada has been declining due to intensive production practices. Compost addition may rapidly increase soil organic matter and reverse declining productivity. Five diverse compost products were fall-applied at 45 Mg ha^{-1} dry weight in 2015 and 2016 to field plots, also receiving inorganic fertilizers, and were compared with a no-compost control for effects on tuber yield and selected soil quality (SQ) indicators. Compost affected soil nutrient availability (particularly K) and pH; permeability; carbon content; and biological activity. Responses in SQ indicators varied with the properties of compost applied. Reductions in soil-borne diseases were observed in the field and in a complementary growth room experiment, but effects were inconsistent. Despite SQ improvements, no significant potato yield response was observed. Overall, results suggest that mature compost products, high in carbon and dry matter, are most suitable for enhancing SQ in potato production systems.

LIST OF ABBREVIATIONS AND SYMBOLS USED

A – Area

a – Intercept of standard curve

Abs – Absorbance of sample at 550 nm

AKR – Apparent potassium recovery

ANR – Apparent nitrogen recovery

APR – Apparent phosphorus recovery

b – Slope of standard curve

BD – Soil bulk density

BS – Black scurf

CEC – Cation exchange capacity

CS – Common scab

DAP – Days after planting

DM – Dry matter

FC – Field capacity

FPMC – Forestry residues and poultry manure compost

FRC – Forestry residues compost

GWC – Gravimetric water content

H_1 – Initial height of water column

H_2 – Final height of water column

HSD – Honest significant difference

Inc – Incidence

K_{sat} – Saturated hydraulic conductivity

LC – Lobster shell compost

LSD – Least square difference

MBC – Microbial biomass carbon

MC – Poultry manure compost

MSC – Marine with shells compost

MWD – Mean weight diameter

Nu_a – Nutrient applied

Nu_c – Nutrient uptake for unfertilized control

Nu_t – Nutrient uptake for treatment

OM – Organic matter

PEI – Prince Edward Island

POM – Particulate organic matter

POX-C – Permanganate oxidizable carbon

PS – Powdery scab

PWP – Permanent wilting point

r – Infiltration rate

r_{ot} – Runoff rate

SAS – Soil aggregate stability

SEAC – Sea waste compost

Sev – Severity

SOC – Soil organic carbon

SOM – Soil organic matter

SQ – Soil quality

SS – Silver scurf

SSF – Sand and silt-sized fraction

t – Time interval

T_f – Final time

TN – Total nitrogen

V_t – Average runoff volume

VWC – Volumetric water content

WHC – Soil water-holding capacity

W_S – Dry weight of sand

WSA – Water stable aggregates

W_{SS} – Dry weight of soil in dispersing solution

W_T – Total dry weight

Wt – Weight of oven dried soil in the reaction

ACKNOWLEDGEMENTS

In potato fields, I spent my days
Collecting soil cores and sun burnt legs.
Fueled by coffee and a love for soil,
For a 138-page thesis, I toiled.
My father saying "*aren't you done school **yet**?*"
I am now Dad! But don't you fret!

I've been to Africa, Arizona, and Kamloops, B.C.
To talk about potatoes, dirt and composted trees.
I've dug soil pits, and to my disbelief,
Managed to catch my potato thief!
From under a microscope (thanks Pam!), I've unveiled
That Sminthuridae are my favorite springtails.
But despite traveling the globe, my favorite memory is, by far,
Talking 'dirty' on Fridays in our favorite Truro bar…

But, I would never have finished this degree
Without my personal team of MVPs.
First, to acknowledge my inspirational Dalhousie peers:
Rosalie, a fearless soil crusader and enjoyer of beers
Robyn, a warm-hearted farmer with a listening ear
And Ellen, she's got beef and no fear.

Also to Rob, my fellow lab-mate
For many good times and frustrations calculating soil respiration rates.
To my DAAGS exec: it was a slice.
And Tess, your statistics jokes were a highlight.
For all the dancing and laughs to ease thesis-pains:
Thanks guys, you know who you are (including Hossein).

To the Nook and Cranny, for the very best
Strips and Skins a girl can ingest.
Also, to Megan, Lisa and the ole' Wildflowers lines
Keep your stick on the ice and see you at the Vince Ryan!

A BIG thanks to the technicians at AAFC
Breaking their backs (literally) to apply compost for me.
Special thanks to Karen, the vario MACRO queen
Don't mess her cats, she'll get mean.
And to Ginette, she's great company
Except when I accidently hide the truck keys.
Thanks to Kyle, the office playoff pool *cordon bleu* –
Pressure plates are no problem when 'King of the Lab' is you.
And to Drucie, Yulia, Ellen, Bailey, Kaleigh and Louise,
For being sampling, processing and potato-beetle-picking devotees!

Also, I can't forget to thank my funding agencies
Who made this degree a possibility.
Especially to Gilles and his team at McCain's
The way I look at potatoes will never be the same.
Also for sponsorship through CSSS
To share my work across the country and in the US.

Thanks to John and the Alliance for the opportunity
To work as an intern with New Brunswick's EFP.
And to Murray and the Wild Blueberry Meadows crew,
Reminding me that agriculture was what I was meant to do.

Gratitude, I extend, to all my close friends and family
For tolerating my zombie-like writing-melancholy:
Waugh, I promise McGinnis soon
Doyle, I owe you some birthday balloons.
Jacob, I apologize for being tardy for your suppers,
And Abby, maybe I'll fly out later this summer.
Sally and the girls, we'll be on the next Chick's tour.
Lo and Ty – I'll visit more!
To Maple, I promise more time for walks.
Ellen, it's time for wine, campfires and talks.

To mom and dad and all my family,
For always believing in the best of me.
Teaching me the value of hard work and perseverance
And supporting my dreams in any circumstance.

Thanks to Dave, Claudia, Derek and most of all, Bernie,
Your knowledge, patience and support are extraordinary.
It's been truly an honour and pleasure to work alongside
Such exemplary scientists in the Maritimes.

Finally, a special thanks to Mark, my partner in crime,
A welcome distraction, reality-check and good time.
Now that this is done, let's see where things go…
Owning a Butcher Shop in Sainte-Marie? Who knows?

CHAPTER 1.0 INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important agricultural commodity in New Brunswick, Canada. In 2012, potato production accounted for over $152 million in total farm value in the province (Statistics Canada 2017). In this region, potatoes are commonly grown in two-year rotations (Zebarth et al. 2012) and production involves frequent use of heavy farm machinery (Saini and Grant 1980), limited organic matter (OM) inputs (Gagnon et al. 2001; Stark and Porter 2005), and frequent tillage (Angers et al. 1999). As a result, the productivity and quality of New Brunswick potato field soils has been declining for decades (Saini and Grant 1980; Rees et al. 2014). Soils have become more susceptible to erosion (Gagnon et al. 2001), depleted in OM (Carter 2007), and infested with persistent soil-borne pathogens (Larkin et al. 2011). Large carbon inputs are required to overcome OM depletion, re-build soil structure and reverse trends in productivity (Gagnon et al. 2001).

Compost application is one option for increasing soil OM. When compared with raw manure, compost has a reduced incidence of soil-borne pathogens (Hoitink et al. 1997), is less odorous and is easier to handle (Gagnon and Simard 1999). The compost process also captures nutrients in organic form, resulting in more predictable nutrient availability than raw organic products (Preusch et al. 2002). Following application to land, these nutrients are mineralized over time as the OM is further decomposed. Soil organic matter can also be increased through the incorporation of green manures. Green manure cropping is a valuable soil quality enhancement strategy which adds a significant quantity of labile carbon to the soil. However, green manure addition increases SOM at much slower rate than can be achieved through the addition of stabilized SOM, such as compost. Grandy et al. (2002) found persistent and rapid increases in SOM following compost and manure application. Compost offers an attractive solution as it can be applied within existing rotations and can result in rapid increases in SOM.

In potato field trials, compost application has been shown to improve tuber yield (Carter et al. 2004; Stark and Porter 2005; Larkin et al. 2011), a response attributed to 'nutrient' and 'non-nutrient' effects. Following compost application, mineralized nutrients become available for plant uptake; however, the extent of mineralization depends on several factors, such as compost quality, climatic conditions, and soil properties. Sharifi et al. (2009) found that application of a hog manure-sawdust compost did not influence plant N availability during the growing season compared with an unamended control when applied in the spring prior to planting. This was not unexpected: mature compost is stabilized and the mineralization of N is slow. Under rain-fed potato production, a positive yield response to compost application was more frequently observed in dry years than in wet years, and as a result, it has been hypothesized that the yield response following compost application may be associated, in part, with 'non-nutrient' benefits such as increased soil water-holding capacity and improved soil structure (Carter et al. 2004; Carter 2007; Lynch et al. 2008). These beneficial soil properties, which can enhance crop growth, are commonly referred to as soil quality or soil tilth.

Soil quality (SQ) is assessed by physical, biological and chemical indicators (Nesbitt and Adl 2014). Soil quality can be used to evaluate and compare soil management practices, such as amendment application (Nesbitt and Adl 2014). Following compost application, improvements in soil quality include increased soil organic matter (SOM) content (Gagnon et al. 2001), macroaggregation (Gagnon et al. 2001), water holding capacity (Foley and Cooperband 2002; Carter et al. 2004), particulate organic matter carbon (POM-C) content (Carter et al. 2004; Sharifi et al. 2014) and decreased soil bulk density (Carter et al. 2004). Although these changes are indicative of 'non-nutrient' crop benefits of compost, it is difficult to completely distinguish them from nutrient benefits because changes in these properties may also influence the availability and retention of plant nutrients in the soil.

An additional benefit of compost application is its potential to suppress soil-borne diseases (Noble 2011). In potato production, the application of compost has reduced the incidence of *Verticillium dahliae* (Entry et al. 2005; Molina et al. 2014), black scurf caused by *Rhizoctonia solani* (Larkin et al. 2011; Bernard et al. 2014) and common scab associated with *Streptomyces scabiei* (Al-Mughrabi et al. 2008). However, soil-borne disease suppression following compost application is inconsistent. Following compost application, Larkin et al. (2011) observed a reduction in black scurf under non-irrigated conditions only. Compared with an unamended control, a reduction in the incidence and severity of black scurf was observed in one field season following compost application, but an increase in total tuber disease was observed over the duration of the trial (Bernard et al. 2014). Although several field studies have examined the effect of compost and manure application on potato production (Carter et al. 2004; Lynch et al. 2008; Rees et al. 2014), few field studies have examined compost products from a diversity of sources for their effects on tuber disease and soil quality in potato production.

The overall objective of this thesis was to identify properties of a compost product suitable for use in potato production. This study aims to evaluate compost products with diverse properties for their nutrient and ‘non-nutrient’ effects on potato productivity and soil quality. Specifically, the objective of this study is to examine five composts from a diversity of sources and compare their effects on: tuber yield, size and specific gravity, soil nutrient availability, selected soil quality indicators, and severity of soil-borne disease.

This thesis is structured in a manuscript format. Chapter 2 examines the effects of compost products on tuber yield, size and specific gravity and soil nutrient availability. Chapter 3 examines the effects of compost products on soil quality parameters. Chapter 4 examines the effects of compost on severity of soil-borne diseases. Chapter 5 presents overall conclusions from the preceding chapters and provides recommendations for future work.

CHAPTER 2.0 EFFECT OF DIVERSE COMPOST PRODUCTS ON POTATO YIELD AND NUTRIENT UPTAKE

2.1 Introduction

Potato (*Solanum tuberosum* L.) is an important agricultural commodity in New Brunswick, Canada. In 2012, potatoes were seeded on nearly 22,000 hectares with production accounting for over $152 million in total farm value in the province (Statistics Canada 2017). Despite increased use of pesticides and fertilizers and advances in farm mechanization, total yields have increased marginally by an average of 0.13 Mg yr^{-1} per harvested hectare in the past three decades (Figure 2.1). Potato production practices, such as extensive tillage, short rotations, and minimal crop residue return, are resulting in a decline in soil organic matter (SOM), an increase in persistent soil-borne diseases and an overall decrease in soil productivity (Stark and Porter 2005; Larkin et al. 2011). In an effort to mitigate SOM losses and enhance productivity, SOM-conserving and enhancing strategies must be incorporated into potato cropping systems. Potential practices include reducing the frequency of potato in rotation, reducing the frequency of tillage, incorporating green manure cropping, and applying organic amendments such as manure or compost (Angers et al. 1999; Grandy et al. 2002; Fahmy et al. 2010).

Compost is produced through the controlled, aerobic decomposition of organic materials. During the composting process, labile substrates are catabolized, nutrients are immobilized by micro-organisms, and pathogens are inactivated by thermophilic conditions (Rynk 1992). The resulting product is dominated by recalcitrant forms of carbon, has fewer pathogens, and exhibits slower, more predictable nutrient release than raw manures (Dumontet et al. 1999; Preusch et al. 2002). Compost has several

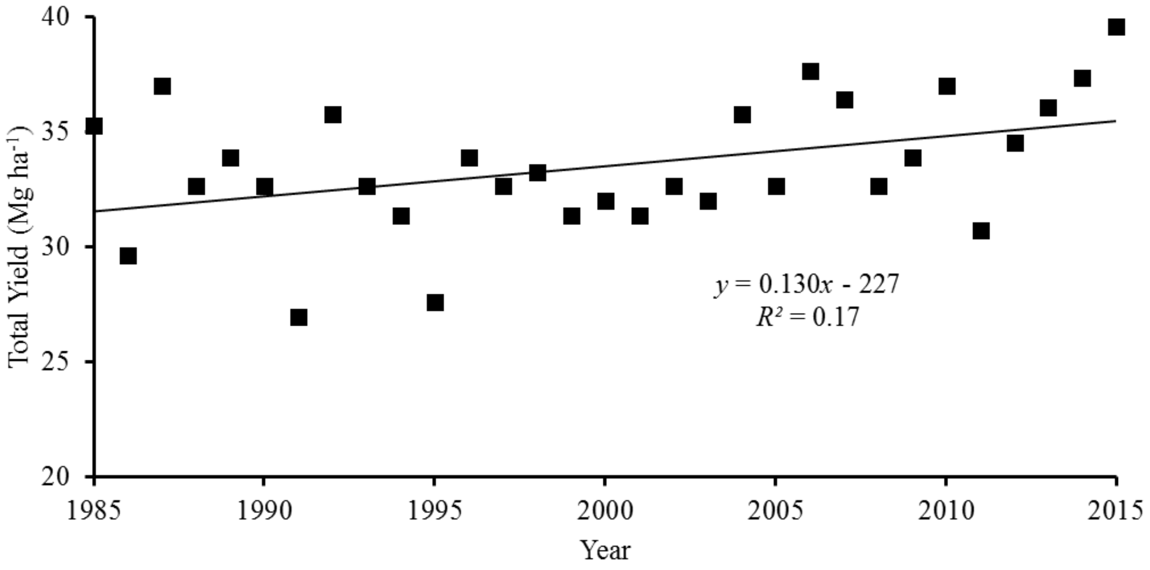

Figure 2.1 Total tuber yield per harvested hectare in the province of New Brunswick, Canada from 1985 to 2015 (Statistics Canada 2017).

advantages for increasing SOM in current conventional potato production systems. Compost application can result in rapid and persistent increases in SOC. When compared with the dry matter C content of green manure (mix of peas, oats and hairy vetch), the application of organic amendments (manure applied at 45 Mg ha^{-1} and compost applied at 22 Mg ha^{-1}) would contribute 1.8 time more C to the soil on a dry matter basis (Grandy et al. 2002). Compost is also easy to handle and its application can be readily integrated into current potato cropping rotations which makes it an attractive alternative to lengthening rotations and planting potato less frequently.

When applied as a soil amendment in conventional potato production, compost resulted in increased potato yield in studies across eastern Canada and Maine (Carter et al. 2004; Stark and Porter 2005; Larkin et al. 2011; Bernard et al. 2014). Increases in yield were often due to increases in tuber size as the weight of large and extra-large size tubers, and the percentage of tubers in these size classes, was increased (LaMondia et al.

1999; Porter et al. 1999; Bernard et al. 2014). This yield response has been attributed primarily to 'non-nutrient' related benefits, specifically, an increase in soil moisture retention (Stukenholtz et al. 2002; Carter et al. 2004; Lynch et al. 2008). Larkin et al. (2011) observed significant increases in total tuber yield following annual compost application in a soil-improving cropping system under non-irrigated conditions whereas no significant response occurred when potatoes were irrigated. This suggests that the benefit from compost may be the result of increased water holding capacity. In a three year study, Bernard et al. (2014) observed greater increases in total tuber yield in response to compost application in drier years than wetter years. Carter et al. (2004) observed an increase in tuber yield following compost addition that exceeded maximum yield obtained with use of inorganic fertilizer alone and suggested that this yield increase may be related to a small, but significant, improvement in soil water-holding capacity. These findings suggest that improvements in soil water-holding capacity may be an important non-nutrient benefit of compost application.

Compost also provides a slow-release source of organic nutrients, which may contribute to a 'nutrient' yield response. However, the degradation of compost is slow and the quantity of compost N mineralized in the year after application is almost negligible as indicated by very low apparent nitrogen recovery (ANR) by the crop (Lynch et al. 2008; Sharifi et al. 2009). Conversely, not all composts are the same. For example, ANR from different dairy manure composts ranged from -14% (Gagnon et al. 1997) to 15.1% (Lynch et al. 2004) and varied across application rates. The inability to adequately predict N availability from organic amendments limits the potential use of compost as a soil fertilizer (Lynch et al. 2004; Stark and Porter 2005; Zebarth et al. 2012; Lehrsch et al. 2016).

Sufficient N is necessary for potato growth and tuber yield (Porter and Sisson 1991; Lynch et al. 2008). High yielding potato crops require 2.5 to 5.9 kg N per Mg of yield (Lynch et al. 2012). However, excessive N fertility can result in reductions in tuber quality through excessive haulm growth, delays in tuber initiation and maturation, and decreases in tuber specific gravity (Porter et al. 1999; Lynch et al. 2012). Excessive N fertility can also result in the accumulation of residual soil mineral nitrogen and increase the risk of nitrate leaching during high precipitation or snowmelt events characteristic of the eastern Canadian maritime climate (Preusch et al. 2002; Lynch et al. 2012).

In compost amended soil systems, net N mineralization is affected by several factors including compost quality (e.g. C:N ratio and N concentration), climatic conditions, and soil characteristics (Lynch et al. 2004; Lynch et al. 2012). With no current reliable soil test measure to predict the availability of N over the growing season in eastern Canada (Zebarth et al. 2012), understanding the impact of compost on nutrient availability is essential to achieve productivity and environmental protection goals of a compost-amended potato system. In addition, with the exception of limited studies (Lynch et al. 2008), comparative research of the effect of diverse compost products on tuber yield and quality under humid, eastern Canadian climatic conditions has been largely uninvestigated. Therefore, this study examined the effects of five composts from a diversity of sources on 1) tuber yield, size and specific gravity, and 2) apparent N, P and K availability.

2.2 Materials and Methods

2.2.1 Experimental Site

Two field experiments were established in the fall of 2014 at the Fredericton Research and Development Centre of Agriculture and Agri-Food Canada, Fredericton, New Brunswick, Canada (Lat. $45^{0}55$'N; Long. $66^{0}36$'W). Soils at the site were developed in coarse loamy morainal ablational till over coarse loamy morainal lodgement till and are classified as Orthic Humo-Ferric Podzol (Rees and Fahmy 1984). The soil textural class (pipette method following organic matter removal, Kroetsh and Wang 2007) was a loam with 381 g kg^{-1} sand, 493 g kg^{-1} silt and 126 g kg^{-1} clay at the 0-15 cm depth. Soil pH was 5.9, as determined in 1:1 water by a commercial laboratory. Soil organic carbon and total nitrogen concentrations determined by dry combustion were 19.6 g C kg^{-1} soil and 1.74 g N kg^{-1} soil, respectively (Elementar varioMACRO, Skjemstad and Baldock 2007).

The crop preceding the experiment was spring barley (*Hordeum vulgare* L.) cultivar AC Legend fertilized with 17-17-17 at a rate of 250 kg ha^{-1}. The cereal crop was harvested and the straw was chopped and left on the field.

Growing season (May-September) air temperatures were 6% above the 30 year normal for 2015 and 3% above the 30 year normal for 2016 (Table 2.1). In 2015, growing season total precipitation was 10% above the 30 year normal. By month, total precipitation was 33% below normal in May, 29% above normal in June, 58% below normal in July, 15% below normal in August, and 127% above normal in September 2015. In 2016, growing season total precipitation was 3% below 30 year normal. By month, total precipitation was 40% below normal in May, 26% above normal in June, 9%

Table 2.1 Average daily mean air temperature and total precipitation during the May-September growing season in 2015 and 2016, compared with a long-term (1981-2010) climate normal (Environment Canada 2017).

Month	Average air temperature (°C)			Total precipitation (mm)		
	Normal	2015	2016	Normal	2015	2016
May	11.3	12.8	11.6	103.8	69.4	62.4
June	16.4	14.5	15.9	86.3	111.3	108.5
July	19.4	19.1	19.9	89.0	37.0	81.4
August	18.6	20.7	19.3	85.9	73.1	157.2
September	14.0	17.1	15.4	94.7	215.2	36.8
Average or total	15.9	16.8	16.4	459.7	506.0	446.3

below normal in July, 83% above normal in August, and 61% below normal in September 2016.

2.2.2 Experiment 1

Experiment 1 quantified the effects of diverse compost products on tuber yield and quality parameters. The experiment used a randomized complete block design with six compost treatments and four replicates. Compost treatments were applied in the fall of 2014 and the plots cropped to potatoes in 2015. The same compost treatments were re-applied in fall 2015, and plots cropped to potatoes again in 2016 in effort to study the effect of two subsequent years of compost application on potato yield. Individual plots were 8 m long by six potato rows (5.46 m) wide. The outer two rows were guard rows. Treatments included five compost products and a no compost control (Tables 2.2, 2.3). Feedstock used for the marine with shells compost (MSC) included marine waste (fin and shell fish), chicken compost and ground aged wood fines in a windrow composting system. Poultry manure compost (MC) was windrow composted from chicken manure with ground aged wood fines. The forestry residues compost (FRC) product was windrow composted predominantly from wood-waste feedstock including bark, paper mill residue

Table 2.2 Compost products applied in fall of 2014 for Experiments 1 and 2.

	MSC[1]	MC	FRC	SSOC	FPMC
Dry matter (%)[2]	63.1(1.2)[3]	57.3(2.1)	42.6(1.8)	48.6(1.4)	53.6(2.0)
Ash (g kg^{-1})	748(11)	535(58)	517(41)	591(30)	700(25)
C:N	22.9(0.6)	19.4(1.4)	62.8(0.8)	10.0(0.4)	27.4(1.2)
pH	7.87(0.06)	7.43(0.06)	6.97(0.06)	7.70(0.10)	7.57(0.06)
C (g kg^{-1})	180(6)	247(35)	239(17)	221(26)	172(15)
N (g kg^{-1})	7.9(0.4)	12.7(0.9)	3.8(0.3)	22.0(1.9)	6.3(0.5)
P (g kg^{-1})	1.70(0.66)	4.99(2.33)	0.49(0.02)	8.78(2.88)	2.86(0.10)
K (g kg^{-1})	2.48(0.14)	5.49(2.79)	1.32(0.23)	4.40(0.04)	4.28(0.79)
Ca (g kg^{-1})	134.2(4.1)	10.7(5.0)	7.9(0.7)	38.4(5.6)	36.7(1.0)
Mg (g kg^{-1})	3.13(0.09)	3.71(1.67)	3.15(0.47)	3.80(0.09)	7.35(1.91)
Fe (g kg^{-1})	5.3(2.0)	7.2(2.9)	13.9(1.6)	16.5(3.0)	17.8(6.5)
Cu (mg kg^{-1})	21.2(3.0)	36.6(18.0)	14.0(4.4)	85.0(11.9)	29.5(5.2)
Zn (mg kg^{-1})	79(4)	149(71)	54(3)	189(12)	277(46)
B (mg kg^{-1})	13.3(0.8)	15.4(8.2)	4.4(0.2)	22.0(0.8)	26.1(3.0)
Mn (mg kg^{-1})	456(19)	487(218)	543(13)	624(44)	2599(240)
Nitrate-N (mg kg^{-1})	9(1)	<5	<5	603(55)	184(67)
Ammonium-N (mg kg^{-1})	16.6(1.4)	22.3(1.6)	35.5(1.3)	27.7(5.7)	40.0(6.0)

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] With the exception of dry matter and pH, all values expressed on a dry matter basis.

[3] Standard deviation expressed in parenthesis.

and wood-ash with approximately 5% broiler manure. The municipal source separated organic waste compost (SSOC) was derived from organic curb-side waste in-vessel. The forestry waste and poultry manure compost (FPMC) was produced through windrow composting of poultry manure and wood shaving bedding, forestry wastes, paper mill residue and wood ash. With the exception of MSC, new batches of compost were used in 2016. Compost samples were analyzed in triplicate by a commercial laboratory for dry matter content, ash content, compost pH, total C, N, P, K, Ca, Mg, Cu, Zn, Mg, B, Fe, as well as ammonium-N and nitrate-N (Table 2.2, 2.3).

In early October 2014, soil was cultivated with a chisel plow to a depth of approximately 15 cm, followed by disking to smooth the soil surface prior to compost

Table 2.3 Compost products applied in fall of 2015 for Experiments 1 and 2.

	MSC[1]	MC	FRC	SSOC	FPMC
Dry matter (%)[2]	72.7(1.6)	45.9(2.0)	41.1(0.6)	46.8(0.2)	62.6(2.4)
Ash (g kg^{-1})	760(11)	508(25)	574(17)	509(10)	767(10)
C:N	22.9(0.6)	25.6(1.7)	55.3(0.6)	19.2(1.1)	23.8(1.6)
pH	7.53(0.06)	7.37(0.06)	7.40(0.10)	7.77(0.12)	7.63(0.06)
C (g kg^{-1})	179(4)	259(15)	228(7)	272(8)	131(9)
N (g kg^{-1})	7.8(0.3)	10.1(0.3)	4.1(0.2)	14.2(0.4)	5.5(0.6)
P (g kg^{-1})	2.35(0.14)	4.59(0.37)	0.55(0.10)	2.70(1.21)	2.78(0.02)
K (g kg^{-1})	2.87(0.08)	5.83(0.11)	1.37(0.24)	2.06(1.02)	5.01(0.72)
Ca (g kg^{-1})	151.5(4.3)	11.0(1.3)	8.6(1.4)	12.5(5.9)	39.1(0.5)
Mg (g kg^{-1})	3.47(0.34)	4.52(0.54)	2.81(0.47)	2.21(1.07)	6.45(1.44)
Fe (g kg^{-1})	7.3(1.1)	10.9(2.6)	11.9(2.8)	9.0(4.2)	16.0(7.0)
Cu (mg kg^{-1})	24.1(0.9)	77.6(9.2)	12.6(5.1)	38.8(20.3)	28.5(8.0)
Zn (mg kg^{-1})	81(2)	176(12)	66(14)	100(46)	306(35)
B (mg kg^{-1})	15.9(0.6)	16.7(0.7)	4.9(1.1)	13.5(6.8)	30.8(0.0)
Mn (mg kg^{-1})	487(18)	737(55)	571(99)	643(298)	2409(76)
Nitrate-N (mg kg^{-1})	18.1(15.7)	<5.0	<5.0	12.9(8.0)	15.2(7.0)
Ammonium-N (mg kg^{-1})	18.1(3.5)	30.1(7.9)	47.7(4.9)	62.9(7.3)	27.4(3.0)

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] With the exception of dry matter and pH, all values expressed on a dry matter basis.

[3] Standard deviation expressed in parenthesis.

application. Compost treatments were applied by hand at a rate of 45 Mg ha^{-1} on a dry weight basis from October 9-14, 2014. This relatively high rate was selected in an effort to measurably improve soil quality in a short time period. All plots were cultivated to a depth of 15 cm with an S-tine harrow to incorporate the compost products on October 15, 2014.

On June 5, 2015 hand-cut Shepody seed (57.0 ± 3.0 g) was hand planted at 0.91 m row spacing and 0.3 m within-row spacing. Chieftain potato plants served as guard plants at the end of each harvest row. Fertilizer was banded at planting at a rate of 1060 kg ha^{-1} of granular fertilizer (analysis N:P:K 17:17:17) to reflect commercial grower practices

(GNB 2001; Zebarth et al. 2007). The rate of fertilizer application was not adjusted to account for any nutrient supply from the compost. Recommended practices for tillage operations and the control of insects and disease followed accepted industry standard practices (Bernard et al. 1993). No irrigation was applied as is common under rain-fed potato production in New Brunswick. Vine desiccation occurred on September 17, 2015.

Two representative rows (7.62 m) from each plot were dug and hand-harvested on September 28, 2015. The tubers were divided into four categories and the percentage of tuber weight within each was determined: small (less than 5 cm diameter), medium (greater than 5 cm diameter, less than 284 g in weight), and large tubers (greater than 284 g), and culls (tubers with visible defects such as soft rot) (Zebarth et al. 2004). Marketable yield was calculated as total yield minus culls and small tubers. A representative subsample of 20 tubers of medium size was selected from each plot for tuber specific gravity determination by the weight-in-air to weight-in-water method (Edgar 1951).

On October 13, 2015, soil was cultivated as described for 2014. Compost treatments were re-applied to the same plots on October 15-16, 2015 using the same application rate and procedure as in 2014 in order to determine the cumulative effect of two years of treatment application. Hand-cut Shepody seed (57.0 ± 3.0 g) was planted on May 19, 2016 with the same row and within-row spacing as 2015. Fertilizer application, tillage operations, and insect and disease control were as described for 2015. Vine desiccation occurred on September 12 and tubers were harvested on September 26, 2016. Tubers were graded as described for 2015.

Petiole samples were collected on July 20, August 5, August 18 and September 3, 2015. In 2016, petiole samples were collected on July 4, July 18, August 2, August 15 and August 29. Thirty-five petioles were collected per plot by sampling the last fully expanded leaf, typically the fourth from the top. Leaflet tissue was removed and petioles were dried at 55^0C. Tissue was ground through a 0.841 mm (20 mesh) screen using a bench top Thomas Wiley Mill (Thomas Scientific). Deionized-distilled water (40 mL) was added to a 0.2 g of dried, ground tissue to extract exchangeable NO_3-N (Zebarth et al. 2003). After shaking for 15 min, the solution was filtered, diluted 1:25 with deionized-distilled water using a Microlab 600 Diluter Dispenser (Hamilton Company) and analyzed on a QuikChem 8500 Series 2 Flow Injection Auto-Analyzer (Lachat Instruments). Briefly, nitrate, reduced to nitrite by hydrazine sulfate and a copper catalyst, was diazotized with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride to produce a magenta colour (QuikChem Method 90-107-04-2-A). Petiole NO_3-N concentrations were compared to deficiency standards for Shepody adapted from Porter and Sisson (1991).

2.2.3 Experiment 2

Experiment 2 quantified the effect of diverse compost products on soil nutrient availability. This experiment used the same experimental design as Experiment 1, except for a smaller plot size of 8 m long by 3.64 m (4 potato rows) wide. Experiment 2 was conducted the same as described for Experiment 1, except that no mineral fertilizer was applied. Compost was applied on October 9-14, 2014 and on October 19, 2015. The experiment was planted on June 5 and harvested on September 28 in 2015. In 2016, the experiment was planted on May 19 and harvested on September 21.

Composite soil samples were collected from each plot from a depth of 0-15 cm and 15-30 cm on May 28 (pre-plant) and August 13 (prior to significant leaf senescence) in 2015 and on May 11 (pre-plant), August 8 (prior to significant leaf senescence), and September 21 (post-harvest) in 2016. Each composite sample was comprised of 8-10 cores collected using a random sampling strategy using a 2.54 cm diameter soil probe. Field-moist soil was frozen until analysis. Nitrate-N and ammonium-N concentrations were determined on all sample dates and at both depths by 2.0 M KCl extraction (Zebarth et al. 2005; Maynard et al. 2007). Briefly, soil was thawed, passed through a 2 mm sieve, and 20 g moist was weighed into a 125 mL flask with 100 mL of 2.0 M KCl. Flasks were shaken on a lateral shaker for 30 min and the extracts were vacuum-filtered through a Buchner funnel with Q2 filter paper. Extracts were analyzed on a QuikChem 8500 Series 2 Flow Injection Auto-Analyzer (Lachat Instruments). Briefly, nitrate, reduced to nitrite by hydrazine sulfate with a copper catalyst, was diazotized with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride, producing a magenta colour (QuikChem Method 90-107-04-2-A). Briefly, ammonia was reacted with sodium salicylate and sodium hydroxide, followed by addition of hypochlorite to produce an emerald green colour. Ethylenediaminetetraaccetic acid (EDTA) eliminates precipitation of calcium and magnesium hydroxides and sodium nitroprusside intensifies colour for reading (QuikChem Method 90-107-06-3-A).

Accumulation of N, P and K in unfertilized potato plants can be used as an assay of soil nutrient availability (Zebarth et al. 2005). Two set of four adjacent plants in each plot in Experiment 2 were collected prior to significant leaf senescence on August 13, 2015 and August 8, 2016 as described by Zebarth and Milburn (2003), and separated into tuber, vine and readily recoverable root samples. Fresh biomass was determined and the samples were oven-dried at 55^{0}C for 48 h or until dry matter was stabilized. After weighing dried samples, vine and root tissue were ground in a Wiley Mill to pass a 2 mm screen and tuber samples were ground in a Perten Mill at the finest setting. A sub-sample of vine, root, and tuber tissue was analyzed for total N by dry combustion (Elementar varioMACRO apparatus, Elementar Americas Inc., Mt. Laurel, NJ). Plant P and K were determined by a commercial laboratory on a Technicon TRAACS 800 and Varian Atomic Absorption Spectrophotometer, respectively. Nutrient accumulation and whole plant dry matter were estimated (Zebarth and Milburn 2003). Total N, P, and K uptake were determined by summing the respective nutrient content for all the components of the potato plant (Zebarth et al. 2003).

Nutrient availability of the compost products was assessed as apparent nutrient recovery in the potato crop (Zebarth et al. 2004; Lynch et al. 2008) as:

$$\text{Apparent nutrient recovery (\%)} = 100 \text{ x } (Nu_t - Nu_c)/(Nu_a)$$

where Nu_t = nutrient uptake for treatment; Nu_c = nutrient uptake for unfertilized control; and, Nu_a = nutrient applied.

2.2.4 Statistical Analyses

Statistical analyses were performed separately for years 2015 (after one compost application) and 2016 (after two consecutive years with compost application). Data were analyzed using the General Linear Model procedure in Minitab 17 Statistical Software (Version 17, Minitab Inc., USA) as a randomized complete block design with six treatments and four replicates. When a significant effect was identified in the analysis, Fisher’s protected LSD for multiple means comparisons were computed ($\alpha = 0.05$).

2.3 Results

The five compost products applied in this study were diverse (Tables 2.2, 2.3). The MSC compost, derived primarily from marine wastes, had an average C:N ratio of 22.9, ash concentration of 754 g kg^{-1}, carbon concentration of 180 g C kg^{-1}, pH of 7.7, and NH_4-N:NO_3-N ratio of 1.4, consistent with a mature product (Tables 2.2, 2.3). The ratio of NH_4-N:NO_3-N can be used as an indicator of compost maturity, because as compost decomposes, the pile becomes relatively enriched in NO_3-N and concentrations of NH_4-N decrease (Sánchez-Monedero et al. 2001). The Ca concentration (143 g Ca kg^{-1}) was greater than the Ca concentrations observed for the other compost products in this study, likely the result of the decomposition of shell-fish and other marine wastes. The MC compost, derived from poultry manure and ground aged wood fines, had an average C:N ratio of 22.5, ash concentration of 522 g kg^{-1}carbon concentration of 253 g C kg^{-1}, pH of 7.4, and NH_4-N:NO_3-N ratio > 5.24. The FRC compost, derived from bark, paper mill residue and wood-ash, had an average C:N ratio of 59.1, ash concentration of 546 g kg^{-1}C concentration of 234 g C kg^{-1}, pH of 7.2, and NH_4-N:NO_3-N ratio > 8.3. The C:N ratio of this product greatly exceeded the critical C:N ratio of 20-30 between net immobilization or mineralization suggested by Sims (1990) in Sharifi et al. (2014). The high C:N ratio, high NH_4-N:NO_3-N ratio and undetectable nitrate-N in the compost analysis are consistent with an immature product. The SSOC product was derived from municipal source separated organic waste. On average, the C:N ratio of SSOC was 14.6, ash concentration of 550 g kg^{-1}the C concentration was 247 g C kg^{-1}, the pH was 7.7, and the NH_4-N:NO_3-N ratio was 2.5. This product contained the greatest concentration of total nitrogen (average of 18.1 g N kg^{-1}). The FPMC product, derived from poultry manure, bedding, and paper mill residue, had an average C:N ratio of 25.6, ash concentration of 734 g kg^{-1}, the C concentration was 152 g C kg^{-1}, pH of 7.6, and NH_4-N:NO_3-N ratio of 1.0. This product also contained greater concentrations of several plant nutrients than the other compost products, in particular Mn with an average concentration of 2504 mg Mn kg^{-1}.

2.3.1 Experiment 1

There were no significant differences among compost treatments for total tuber yield or marketable tuber yield in either 2015 or 2016 (Table 2.4). Mean total tuber yield in 2015 was 30.7 t ha^{-1} and mean marketable tuber yield was 27.8 t ha^{-1}. In 2016, mean total tuber yield was 32.1 t ha^{-1} and mean marketable tuber yield was 29.0 t ha^{-1}. There was a significant effect of compost treatment on the percentage of large tubers, but not small or medium tubers, in 2015 and 2016 (Table 2.4). In 2015, the percentage of large-sized tubers was significantly greater for FPMC (37.9%) than for the FRC, MC, MSC and control treatments (average of 23.9%). In 2016, the percentage of large-sized tubers for MC (15.8%) was significantly lower than all other treatments (average of 28.0%). There were no differences in mean tuber weight among treatments in either year.

The mean specific gravity for all treatments was 1.080 in 2015 and 1.086 in 2016 (Table 2.4). In 2016, the FPMC resulted in significantly lower specific gravity (1.084) than all other treatments (average of 1.087). There was no significant effect of compost treatment on specific gravity in 2015.

Petiole NO_3-N concentration is used as an in-season indicator of plant N status (Porter and Sisson 1991). In 2015, there were significant differences in petiole NO_3-N concentration among compost treatments at 40 and 85 days after planting (DAP), but not

Table 2.4 The effect of diverse compost products on tuber yield, size distribution and specific gravity following one application (2015) or two applications (2016) of compost in Experiment 1.

Treatment	Total yield	Marketable yield	Small tubers	Medium tubers	Large tubers	Specific gravity	Mean tuber weight
	(t ha^{-1})		(%)				(g)
			2015				
Control[1]	29.7	27.5	4.4	68.2	24.1b[2]	1.081	177
MSC	30.2	26.6	4.2	63.2	24.6b	1.080	182
MC	32.5	29.8	5.4	70.1	21.6b	1.080	172
FRC	28.9	26.2	6.0	65.4	25.2b	1.081	164
SSOC	32.2	29.7	5.3	60.9	31.1ab	1.079	182
FPMC	30.5	27.2	5.4	50.9	37.9a	1.080	192
Average	30.7	27.8	5.1	63.1	27.4	1.080	178
			2016				
Control	34.3	32.4	3.8	62.8	31.7a	1.086a	194
MSC	33.0	29.4	2.7	57.2	31.1a	1.087a	194
MC	31.7	28.1	4.6	72.7	15.8b	1.087a	169
FRC	31.8	29.5	3.8	67.2	25.6a	1.087a	188
SSOC	29.9	26.7	3.6	63.7	24.6a	1.087a	185
FPMC	31.7	28.0	2.8	61.0	27.1a	1.084b	192
Average	32.1	29.0	3.6	64.1	26.0	1.086	187

[1] See Table 2.2 for treatment descriptions.

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

at 56 and 69 DAP (Table 2.5). At 40 DAP, petiole NO_3-N was significantly greater for the SSOC treatment (44.1 g NO_3-N kg^{-1}) than for the MC, FRC, FPMC and control treatments (average of 39.4 g NO_3-N kg^{-1}). At 85 DAP, petiole NO_3-N was significantly lower for the MC (3.8 g NO_3-N kg^{-1}) and FRC treatments (5.2 g NO_3-N kg^{-1}) than for all other treatments (average of 9.8 g NO_3-N kg^{-1}). In addition, when compared with reference values adapted from Porter and Sisson (1991), the MC and FRC exhibited N-deficient conditions on 85 DAP (Figure 2.2).

Table 2.5 Effect of compost treatments on petiole NO_3-N concentration (g kg^{-1}) of Shepody potatoes collected on four dates in 2015 in Experiment 1.

Treatment	40 DAP[1]	56 DAP	69 DAP	85 DAP
Control[1]	40.2b[2]	26.7	20.0	9.6a
MSC	41.4ab	26.2	21.3	9.6a
MC	38.3b	23.9	18.0	3.8b
FRC	39.6b	26.3	18.6	5.2b
SSOC	44.1a	25.7	21.8	9.8a
FPMC	39.5b	25.8	22.0	10.7a
Average	40.5	25.8	20.3	8.1

[1] DAP = Days after planting.

[2] See Table 2.2 for treatment descriptions.

[3] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

There was a significant effect of compost treatment on petiole NO_3-N concentration in 2016 at 46, 75, and 88 DAP, but not at 60 and 102 DAP (Table 2.6). At 46 DAP, the MSC treatment had significantly greater petiole NO_3-N concentration (37.0 g NO_3-N kg^{-1}) than the MC, FRC, and control treatments (average of 31.9 g NO_3-N kg^{-1}). In addition, the control treatment had significant lower petiole NO_3-N concentration (29.9 g NO_3-N kg^{-1}), than the SSOC and FPMC treatments (average of 35.1 g NO_3-N kg^{-1}). At 75 DAP, the control treatment had significantly greater petiole NO_3-N concentration (9.9 g NO_3-N kg^{-1}) than MC, FPMC and FRC treatments (average of 5.3 g NO_3-N kg^{-1}). In addition, the FRC treatment (4.4 g NO_3-N kg^{-1}) had significantly lower petiole NO_3-N concentration than the MSC treatment (7.7 g NO_3-N kg^{-1}). At 88 DAP, the SSOC and MSC treatments (average of 6.0 g NO_3-N kg^{-1}) had significantly greater petiole NO_3-N concentration than MC and FRC treatments (average of 2.0 g NO_3-N kg^{-1}). In addition, the MC treatment (1.5 g NO_3-N kg^{-1}) had significantly lower petiole NO_3-N than the control and FPMC treatments (average of 4.3 g NO_3-N kg^{-1}). On 75 and 88 DAP, all

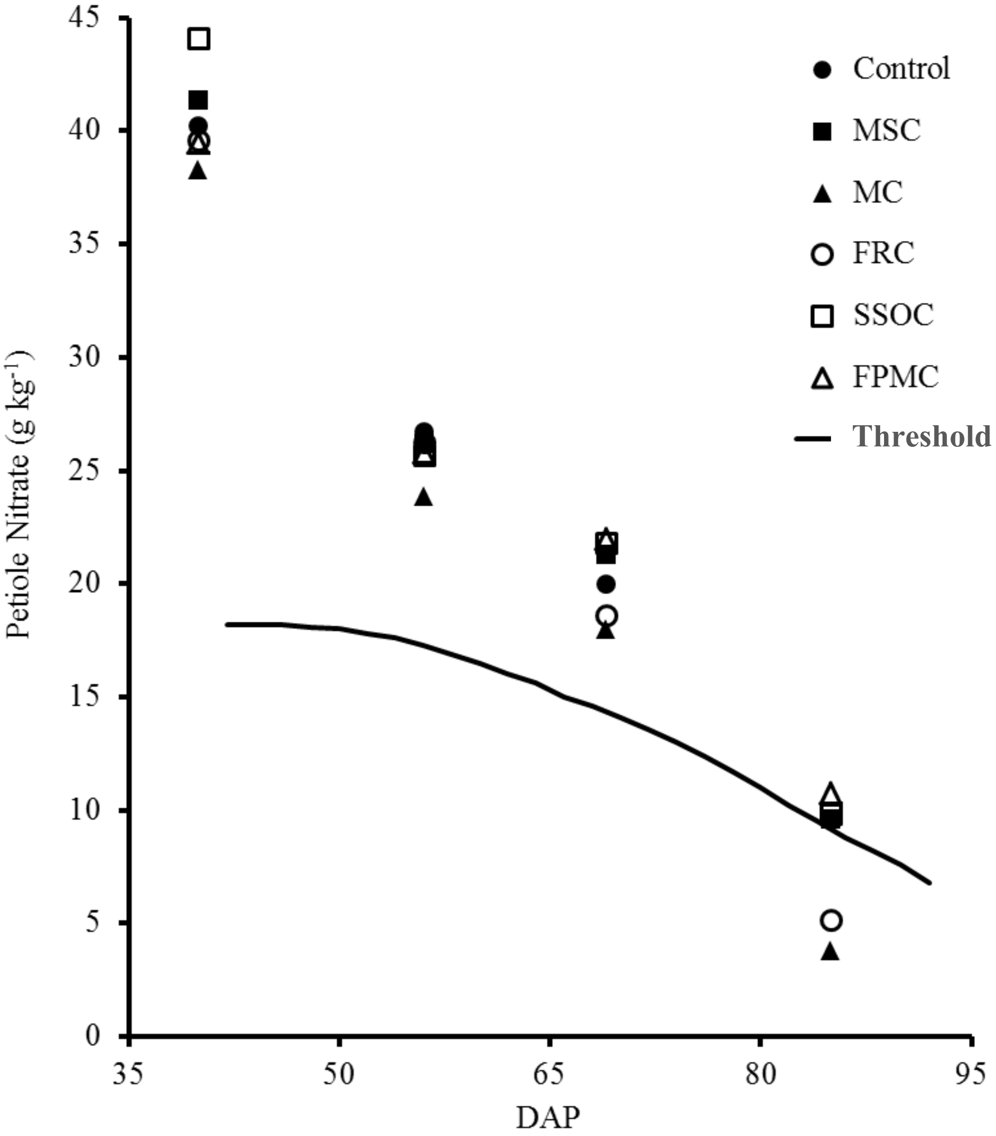

Figure 2.2 Petiole NO$_3$-N concentration of Shepody potatoes collected on four sampling dates in 2015 in Experiment 1 compared with values adapted from Porter and Sisson (1991) for marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

treatments indicated N-deficient conditions when compared with reference values adapted from Porter and Sisson (1991) (Figure 2.3).

2.3.2 Experiment 2

Experiment 2 did not receive inorganic fertilizer and accordingly, the average

Table 2.6 Effect of compost treatments on petiole NO_3-N concentration (g kg^{-1}) of Shepody potato collected on five dates in 2016 in Experiment 1.

Treatment	46 DAP[1]	60 DAP	75 DAP	88 DAP	102 DAP
Control[2]	29.9c[3]	19.3	9.9a	4.6ab	2.3
MSC	37.0a	20.0	7.7ab	6.2a	4.5
MC	32.2bc	17.5	5.1bc	1.5c	1.7
FRC	33.7bc	17.6	4.4c	2.4bc	1.4
SSOC	35.1ab	19.8	7.2abc	5.8a	3.1
FPMC	35.1ab	20.4	6.4bc	3.9ab	3.1
Average	33.8	19.1	6.8	4.1	2.7

[1] DAP = Days after planting.

[2] See Table 2.2 for treatment descriptions.

[3] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

total tuber yield was low in 2015 (14.9 t ha^{-1}) and 2016 (11.3 t ha^{-1}) (Tables 2.7, 2.8). There were significant differences in total tuber yield among compost treatments in both years of Experiment 2. In 2015, the FPMC treatment had significantly greater total tuber yield (16.9 t ha^{-1}) than the MC and FRC treatments (average of 12.3 t ha^{-1}) (Table 2.7). In 2016, the FPMC treatment (14.1 t ha^{-1}) had significantly greater tuber yield than the control, MC, SSOC and FRC treatments (average of 10.0 t ha^{-1}) (Table 2.8). In both years, the FRC treatment had significantly lower dry matter yield than all other treatments.

There were significant differences among compost treatments for plant nutrient uptake in 2015 (Table 2.7). The FRC treatment had significantly lower N uptake (21.0 kg N ha^{-1}) than all other treatments (39.6 kg N ha^{-1}). The SSOC treatment had significantly greater N uptake (45.2 kg N ha^{-1}) than the control treatment (36.7 kg N ha^{-1}). The P and K uptake followed the same pattern with the FRC treatment having significantly lower P and K uptake (3.68 kg P ha^{-1}, 82.5 kg K ha^{-1}) than all other treatments. Also, the SSOC treatment had significantly greater P and K uptake (7.65 kg P ha^{-1}, 82.5 kg K ha^{-1}) than

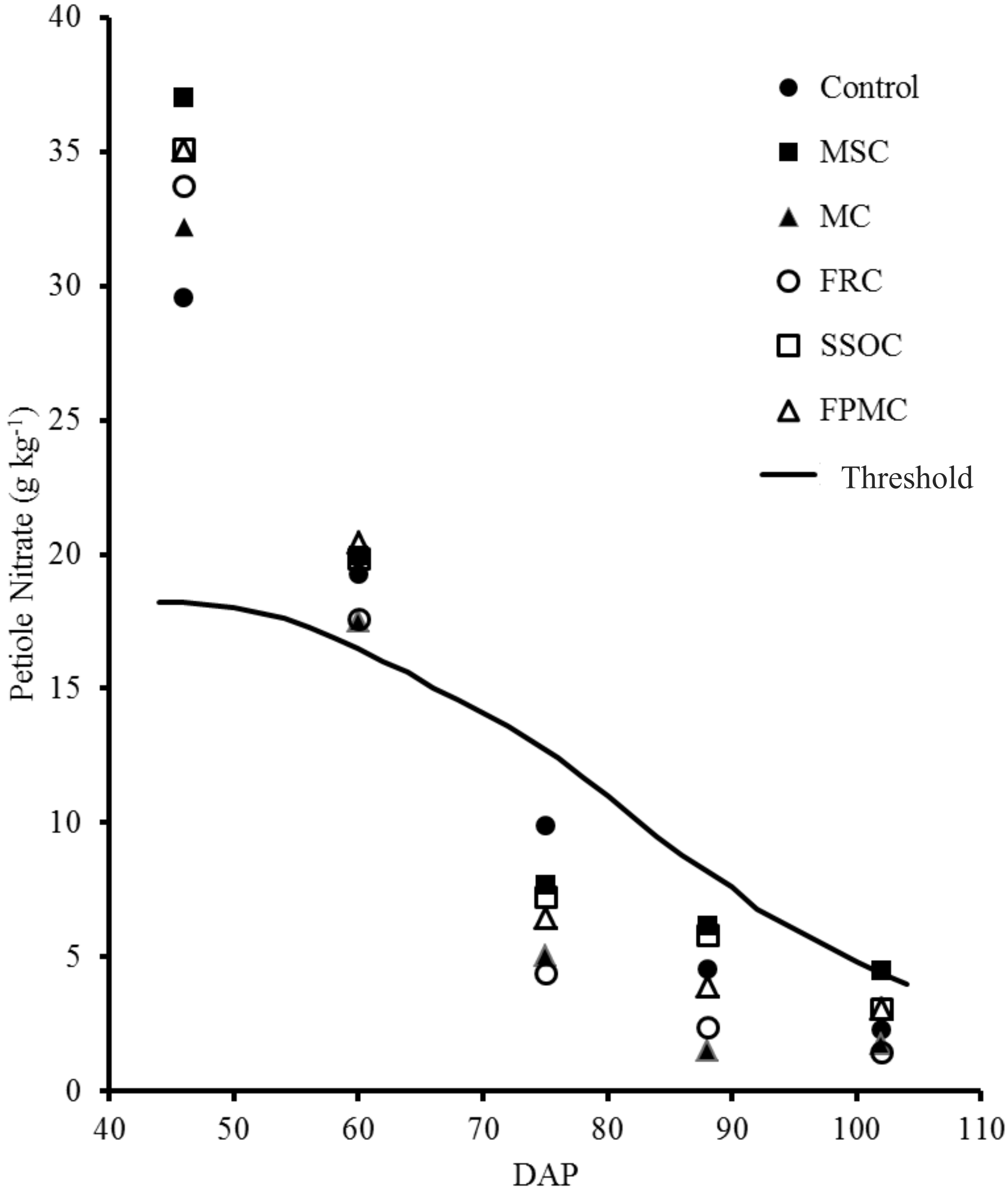

Figure 2.3 Petiole NO_3-N concentration of Shepody potatoes collected on five sampling dates in 2016 in Experiment 1 compared with values adapted from Porter and Sisson (1991) for marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

the control (5.43 kg P ha^{-1}, 57.6 kg K ha^{-1}). The average apparent nitrogen recovery (ANR) was low (0-1%), but positive, for all compost treatments except FRC. The FRC treatment had a negative ANR of -9.20%. Apparent phosphorus recovery (APR) and

Table 2.7 Effect of diverse compost products on total tuber yield, plant nutrient uptake, and apparent nutrient recovery in 2015 following a single application of compost in Experiment 2.

Treatment	Total tuber yield	Dry matter yield	Plant nutrient uptake (kg ha^{-1})			Apparent recovery (%)[1]		
	(t ha^{-1})	(t ha^{-1})	N	P	K	N	P	K
Control[2]	15.7ab[3]	2.46b	36.7b	5.43b	57.6b	-	-	-
MSC	16.5ab	2.89ab	39.2ab	6.57ab	69.6ab	0.69	1.49	10.7
MC	14.9b	2.77ab	37.9ab	6.45ab	67.9ab	0.21	0.45	4.2
FRC	9.7c	1.52c	21.0c	3.68c	35.3c	-9.20	-7.94	-37.6
SSOC	15.9ab	3.38a	45.2a	7.65a	82.5a	0.86	0.56	12.6
FPMC	16.9a	2.69b	39.0ab	6.32ab	65.2b	0.81	0.69	3.9
Average	14.9	2.62	36.5	6.02	63.0	-1.33	-0.95	-1.24

[1] Calculated from treatment means, no statistics presented

[2] See Table 2.2 for treatment descriptions.

[3] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

Table 2.8 Effect of diverse compost products on total tuber yield, plant nutrient uptake, and apparent nutrient recovery in 2016 following two applications of compost in Experiment 2.

Treatment	Total tuber yield	Dry matter yield	Plant nutrient uptake (kg ha^{-1})			Apparent recovery (%)[1]		
	(t ha^{-1})	(t ha^{-1})	N	P	K	N	P	K
Control[2]	11.6bc[3]	2.71a	28.1ab	6.24	49.7ab	-	-	-
MSC	13.6ab	3.28a	35.9a	7.72	69.0a	2.23	0.52	14.9
MC	9.5cd	2.71a	27.7ab	6.86	56.9a	-0.09	-0.04	2.8
FRC	7.9d	1.87b	19.8b	4.78	37.3b	-4.49	-0.15	-20.1
SSOC	10.9c	3.00a	33.3a	7.17	60.0a	0.82	-0.10	11.2
FPMC	14.1a	2.84a	30.5a	6.62	55.3a	0.95	-1.19	2.5
Average	11.3	2.74	29.2	6.57	54.7	-0.12	-0.19	2.26

[1] Calculated from treatment means, no statistics presented

[2] See Table 2.2 for treatment descriptions.

[3] Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

apparent potassium recovery (AKR) were positive for all treatments, except FRC which had negative values of APR and AKR of -7.94, and -37.6%, respectively.

There were significant differences among compost treatments for plant N and K uptake in 2016 (Table 2.8). The FRC had significantly lower N uptake (19.8 kg N ha^{-1}) than the MSC, SSOC and FPMC treatments (average of 33.2 kg N ha^{-1}). The FRC also had significantly lower K uptake (37.3 kg K ha^{-1}) than all other treatments except the control (average of 60.3 kg K ha^{-1}). There were no significant differences in P uptake. All treatments, except MSC and FRC, had low ANR from approximately zero to <1%. The MSC treatment had a low, but not negligible, positive ANR (2.23%). Similar to 2015, the FRC treatment had a negative ANR (-4.49%). Apparent phosphorus recovery was negligible to slightly negative for all treatments. Apparent potassium recovery was positive for all treatments (range to 2.5 to 14.9%) except FRC (-20.1%).

There were significant differences among treatments for soil NO_3-N content (0-30 cm depth) pre-plant and at plant harvest in 2015 (Table 2.9). Pre-plant NO_3-N content was significantly lower for the FRC treatment (7.5 kg NO_3-N ha^{-1}) than all other treatments (average of 10.8 kg NO_3-N ha^{-1}). At plant harvest, the MSC and FPMC treatments had significantly greater soil NO_3-N content (average of 4.9 kg NO_3-N ha^{-1}) than MC and FRC treatments (average of 2.6 kg NO_3-N ha^{-1}). In addition, the FRC treatment had significant lower soil NO_3-N content (2.0 kg NO_3-N ha^{-1}) than all other treatments except MC (4.4 kg NO_3-N ha^{-1}). There were no significant differences among treatments for soil NH_4-N content.

There were significant differences among treatments for soil NO_3-N and NH_3-N content in 2016 (Table 2.9). Pre-plant NO_3-N content was significantly lower for FRC (16.4 kg NO_3-N ha^{-1}) than all other treatments (average of 26.3 kg NO_3-N ha^{-1}). In addition, the control and MC treatments (average of 22.0 kg NO_3-N ha^{-1}) had significantly lower soil NO_3-N content than the MSC, SSOC and FPMC treatments (average of 29.2 kg NO_3-N ha^{-1}). At plant harvest, the FRC treatment had significantly lower soil NO_3-N content (2.1 kg NO_3-N ha^{-1}) than all other treatments (average of 4.2 kg NO_3-N ha^{-1}) except the control (3.2 kg NO_3-N ha^{-1}). Pre-plant NH_4-N content was significantly lower for the control treatment (3.4 kg NH_4-N ha^{-1}) than all other treatments (average of 4.9 kg NH_4-N ha^{-1}), except FPMC (4.3 kg NH_4-N ha^{-1}). In addition, pre-plant soil NH_4-N content was significantly greater for the SSOC treatment (5.6 kg NH_4-N ha^{-1}) than for the control, FRC and FPMC treatments (average of 4.0 kg NH_4-N ha^{-1}). At plant harvest, soil NH_4-N content was significantly lower for the control treatment (4.0 kg NH_4-N ha^{-1}) than all other treatments (average of 6.3 kg NH_4-N ha^{-1}). In addition, the MC and SSOC treatment had significantly greater plant harvest soil NH_4-N content (average of 7.0 kg NH_4-N ha^{-1}) than the FRC and control treatments (average of 4.6 kg NH_4-N ha^{-1}).

2.4 Discussion

The compost products applied in this study were derived from a range of feedstocks including marine wastes, forestry residues, and municipal source separated organics. The properties of the compost products varied. For example, the average C:N ratio ranged from 14.6 to 59.1 and the average C concentration ranged from 152 to 253 g C kg^{-1}. There was also variability in ash content: two products had concentrations of ash > 700 g kg^{-1}, and three products had concentrations of ash < 600 g kg^{-1}. Two products (FRC, MC) had NH_4-N:NO_3-N ratios greater than 5 and undetectable concentrations of nitrate, consistent with immature compost products. The percentage of total N as mineral N (< 4%) was typical of compost products.

Table 2.9 Effect of diverse compost products on KCl-extractable ammonium-N and nitrate-N (0-30 cm depth) at pre-plant and plant harvest in 2015 and 2016 in Experiment 2.

Treatment	Pre-plant		Plant harvest	
	NH_4-N (kg N ha^{-1})	NO_3-N (kg N ha^{-1})	NH_4-N (kg N ha^{-1})	NO_3-N (kg N ha^{-1})
		2015		
Control[1]	13.16	10.50a	5.28	3.83ab
MSC	15.12	11.29a	6.15	4.97a
MC	13.49	10.25a	6.77	3.08bc
FRC	13.21	7.50b	5.77	2.03c
SSOC	12.64	11.59a	7.11	3.92ab
FPMC	12.80	10.52a	6.78	4.83a
Average	13.40	10.27	6.31	3.78
		2016		
Control	3.42c	22.47b	3.98c	3.19ab
MSC	4.82ab	29.81a	6.37ab	4.41a
MC	4.78ab	21.50b	6.93a	3.84a
FRC	4.33b	16.36c	5.27b	2.07b
SSOC	5.58a	28.59a	7.06a	4.69a
FPMC	4.28bc	29.08a	5.89ab	3.83a
Average	4.53	24.63	5.92	3.67

[1] See Table 2.2 for treatment descriptions.

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

Despite testing a variety of compost products at a high application rate chosen to rapidly improve soil quality, no significant yield benefits were observed following application of these products in combination with mineral fertilizer to a potato production system managed conventionally. The average total yield in 2015 and 2016 for the untreated control plots were 29.7 and 34.3 t ha^{-1}, respectively. For compost treated plots, average total yields were 30.9 and 31.7 t ha^{-1} in 2015 and 2016, respectively. These yields were lower than provincial averages of 39.6 t ha^{-1} in 2015 and 38.3 t ha^{-1} in 2016 (Statistics Canada 2017). In 2015, total yield in this experiment was likely reduced by severe Colorado potato beetle (CPB) damage and delayed planting. Defoliation of potato plants by CPB have negated compost-induced yield benefits in other studies (LaMondia et al. 1999). In 2016, water-logged soil conditions may have resulted in lower yields and negated a compost-induced yield benefit. For example, in Maine, compost-induced yield benefits were more frequently observed in drier years or under drier conditions in potato production (Larkin et al. 2011; Bernard et al. 2014). In 2016, petiole NO_3-N concentrations on 75 and 88 DAP in 2016 are consistent with N-deficient soil conditions under all treatments. Although petiole NO_3-N concentration can also be reduced by dry weather (Porter and Sisson 1991), precipitation in July and August of 2016 approached or exceeded 30 year normals (Table 2.1). Nitrogen deficiencies may have been the result of water-logged soil in the two weeks following planting and fertilizer banding which would have promoted N-leaching and denitrification (Gagnon et al. 1997). This may have resulted in lower tuber yields in 2016.

Despite the lack of total or marketable tuber yield response, tuber size and quality responded to the compost treatments. In 2015, tubers were significantly larger under the FPMC treatment. Increases in the size and number of large sized tubers following compost application have been observed in several other studies (LaMondia et al. 1999; Porter et al. 1999; Bernard et al. 2014). However, it is unclear whether this response was due to nutrient or non-nutrient effects of this compost product. In 2016, tuber size and quality was negatively affected by the application of MC and FPMC treatments, respectively. The MC resulted in a reduction in large-sized tubers and the FPMC resulted in a reduction in specific gravity. It is unclear what caused these quality reductions.

In the experiment receiving no mineral fertilizer (Experiment 2), the average total tuber yield and plant N uptake of unamended (control) plots were 15.7 t ha^{-1} and 36.7 kg

N ha^{-1} in 2015, and 11.6 t ha^{-1} and 28.1 kg N ha^{-1} in 2016. These values are low, but not unexpected. The plant N accumulation from potatoes grown under no fertilizer N at 56 sites across New Brunswick and Prince Edward Island ranged from 26 to 162 kg N ha^{-1} (Zebarth et al. 2005). The lower plant N accumulation in 2016 was likely the result of the preceding potato crop in 2015, returning minimal crop residues to the soil or greater in-season N losses, as well as water-logged spring conditions resulting in N losses.

The concentrations of soil mineral N in Experiment 2 in 2015 and 2015 were also low, but not unexpected for soils receiving no fertilizer N. The average pre-plant NH_4-N and NO_3-N content of unamended (control) plots were 13.2 kg NH_4-N ha^{-1} and 10.5 kg NO_3-N ha^{-1}, respectively in 2015, and 3.4 kg NH_4-N ha^{-1} and 22.4 kg NO_3-N ha^{-1} in 2016. Zebarth et al. (2005) found the mean soil NH_4-N and NO_3-N content at planting ranged from 5 to 75 kg NH_4-N ha^{-1} and 4 to 30 kg NO_3-N ha^{-1} respectively, on 56 sites of potato receiving no fertilizer N. The low total tuber yields, low soil mineral N content, and low plant N uptake in Experiment 2 suggest that this field site has low inherent N fertility.

In this experiment, compost products were fall-applied. Fall application of organic amendments reduces the potential for nutrient immobilization in the spring and ensures sufficient time (<120 days) between amendment application and potato harvest. In addition, potato producers may not have time to apply compost in the spring if field conditions are too wet or if it will delay planting. However, nutrients (e.g. nitrate) applied in the fall are especially susceptible to loss by over-winter leaching in the Maritime climate. Applying compost in the spring would reduce losses and the mineral N applied by these products would be readily available for plant uptake. For example, the SSOC applied in 2014 contained a concentration of mineral-N of 631 mg N kg^{-1}. If this product was applied prior to planting, this would be equivalent to approximately 28 kg N ha^{-1} which would be readily available for plant uptake.

The compost treatments affected the availability of N in both experiments. Evidence of a marginal, but significant, increase in N-supply was demonstrated by SSOC, and to a lesser extent, the MSC and FPMC treatments. The SSOC increased petiole nitrate-N concentration in Experiment 1, and increased dry matter yield, plant N uptake, and soil mineral N content in Experiment 2 relative to the no compost control treatment. Compared with the control, the FPMC treatment increased tuber size, reduced specific gravity, and increased petiole NO_3-N concentrations in Experiment 1 and increased total tuber yield and soil mineral N content in Experiment 2. The MSC increased petiole NO_3-N concentrations in Experiment 1, and increased soil mineral N in Experiment 2. The NH_4-N:NO_3-N ratios of these products ranged from 1.0 and 2.5, which is consistent with mature composts. In addition, the C:N ratios ranged from 14.6 to 25.6. As the C:N ratio of compost decreases below the 20-30 range, net mineralization may be expected following application of organic amendments to soil (Sharifi et al. 2014). However, these may depend on the composition of N and C in the amendment (Miller et al. 2009). Despite some evidence of increased N-supply, overall the SSOC, FPMC and SSOC supplied minimal nitrogen to growing potato crop. The apparent nitrogen recovery from these products was approximately zero in 2015 and <2% in 2016. In addition, no compost product was able to increase N uptake relative to the control in 2016 following two applications. These results were not unexpected. The degradation of mature compost is slow and the quantity of N mineralized from compost can be near negligible in the year after application (Lynch et al. 2008; Sharifi et al. 2009).

Evidence of N immobilization was demonstrated by FRC, and to a lesser extent, the MC treatment. Compared with an un-amended control, the FRC reduced petiole NO_3-N concentrations in Experiment 1 and reduced total tuber yield, reduced dry matter yield, reduced plant nitrogen uptake, and reduced soil mineral N content in Experiment 2. The evidence of N immobilization from FRC is not unexpected. This product had a high C:N ratio and high NH_4-N:NO_3-N ratio, consistent with an immature product. The FRC was also rich in bark and other lignin-rich products with lower C degradability that have been shown to potentially immobilize N when applied to soil (Gagnon et al. 1997) and may explain the resulting reduction in plant N uptake observed in this study. The MC product had a lesser effect on N-supply. The average C:N ratio this product was 22.5; however when comparing compost products from a variety of feedstocks and sources, the degree of degradability of carbon in compost controls the release of nutrients to a greater extent than the C:N ratio (Gagnon and Simard 1999). The MC product was partially derived from ground wood fines which may have affected degradability. In addition, this product had a NH_4-N:NO_3-N ratio >5 and undetectable nitrate-N, both of which are consistent with an immature compost. Despite evidence of a reduction in N supply following the application of FRC compost, there was no negative yield response observed in Experiment 1. This suggests that this product can still be used to build up OM when applied at high-rates in conventionally fertilized potato production. However, in the absence of mineral fertilizers, the product resulted in significant total yield losses. The FRC product also had an additional benefit: reducing soil NO_3-N content in 2016 at plant harvest in Experiment 2, relative to the control. Therefore, applying this product after a rotation crop with high residual soil nitrate would promote net immobilization and thereby reduce the risk of over-winter losses.

Plant uptake of P and K was measured in Experiment 2 to examine the effects of compost on the availability of these nutrients. However, the combination of N-limiting conditions and high spring soil test P and K for this field site in 2015 likely limited the usefulness of this approach as plant P and K uptake was more likely influenced by crop growth rate based on N availability than on soil P and K availability.

2.5 Conclusions

In this study, compost did not have a significant effect on yield following one or two annual applications under conventional potato production practices (e.g. with mineral fertilizers) in this study. However, potential yield responses may have been negated by significant pest damage in 2015 and wet soil conditions in 2016. Despite a lack of yield response, tuber size was significantly increased in 2015 by FPMC product. It is unclear whether this was due to nutrient or non-nutrient benefits of compost. In 2016, two applications of compost negatively affected the size and quality of tubers: the FPMC reduced specific gravity and the MC reduced the percentage of large-sized tubers. Investigating the yield-effect of these diverse compost products over various application rates in a moisture-controlled environment would help to quantify yield benefits/detriments from compost, and better differentiate nutrient and non-nutrient effects.

The compost products affected the availability of nitrogen. The SSOC, FPMC and MSC treatment showed evidence of N-supply to the growing potato crop, although limited in magnitude. The MC and FRC treatment showed evidence of N immobilization and reduced plant N supply. Despite strong evidence of N immobilization following application of FRC and reductions in tuber quality in 2016; none of the compost products negatively affected total or marketable potato yield in Experiment 1. This does provide some re-assurance that high-carbon immature compost products (such as FRC) may be used as soil conditioners, as long as they were applied in addition to conventional inorganic fertilizers. However, when these compost products are applied as soil fertilizers in potato systems (e.g. in organic potato production), immature products may result in N immobilization and yield reductions. Having an indication of the maturity, quality and degradability of compost products is an important consideration for potato producers looking to apply compost, especially as soil fertilizers.

CHAPTER 3.0 EFFECT OF DIVERSE COMPOST PRODUCTS ON SOIL QUALITY IN A POTATO PRODUCTION SYSTEM

3.1 Introduction

High quality soil is a prerequisite for sustaining agricultural productivity. However, the soil organic matter (SOM) content of intensively cropped potato fields in New Brunswick has been declining since the early 1960s (Eilers et al. 2010; Rees et al. 2014). Low levels of SOM, 2-3.5%, are commonly found in potato-producing soils in the province (MacMillan and Buchanan 1988).Exposure to frequent soil disturbance, as observed in potato production, aerates soils and breaks down aggregates, exposing organic matter and increasing decomposition (Grandy et al. 2002). In addition, potatoes return minimal quantities (estimated at 1500 kg ha^{-1}) of low C:N ratio residue to the soil, resulting in rapid OM decomposition (Grandy et al. 2002). Unless major changes in crop management practices occur in the province, the SOM content is expected to continue to decline (Eilers et al. 2010). As SOM is depleted, soil functioning is hindered through degradation of soil structure and a reduction in biological activity (Haynes and Tregurtha 1999; Gagnon et al. 2001). Ultimately, the depletion of soil quality has reduced potato productivity in New Brunswick (Saini and Grant 1980; Gagnon et al. 2001; Grandy et al. 2002; Rees et al. 2014) and large carbon inputs are required to overcome SOM depletion and reverse trends in productivity and soil quality (Gagnon et al. 2001).

Soil quality (SQ) is defined as 'the capacity of a soil function to sustain productivity, maintain environmental quality, and promote plant and animal health' (Doran and Parker 1994). By integrating a range of physical, chemical, and biological soil properties or SQ indicators, a holistic assessment of soil quality can be obtained and used to compare different soil management systems (Haynes and Tregurtha 1999; Nesbitt and Adl 2014; Li et al. 2015). For a given SQ assessment, the indicators that are selected should be sensitive to changes in soil management, related to relevant soil functions, and consistent and reproducible (Gregorich et al. 1994; Moebius-Clune et al. 2016). In New Brunswick's rain-fed potato production, high quality soils are those that can hold plant available water, resist soil erosion and compaction, store and supply plant nutrients, and contain a minimum of 20.0 g kg^{-1} of SOC (Rees et al. 2014). Therefore, the indicators selected for assessing SQ in this soil system should reflect these critical soil functions.

Soil organic matter has been identified as the most important SQ indicator (Gregorich et al. 1994; Li et al. 2015). As total soil C may be slow to change, quantifying more labile fractions of C (e.g., particulate organic matter, microbial biomass carbon, and permanganate oxidizable carbon) can provide sensitive and early indicators of changes in SQ and provide a measure of soil biological activity (Li et al. 2015). Soil invertebrates are sensitive to physical and chemical disturbances to soils and therefore, are also potential indicators of soil quality (Blair et al. 1996). Specifically, springtails (Class: Collembola) are an attractive SQ indicator because they are relatively easy to extract and identify, have been positively correlated with soil quality in other studies (Parisi et al. 2005), and have been identified as a good bio-indicator of changes in soil management (Behan-Pelletier 2003; Nelson et al. 2011; Twardowski et al. 2016). Soil physical properties relating to soil structure and water retention are critical measures of SQ in intensively managed, non-irrigated potato production systems. These measures include: soil water holding capacity, aggregate stability, resistance to penetration, and saturated hydraulic conductivity. To assess changes in chemical properties, cation exchange capacity, macronutrient content, and soil pH can also be measured as these are strongly related to soil fertility and plant nutrient availability.

The application of composted organic amendments can increase SOM and improve the quality of soils in potato production. Due to stabilization of carbon during the composting process, the application of compost has greater potential to increase SOM than more labile organic inputs, such as crop residues or animal manures. In eastern Canada and Maine, compost application has increased macroaggregation and soil organic matter content (Gagnon et al. 2001), soil water holding capacity (Foley and Cooperband 2002; Carter et al. 2004), particulate organic matter (Carter et al. 2004; Sharifi et al. 2014), soil microbial biomass and activity (Sharifi et al. 2014) and decreased soil bulk density (Carter et al. 2004) of soil in potato production. However, changes in soil properties following compost application are not consistent across compost treatments or across studies in potato production. Sharifi et al. (2014) observed greater increases in microbial biomass carbon (MBC) under municipal solid waste compost (applied at 12 Mg ha^{-1} wet weight) than composted paper mill biosolids (applied at 30 Mg ha^{-1} wet weight) in a three-year organic potato rotation in Nova Scotia. However, no difference in MBC was observed by Carter et al. (2004) when compost (a mix of potato, sawdust, and manure feedstock) was applied to a potato rotation in Prince Edward Island. Understanding how different quality composts affect SQ and SOC will provide valuable information in targeting compost products to meet specific agronomic and environmental goals (Carter et al. 2004; Lynch et al. 2005).

The objective of this study was to evaluate five compost products with diverse properties for their effects on SQ through an assessment of selected biological, chemical and physical soil quality indicators. In particular, indicators were selected based on the evaluation of key soil functions for intensive potato production in the region (Figure 3.1).

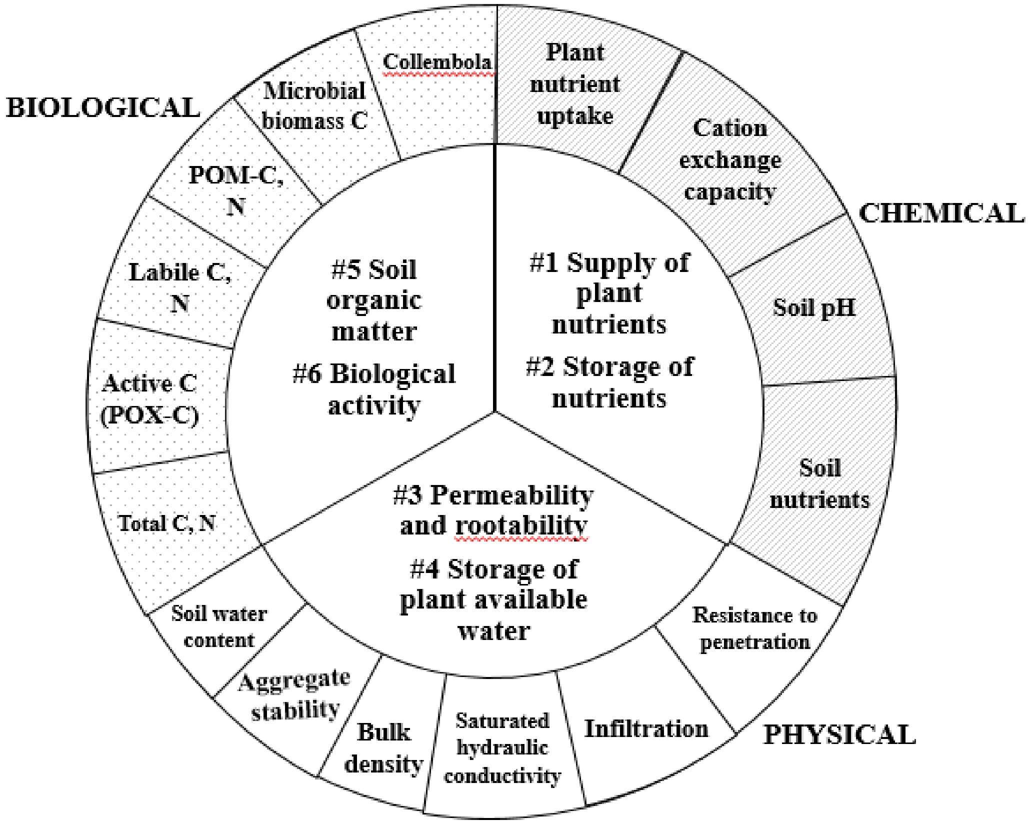

Figure 3.1 Key soil functions (inner circle) and associated soil quality indicators (outer circle) measured in this study.

3.2 Materials and Methods

3.2.1 Experimental Site and Design

This study used one field experiment (Experiment 1 as described previously in Chapter 2) established in the fall of 2014 at the Fredericton Research and Development Centre of Agriculture and Agri-Food Canada, Fredericton, New Brunswick, Canada (Lat. $45^0$55'N; Long. $66^0$36'W). Soils and cropping history at the site were previously described (Chapter 2).

The objective of this field study was to quantify the effects of diverse compost products on SQ indicators. The experiment used a randomized complete block design with six treatments and four replicates. Individual plots were 8 m long by six potato rows (5.46 m) wide. Treatments included five compost products and a no compost control (Tables 2.1, 2.2) and were previously described (Chapter 2).

Compost treatments were applied (45 Mg dry weight ha^{-1}) October 9-14, 2014 and the plots cropped to potatoes (cv. Shepody) in 2015. The same compost treatments were re-applied October 15-16, 2015, and plots cropped to potatoes again in 2016, as previously described (Chapter 2). Recommended practices for fertilization, tillage operations and the control of insects and disease followed accepted industry standard practices (Bernard et al. 1993; Zebarth et al. 2007).

Composite soil samples were collected from each plot on May 27, 2015 (spring pre-plant), September 29, 2015 (fall post-harvest), May 12, 2016 (spring pre-plant) and September 26, 2016 (fall post-harvest). Each composite sample was comprised of 8-10 cores (0-15 cm depth) collected using a random sampling strategy using a Dutch auger. Soil samples were used to assess several soil properties including soil pH, cation exchange capacity (CEC), soil nutrients, soil water-holding capacity (WHC), aggregate stability (SAS), total C and N, microbial biomass carbon (MBC), particulate organic matter (POM), soil respiration (mineralizable C), and permanganate oxidizable carbon (POX-C) (Figure 3.1). On each sampling date, an additional composite sample, comprised of three cores (15 cm high and 5 cm in diameter), was collected per plot for extraction of micro-arthropods.

Intact core samples (4.05 cm high and 5.6 cm in diameter), five per plot, were collected once during the growing season in 2015 and 2016 to determine saturated hydraulic conductivity (K_{sat}). The same cores were used for determining soil bulk density (BD) and gravimetric water content (GWC).

3.2.2 Soil Chemical Properties

Composite soil samples collected May 27, 2015 and May 12, 2016 were air-dried and passed through a 2 mm sieve. Initial testing indicated that little compost was discarded in >2 mm fraction. These samples were analyzed for soil chemical properties including soil pH (1:1 water), CEC, and soil test Mehlich-3 extractable nutrients by a commercial laboratory.

3.2.3 Soil Physical Properties

To assess the ability of soil to hold plant-available water, soil water content and WHC were determined. Data loggers Em50 (Decagon Devices) were installed in potato hill guard rows during the growing season in 2015 and 2016. Data loggers were installed in replicates 1, 2 and 3 in two treatments: the no compost control and FRC treatment. In each plot, three probes (5TE, Decagon) were placed at a depth of 7.5 cm and two probes were placed at a depth of 22.5 cm to measure soil volumetric water content (VWC). In addition, a hand-held Decagon ProCheck with 10HS probe (Decagon) was used to determine VWC in all plots every seven days from June to September in 2015 and 2016. Eight readings were obtained per plot with the probe inserted into the side of the hill perpendicular to soil surface to a depth of 10 cm. Water-holding capacity was determined on composite soil samples collected on September 29, 2015 and September 26, 2016. Soil samples were air-dried and passed through a 2 mm sieve. Gravimetric water content at -

33.3 and -1500 kPa matric potential was determined using the pressure plate method (Topp et al. 1993) to represent field capacity and permanent wilting point, respectively. Approximately 30 g of soil was used and placed in cores with a height of 10 mm. The soil WHC was defined as the difference in GWC between field capacity and permanent wilting point.

To assess water infiltration and potential runoff from the potato hill, soil aggregate stability, water infiltration, and saturated hydraulic conductivity were determined. Aggregate stability was determined on composite soils sampled May 27 and September 29, 2015, and May 12 and September 26, 2016 using an Eijkelkamp Wet Sieving Apparatus according to a method modified from Angers and Mehuys (1993). Briefly, 4.0 g of air-dried soil aggregates 1-2 mm in size were placed into a 250 µm sieve, gently moistened, and shaken for 3 min in water. The particles and aggregate fragments that broke loose and passed through the sieve were filtered, dried and weighed. The remaining particles in the sieve were shaken in a 2 g L^{-1} NaOH dispersing solution for intervals of 5 min, until there were only sand particles remaining in the sieve. The soil aggregate stability (SAS) was calculated as:

$$\text{SAS}\ (\%) = [(W_{SS} - W_S) / (W_T - W_S)] \times 100$$

where W_{SS} = dry weight of soil in dispersing solution, W_S = dry weight of sand, and W_T = total dry weight.

A Cornell Sprinkler Infiltrometer was used to measure infiltration rates (Ogden et al. 1997) in 2015. One measurement was obtained per plot on either July 27 or July 29, 2015. A 24.1 cm diameter steel infiltration ring with a runoff tube was inserted into the potato hill to a depth of 7.5 cm. The sprinkler unit was placed 10 to 15 cm above the ring and the initial height of the water column inside was recorded (H_1). A constant simulated rainfall rate of 25 to 30 cm hr^{-1} was maintained by adjusting the height of an air-entry tube. In general, this rate ensures ponding will occur for each measurement and will allow a measurement period to occur within an hour, preventing the requirement for refills. Runoff was collected in a beaker and the volume of runoff was recorded within the given time interval, t = 3 min. After three consecutive readings of runoff, the average runoff volume (V_t) was calculated. The final height (H_2) and final time (T_f) were also recorded. The runoff rate (r_{ot}; cm min^{-1}) was calculated as:

$$ro_t = Vt / (A * t), \qquad [1]$$

where A, the area of the ring, was 457.3 cm^2. The infiltration rate (r; cm min^{-1}) was calculated as:

$$r = [H_1 - H_2]/T_f \qquad [2]$$

where, $[H_1 - H_2]$ was the change in height of the water column.

Results obtained with the Cornell Sprinkler Infiltrometer in 2015 were variable. In addition, the time required for each measurement (1-2 hours) made it difficult to compare plots under similar soil conditions. Therefore in 2016, Mini Disk Infiltrometers (Decagon Devices, Inc.) were used to obtain an in-field measurement of infiltration. This device provided a more rapid measurement of infiltration (10 to 20 min per measurement), therefore allowing multiple measurements per plot, but on a smaller surface area (approximately 15.9 cm^2). Mini Disk Infiltrometers were used to measure unsaturated hydraulic conductivity from July 19 to 27, 2016. Briefly, the Infiltrometer was filled with water and placed on a smooth and level location on the potato hill (Mini Disk Infiltrometer Manual, Decagon Devices, Inc.). A ring stand and clamp was used to hold the Infiltrometer in place. The decrease in the level of water in the Infiltrometer was recorded every 30 seconds, until at least 15 mL of water had infiltrated. The unsaturated hydraulic conductivity of soil was determined by the method proposed by Zhang (1997).

Saturated hydraulic conductivity was determined using the constant head method using intact soil cores. Five soil cores (4.05 cm high and 5.6 cm in diameter) were collected per plot from approximately 2 to 6 cm depth in the potato hill. This depth was chosen to correspond to the depth of insertion of the Cornell infiltration ring (0 to 7.5 cm), ensure that intact cores were collected that did not disturb the growing tubers, and avoid the very loose soil at the top of the potato hill. Samples were obtained mid-season from July 27 to August 11, 2015 and July 11 to 29, 2016. Saturated hydraulic conductivity was determined by the constant head method on a Laboratory Permeameter (Eijkelkamp). Soil cores were saturated for at least 24 h prior to analysis. A derivation of Darcy’s Law, a flux equation used to describe one-dimensional vertical flow of water in soils, was used to calculate permeability (Klute and Dirksen, 1986). Soil bulk density and GWC were also determined on these cores. Bulk density values were corrected for coarse fragments larger than 2 mm, assuming the stones had a density of 2.65 Mg m^{-3}.

To measure the resistance of soil to compaction, a recording digital penetrometer (Eijkelkamp Penetrologger, Eijkelkamp) was used to measure soil resistance to penetration in the potato hill. The penetrometer cone had a basal area of 1 cm^2 and angle of 60^0. The device was inserted into the soil at a constant rate of approximately 2 cm s^{-1}. Penetrometer readings were obtained on June 24 and 25, 2015 (9 and 10 days after hilling) and June 18, 2016 (11 days after hilling). Readings were also obtained on August 15, 2015 and August 30, 2016 during tuber bulking. The penetrometer was inserted to a depth of 30 cm, except on August 15, 2015 when it was inserted to a depth of 25 cm. Beyond these depths, the average resistance to penetration exceeded 3 MPa, regarded as the upper limit for uninterrupted root growth (Stalham et al. 2005). Ten penetrometer measurements were obtained per plot and values were expressed at 1 cm increments from the soil surface. To analyze the data, the mean resistance to penetration was determined for the following depth intervals from the soil surface: 0-5 cm, 6-10 cm, 11-15 cm, 16-20 cm, 21-25 cm, and 26-30 cm.

3.2.4 Soil Biological Properties

Particulate organic matter (POM) was measured on composite soil samples collected on June 4 and September 29, 2015, and May 12 and September 26, 2016 Air-dried soil was passed through a 2 mm sieve and POM was determined by the method of Gregorich and Ellert (1993). Briefly, 100 mL of 5 g L^{-1} sodium hexametaphosphate solution was added to 25 g of soil and shaken for 60 min. The suspension was poured through a 53 µm sieve and rinsed with distilled water. The sand and macro-organic matter or sand-sized fraction (SSF) retained on the sieve was dried at 60°C and weighed. A Retsch Mixer Mill MM400 (Verder Scientific, Germany) was used to grind a sub-sample of the SSF and a sub-sample of the whole soil to pass through a 250 µm sieve. The concentrations of carbon and nitrogen in whole soil and SSF were determined by dry combustion on a 0.2 g sub-sample using an Elementar varioMACRO apparatus (Elementar Americas Inc., Mt. Laurel, NJ).

Permanganate oxidizable carbon (POX-C) was measured on composite soil samples, collected on June 4 and September 29, 2015, and on May 12 and September 26, 2016. Air-dried soil was passed through a 2 mm sieve. Permanganate oxidizable carbon was determined in duplicate according to the method of Weil et al. (2003) modified by Culman et al. (2012). Air-dried soil (2.5 g) was mixed with 0.02 M $KMnO_4$. The mixture was shaken for 2 min at 240 rpm on a lateral shaker and allowed to settle for 10 min. A 0.5 mL aliquot of supernatant was diluted in 49.5 mL of deionized water and the absorbance was determined at 550 nm on a Biochrom Libra S60 Spectrophotometer (Biochrom Ltd., UK). The absorbance of four standard solutions was also determined (0.00005, 0.0001, 0.00015, and 0.0002 mol L^{-1} $KMnO^4$). Permanganate oxidizable carbon was calculated as (Culman et al. 2012):

$$\text{POX-C (mg kg}^{-1}\text{)} = \frac{[0.02 \text{ mol L}^{-1} - (\text{a}+\text{b}*\text{Abs})]*[9000 \text{ mg C mol}^{-1}]*[0.02 \text{ L}]}{\text{Wt}}$$

where 0.02 mol L^{-1} = the concentration of the initial $KMnO_4$ solution; a = intercept and b = slope of standard curve; Abs = absorbance of sample; 9000 mg C mol^{-1}= amount of C oxidized by 1 mol of MnO_4 changing from Mn^{7+} to $Mn^{4+;}$ 0.02 L = volume of $KMnO_4$ solution reacted, and Wt = weight of oven dried soil in reaction.

Two labile C respiration assays were completed. The first assay, the 24 h burst test, was equivalent to the 24 h burst test of Haney (Haney et al. 2008) which measures CO_2-C emissions over a 24 h period following rewetting of air dry soil. The second assay was the soil respiration rate measured ten days after soil rewetting, to avoid any burst of CO_2-C emissions associated with soil rewetting. The soil respiration rate was determined at standard soil temperature and water content and was assumed to be a measure of mineralizable C in the soil. Composite soil samples collected on June 4 and September 29, 2015, and on May 12 and September 26, 2016 were air-dried and passed through a 2 mm sieve. Briefly, 40 grams of soil was placed in a 50 mL perforated beaker developed for the Solvita test (Solvita and Woods End Laboratories). The perforated beaker was then placed into a 500 mL Mason jar containing 20 mL of water, which allowed the water to wet the soil in the perforated beaker. The Mason jar was immediately covered with a lid containing a septum and 20 mL of compressed air was added. Samples were incubated at 25°C for 24 h and a 20 mL gas sample was collected and injected into a 12 mL pre-evacuated exetainer. The concentration of CO_2-C was determined using a Varian Star 3800 Gas Chromatograph (Varian, Mississauga, ON) as described in Burton et al. (2008). The burst test value was calculated as the mass of C in the headspace at the end of the 24 h incubation per unit weight of oven-dried soil. Following the collection of 24 h burst test gas sample, the lid was replaced with Parafilm and samples were incubated an additional nine days at 25°C. At the end of this period, the Parafilm was removed and the headspace was then flushed with compressed air for 20 seconds. A lid containing a septum was placed on the jars and 80 mL of compressed air was added. A 20 mL gas sample was collected at 0, 30, 60 and 90 min using a syringe and placed into a pre-evacuated exetainer. A subsample of moist soil (~10 g) was then collected and used to determine GWC. Taking in account the volume of air in the headspace at each time point and the removal of CO_2 by gas sampling, the mass of C kg per g of air-dried soil was determined at each time point. The respiration rate was then calculated as the slope of the regression of the mass of C per kg of air-dried soil against time.

Labile N was determined using a 14 day aerobic incubation on composite soil samples collected on June 4, 2015, and on May 12, 2016. The flush of mineral N occurring in the 14 days of incubation following rewetting of air-dry soil has been defined as *Pool I*, which represents mineralizable of a labile organic N pool and may provide a more robust index of N availability when considered in addition to pre-plant soil mineral N in eastern Canada (Sharifi et al. 2007; Nyiraneza et al. 2012). Briefly, air-dried soil was passed through a 2 mm sieve. In triplicate, a 30.0 g soil sample was mixed with 30.0 g of Ottawa sand. Using a Buchner funnel apparatus with detachable funnel and Q2 filter paper, samples were leached for inorganic N using 200 mL of 0.01 M $CaCl_2$ under vacuum filtration. Aliquots of 25 mL of $CaCl_2$ solution were poured slowly and uniformly over the soil in the funnel to minimize sample disturbance, but ensure effective leaching. The volume of leachate collected was determined. Following leachate collection, the detachable funnel was removed. The samples were covered on top and bottom with Parafilm and were placed in an incubation chamber at 25°C for 14 days. Following incubation, the Parafilm was removed, the detachable funnel reattached, and the samples were leached a second time, as described above. The volume of leachate was recorded. Leachate was analyzed for concentrations of NO_3-N and NH_4-N on a QuikChem 8500 Series 2 Flow Injection Auto-Analyzer (Lachat Instruments). Briefly, nitrate, reduced to nitrite by hydrazine sulfate with a copper catalyst, was diazotized with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride, producing a magenta colour (QuikChem Method 90-107-04-2-A). Briefly, ammonia was reacted with sodium salicylate and sodium hydroxide, followed by addition of hypochlorite to produce an emerald green colour. Ethylenediaminetetraacetic acid eliminates precipitation of calcium and magnesium hydroxides and sodium nitroprusside intensifies colour for reading (QuikChem Method 90-107-06-3-A). The initial leaching, prior to incubation, represented $CaCl_2$-extractable NO_3-N and NH_4-N, and the soil mineral N extracted after 14 days of incubation represented *Pool I* or labile N.

Microbial biomass carbon (MBC) was determined by fumigation-extraction on composite soil samples collected on September 29, 2015 and September 26, 2016, as described by Voroney et al. (1993). Field-moist soil was passed through a 4.75 mm sieve and 25 g of each soil sample was weighed into two flasks. One set of flasks was placed in a glass desiccator in a fume hood for fumigation. The other set of flasks was immediately extracted by adding 50 mL of 0.5 M K_2SO_4 and shaking for 1 h on a lateral shaker. After shaking, the samples were filtered through Q2 filter paper and stored at -27^{0}C until analyzed for dissolved organic carbon using a Technicon Auto Analyzer II system, following Technicon Industrial Method #455-76 W/A (Technicon Industrial Systems, Terrytown, MA). For fumigation, a 150 mL beaker containing approximately 25 mL of chloroform and boiling chips was placed in the desiccator along with the flasks of soil. A vacuum was applied to seal and evacuate the desiccator and force the chloroform to boil vigorously for approximately 1 min. After 24 h, the desiccator was vented by a vacuum three times for approximately 30 seconds each time. The soils were extracted with 0.5 M K_2SO_4 and analyzed as described above. Microbial biomass C was determined by dividing the change in soluble C between fumigated and un-fumigated soil samples by a factor of 0.25 to correct for the efficiency of C extraction, a coefficient used in other studies of eastern Canadian soils (Carter et al. 2004; Lynch et al. 2005).

On each sampling date, three soil cores (15 cm high and 5 cm in diameter) were collected on June 4 and September 29, 2015 and May 12 and September 26, 2016 for quantification of Collembola. The entire composite sample of three cores was placed in a modified Tullgren funnel apparatus at 15^{0}C for extraction for micro-arthropods, as previously described for compost (Winter and Behan-Pelletier 2008; Carter et al. 2009).

Collembola were quantified and identified to family level under dissecting and compound microscopes. Soil Collembola abundance was determined as the number of individuals per sample and richness was defined as the total number of families identified (Neave and Fox 1998).

3.2.5 Statistical Analyses

Statistical analyses were performed separately for years 2015 (after one compost application) and 2016 (after two consecutive years with compost application). Data were analyzed using the General Linear Model procedure in Minitab 17 Statistical Software (Version 17, Minitab Inc., USA) as a completely randomized block design with six treatments and four replicates. Normality and constant variance were tested, and transformations were used as appropriate. When a significant effect was identified in the analysis, Fisher's protected LSD for multiple means comparisons were computed ($\alpha = 0.05$). Pearson correlation coefficients between compost parameters and soil quality indicators were determined.

3.3 Results

3.3.1 Soil Chemical Properties

There was a significant effect of compost treatment on soil pH in both years (Table 3.1). Soil pH in 2015 was significantly greater for MSC and FPMC than MC, FRC, and control treatments; greater for SSOC than for FRC and control treatments; and lower for the control than for all other treatments. Soil pH in 2016 followed a similar pattern where soil pH was greater for MSC and FPMC than for all other treatments; greater for SSOC than for MC and control treatments; and lower for the control than for all other treatments. Soil CEC was not significantly affected by compost treatment and averaged 10.6 and 13.6 meq/100 g in 2015 and 2016, respectively.

Table 3.1 Effect of diverse compost products on soil chemical properties measured pre-plant in 2015 and 2016.

Treatment	pH	CEC (meq/100g)	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	P (mg kg^{-1})
			2015				
Control[1]	5.90d	10.3	122bc[2]	738b	89c	18.0b	161
MSC	6.35a	10.8	126bc	1244a	98bc	19.5b	178
MC	6.13bc	10.5	177a	871b	123a	19.3b	206
FRC	6.10c	11.0	116c	839b	101bc	17.5b	158
SSOC	6.28ab	11.0	159a	1126a	105b	19.3b	199
FPMC	6.35a	10.0	140b	1132a	109ab	27.0a	165
Average	6.19	10.6	140	992	104	20.1	178
			2016				
Control	5.70d	13.8	142d	797e	91c	22.5b	148
MSC	6.53a	13.5	148cd	1751a	103bc	23.8b	168
MC	5.90c	13.0	224a	965d	136a	22.3b	197
FRC	5.85cd	14.8	133d	947d	106b	22.3b	151
SSOC	6.13b	13.5	167bc	1263c	112b	23.5b	180
FPMC	6.40a	13.0	185b	1475b	134a	39.5a	167
Average	6.09	13.6	167	1200	114	25.7	169

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

There was a significant effect of compost treatment on soil extractable K, Ca, Mg and S in both years whereas there was no significant effect on soil extractable P in either year (Table 3.1). Soil extractable K in 2015 was significantly greater for MC and SSOC than for all other treatments; and greater for FPMC than for the FRC treatment. Soil K in 2016 was significantly greater for MC than for all other treatments; greater for FPMC than for MSC, control and FRC treatments; and greater for SSOC than for control and FRC treatments. Soil extractable Ca in 2015 was significantly greater for MSC, FPMC, and SSOC than for all other treatments. Soil Ca in 2016 was significantly greater for

MSC than for all other treatments; greater for FPMC than SSOC, MC, FRC and control treatments; greater for SSOC than MC, FRC and control treatments; and lower for the control than all other treatments. Soil extractable Mg in 2015 was significantly greater for MC than for the SSOC, FRC, MSC, and control treatments; and greater for FPMC and SSOC than for the control treatment. Soil extractable Mg in 2016 was significantly greater for the MC and FPMC than for all other treatments; and greater for SSOC and FRC than for the control treatment. Soil extractable S in 2015 and 2016 was significantly greater for FPMC than for all other treatments.

Compost treatment had a significant effect on soil extractable B, Zn, and Mn in both 2015 and 2016, on soil extractable Na in 2015 only, and on soil extractable Al in 2016 only, but had no significant effect on soil extractable Cu and Fe in either year (Table 3.2). Soil extractable B in 2015 was significantly greater for FPMC than for MSC, FRC and control treatments; and greater for MC than for the control. Soil extractable B in 2016 was significantly greater for FPMC than for all other treatments; and greater for MSC than for the control treatment. Soil extractable Zn in 2015 was significantly greater for the FPMC, MSC, and SSOC than for all other treatments; greater for MSC than for FRC and control treatments; and lower for the control than for all other treatments. Soil extractable Zn in 2016 was significantly greater for FPMC than for all other treatments; greater for MC than for SSOC, MSC, FRC and control treatments; greater for SSOC than for MSC, FRC, and control treatments; and greater for MSC than for the control treatment. Soil extractable Mn in 2015 was significantly greater for FPMC than for all other treatments; and lower for the control than for MC, SSOC and MSC treatments.

Table 3.2 Effect of diverse compost products on soil micronutrients measured pre-plant in 2015 and 2016.

Treatment	B (μg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Na (mg kg^{-1})	Al (g kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})
				2015			
Control[1]	375c	1.00d	13.3c	11.8b	1.56	1.73	200
MSC	450bc	1.80b	16.3b	18.8a	1.48	2.00	187
MC	500ab	3.20a	17.8b	19.3a	1.51	2.38	195
FRC	400bc	1.23c	16.0bc	12.5b	1.50	1.98	207
SSOC	475abc	2.80a	16.8b	20.5a	1.53	1.80	195
FPMC	575a	3.58a	30.5a	13.5b	1.48	2.05	183
Average	463	2.27	18.5	16.1	1.51	1.99	195
				2016			
Control	625c	1.38e	20.5c	25.8	1.70a	2.03	251
MSC	800b	2.35d	23.5bc	39.8	1.57c	1.98	231
MC	770bc	4.10b	26.0b	33.0	1.68ab	2.35	241
FRC	725bc	1.85de	26.3b	32.0	1.67ab	2.10	269
SSOC	750bc	3.43c	23.0bc	40.5	1.67ab	2.55	234
FPMC	1025a	5.70a	48.0a	29.8	1.64b	2.30	228
Average	783	3.14	27.9	33.5	1.66	2.22	242

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

Similarly, soil Mn in 2016 was significantly greater for FPMC than for all other treatments; and lower for the control than for MC, FRC and FPMC treatments. Soil extractable Na in 2015 was significantly greater for SSOC, MC and MSC than all other treatments. Soil extractable Al in 2016 was significantly greater for the control than for FPMC and MSC treatments; and lower for MSC treatment than for all other treatments.

3.3.2 Soil Physical Properties

Soil VWC was measured continuously over the growing season at two depths in the potato hill (7.5 cm and 22.5 cm) for two treatments (control and FRC). In 2015, the mean VWC generally decreased over the growing season from June until late August

(Figure 3.2). The VWC was similar between treatments at 7.5 cm depth, whereas at the 22.5 cm depth, the control treatment tended to have slightly greater mean VWC than the FRC treatment. In 2016, mean VWC tended to increase from July until late August (Figure 3.3). At both depths, VWC for the control treatment was generally lower than for the FRC treatment.

Soil VWC was also measured weekly from the 0-10 cm depth using a hand-held meter. Measurements for all treatments were obtained and each sampling date was compared separately. There were no significant differences among treatments for VWC on any sampling date. The mean VWC varied from 0.096 to 0.283 m^3 m^{-3} and from 0.086 to 0.316 m^3 m^{-3} in 2015 and 2016, respectively (data not presented).

There was a significant effect of compost treatment on soil bulk density, saturated hydraulic conductivity and gravimetric water content during the growing season (Table 3.3). Soil bulk density in 2015 was significantly lower for FRC than for control, MSC, FPMC and MC treatments; and lower for SSOC than for control, MSC, and FPMC treatments. Soil bulk density in 2016 was significantly greater for FPMC and control than for all other treatments. Soil saturated hydraulic conductivity (K_{sat}) in 2015 was significantly greater for SSOC than for the MSC and control treatments; and greater for FRC and MC than the control treatment. In 2016, K_{sat} was not significantly affected by compost treatment and averaged 65.0 cm hr^{-1}. Gravimetric water content of soil at the time of core sampling was not determined in 2015. In 2016, GWC was significantly greater for SSOC than for MC and control treatments; and greater for FRC, FPMC, and MSC than for the control treatment.

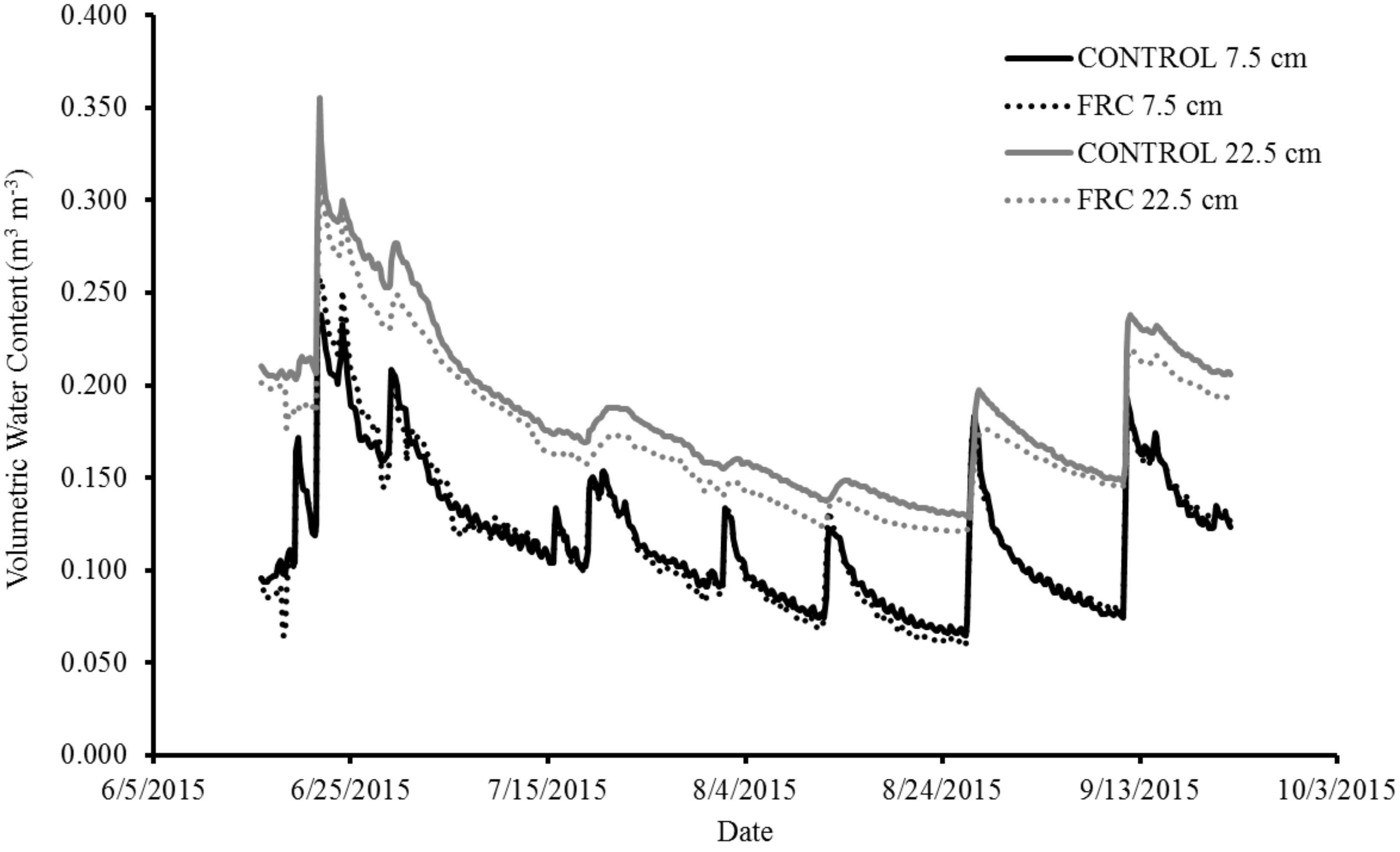

Figure 3.2 Mean volumetric water content for no compost control and FRC (forestry residue compost) over the 2015 growing season at two soil depths. Values presented are averaged across measurements obtained every 4 hours from three replicates of the experiment.

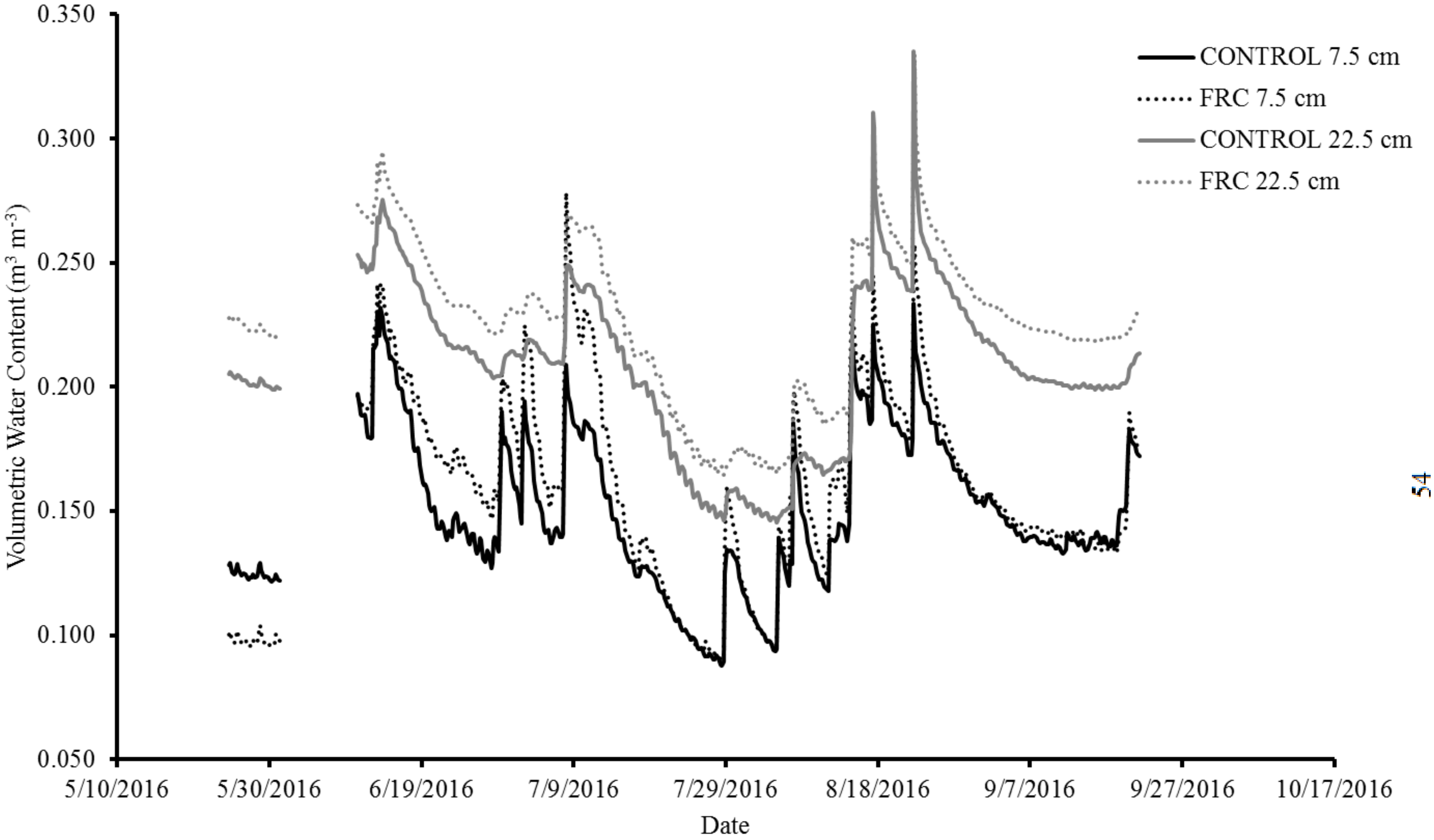

Figure 3.3 Mean volumetric water content for no compost control and FRC (forestry residue compost) over the 2016 growing season at two soil depths. Values presented are averaged across measurements obtained every 4 hours from two replicates of the experiment.

Table 3.3 The effect of diverse compost products on bulk density, K_{sat} and gravimetric water content (GWC) at 2 to 6 cm depth sampled in July 2015 and 2016 from the potato hill.

Treatment	Bulk density (Mg m^{-3})	K_{sat} (cm h^{-1})	GWC (g g^{-1})
	2015		
Control[1]	1.04a[2]	26.8c	ND[3]
MSC	1.03a	30.5bc	ND
MC	1.00ab	38.6ab	ND
FRC	0.96c	38.6ab	ND
SSOC	0.98bc	43.5a	ND
FPMC	1.02a	34.7abc	ND
Average	1.01	35.5	
	2016		
Control	1.02a	56.1	0.234c
MSC	0.95b	60.1	0.254ab
MC	0.94b	57.0	0.246bc
FRC	0.94b	96.0	0.257ab
SSOC	0.95b	55.2	0.267a
FPMC	1.00a	65.8	0.255ab
Average	0.97	65.0	0.252

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

[3] Not determined

There was a significant effect of compost treatment on GWC at field capacity (FC) and permanent wilting point (PWP) in 2016, but not in 2015 (Table 3.4). The GWC at FC in 2016 was significantly greater for the SSOC treatment than for FPMC, MC, control and MSC treatments; and greater for FRC than for the MSC treatment. The GWC at PWP in 2016 was significantly greater for SSOC than for MSC, FPMC and control treatments; and greater for FRC and MC than for the control treatment. The WHC, taken to be the difference between GWC at FC and PWP, was not significantly affected by compost treatment and averaged 0.171 and 0.180 g g^{-1} in 2015 and 2016, respectively.

Table 3.4 The effect of diverse compost products on gravimetric water content at field capacity (FC), GWC at permanent wilting point (PWP) and water-holding capacity on post-harvest soils 2015 and 2016.

Treatment	GWC at FC ($g\ g^{-1}$)	GWC at PWP ($g\ g^{-1}$)	WHC ($g\ g^{-1}$)
	2015		
Control[1]	0.244	0.0709	0.173
MSC	0.238	0.0712	0.167
MC	0.245	0.0741	0.171
FRC	0.247	0.0729	0.174
SSOC	0.247	0.0740	0.172
FPMC	0.243	0.0716	0.171
Average	0.244	0.0725	0.171
	2016		
Control	0.254bc[2]	0.0743c	0.180
MSC	0.251c	0.0751bc	0.176
MC	0.256bc	0.0773ab	0.179
FRC	0.260ab	0.0775ab	0.182
SSOC	0.265a	0.0791a	0.186
FPMC	0.257bc	0.0758bc	0.181
Average	0.257	0.0765	0.181

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

There was a significant effect of compost treatment on resistance to penetration in 2016, but not in 2015 (Figure 3.4A). The resistance to penetration on June 18, 2016 from the 0-5 cm depth was significantly greater for MSC than for the FRC and MC treatments; and greater for the control than for MC treatment. On the same sampling date, the resistance to penetration from the 6-10 cm depth was significantly greater for the control than for the MC and FRC treatments; and greater for MSC and FPMC than for the FRC treatment. The resistance to penetration from the 21-25 cm depth was significantly greater for FPMC and SSOC treatments than for the control, FRC and MC treatments; and greater for MSC than for the MC treatment. The resistance to penetration on June 18,

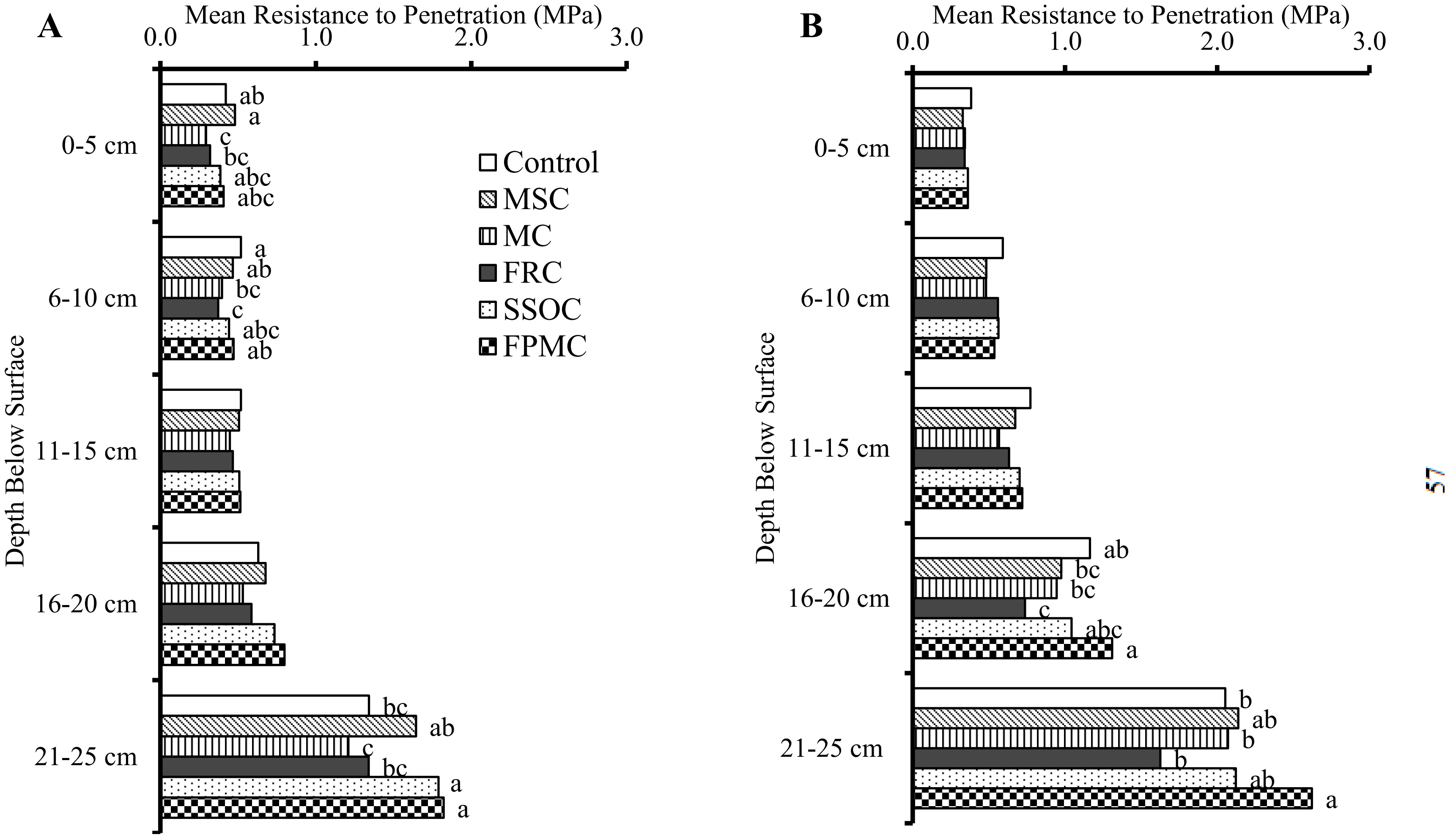

Figure 3.4 Effect of diverse compost products on the resistance to penetration at depth intervals measured on (A) June 18 and (B) August 30, 2016 for marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC). Means within a given depth followed by the same letter are not significantly different according to Fisher's Protected LSD (*P* < 0.05).

2016 from 11-15 and 16-20 cm depths was not significantly affected by compost treatment.

The resistance to penetration on August 30, 2016 from the 16-20 cm depth was significantly greater for FPMC treatment than for the MSC, MC and FRC treatments; and greater for the control than for the FRC treatment (Figure 3.4B). On the same date, the resistance to penetration from the 21-25 cm depth was significantly greater for the FPMC treatment than for the control, MC and FRC treatments. The resistance to penetration on this date from the 0-5, 6-10, and 11-15 cm depth was not significantly affected by compost treatment.

There were no significant differences among compost treatments for infiltration or soil aggregate stability (data not presented). Infiltration measured by a Cornell Sprinkler Infiltrometer in 2015 was not significantly affected by compost treatment. For a mean simulated rainfall rate of 28.5 cm h^{-1}, runoff averaged 8.5 cm h^{-1} and infiltration rate averaged 20.0 cm h^{-1}. Infiltration measured by a Mini-Disk Infiltrometer in 2016 was not significantly affected by compost treatment and averaged 1.05 cm h^{-1}. Soil aggregate stability was not significantly affected by compost treatment in both years. In 2015, aggregate stability (1.0-2.0 mm) averaged 75.1% and 72.2% pre-harvest and post-harvest, respectively. In 2016, aggregate stability averaged 67.7% and 68.0%, pre-harvest and post-harvest, respectively.

3.3.3 Soil Biological Properties

There was a significant effect of compost treatment in both years, and at both pre-plant and post-harvest sampling dates, on concentrations of soil organic carbon (SOC),

Table 3.5 Comparison of soil organic carbon (SOC), soil total nitrogen (TN), particulate organic matter (POM), and permanganate oxidizable carbon (POX-C) measured pre-plant and post-harvest from 0-15 cm depth over two years following application of five compost treatments and an unamended control on a loamy New Brunswick soil.

Treatment	SOC (g kg^{-1})	TN (g kg^{-1})	C:N	POM-C (g kg^{-1})	POM-N (g kg^{-1})	POM-C:N	POX-C (mg kg^{-1})
Pre-plant 2015							
Control[1]	19.5c[2]	1.79b	10.9cd	3.69d	0.31d	12.1c	249c
MSC	20.6bc	1.80b	11.4bc	5.00c	0.34cd	14.7b	327ab
MC	21.4bc	1.90b	11.3bc	6.22ab	0.40b	15.6b	286abc
FRC	22.0ab	1.76b	12.4a	6.51a	0.34c	18.9a	348a
SSOC	24.0a	2.30a	10.4d	7.49a	0.65a	11.6c	338a
FPMC	20.6bc	1.76b	11.7b	5.17bc	0.35bc	14.9b	264bc
Average	21.4	1.89	11.4	5.68	0.40	14.6	302
Post-harvest 2015							
Control	19.4d	1.70c	11.5bc	3.48d	0.27e	12.7cd	325c
MSC	21.4bc	1.79bc	12.0b	5.95bc	0.42bc	14.3bc	361bc
MC	22.3ab	1.90b	11.8bc	6.98ab	0.45b	15.6b	391ab
FRC	23.6a	1.70c	13.8a	8.10a	0.37cd	21.7a	431a
SSOC	23.7a	2.15a	11.0c	6.48bc	0.59a	11.1d	436a
FPMC	20.3cd	1.72bc	11.8bc	5.52c	0.35d	15.7b	359bc
Average	21.8	1.83	12.0	6.09	0.41	15.2	384
Pre-plant 2016							
Control	19.7c	1.71c	11.5c	3.69c	0.37d	10.0d	369d
MSC	22.1b	1.92b	11.5c	6.04b	0.46c	13.2bc	440b
MC	24.2a	1.90b	12.7b	8.09a	0.55b	14.6b	443b
FRC	23.8a	1.78c	13.4a	7.66a	0.43c	17.9a	488a
SSOC	24.5a	2.22a	11.0c	7.46a	0.66a	11.4cd	496a
FPMC	21.4b	1.72c	12.4b	5.74b	0.43c	13.5b	410c
Average	22.6	1.88	12.1	6.45	0.48	13.4	441
Post-harvest 2016							
Control	20.0d	1.80cd	11.1d	4.09d	0.38d	10.6c	420c
MSC	22.3c	1.90bc	11.7bcd	5.91c	0.45c	13.0b	463bc
MC	24.2b	1.95b	12.4b	8.84a	0.57b	15.6a	557ab
FRC	23.8b	1.77d	13.5a	7.75b	0.46c	16.8a	576ab
SSOC	25.4a	2.21a	11.5cd	8.86a	0.69a	12.8b	601a
FPMC	21.7c	1.82bcd	11.9bc	5.80c	0.44cd	13.2b	526abc
Average	22.9	1.91	12.0	6.88	0.50	11.8	524

[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

soil total nitrogen (TN) and soil C:N ratio (Table 3.5). Soil organic carbon pre-plant in 2015 was significantly greater for SSOC than for the MC, FPMC, MSC and control treatments; and greater for FRC than for the control treatment. Post-harvest in 2015, SOC was significantly greater for SSOC and FRC than for the MSC, FPMC, and control treatments; greater for MC than for the FPMC and control treatments; and greater for MSC than for the control treatment. Soil organic carbon pre-plant in 2016 followed the pattern MC, FRC, SSOC > FPMC, MSC > control. Post-harvest in 2016, SOC followed the pattern SSOC > MC, FRC > MSC, FPMC > control.

Soil TN measured pre-plant in 2015 was significantly greater for SSOC than for all other treatment (Table 3.5). Post-harvest in 2015, soil TN was significantly greater for SSOC than all other treatments; and greater for MC than for the FRC and control treatments. Soil TN pre-plant in 2016 followed the pattern SSOC > MSC, MC > FRC, FPMC, control. Post-harvest in 2016, soil TN was significantly greater for SSOC than all other treatments; greater for MC than for the control and FRC treatments; and greater for MSC than for the FRC treatment. The soil C:N ratio pre-plant in 2015 was significantly greater for FRC than for all other treatments; greater for FPMC than for the control and SSOC treatments; and greater for MSC and MC than for SSOC treatment. Post-harvest in 2015, the C:N ratio of soil was significantly greater for FRC than for all other treatments; and greater for MSC than for the SSOC treatment. The C:N ratio pre-plant in 2016 followed the pattern FRC > MC, FPMC > MSC, control and SSOC. Post-harvest in 2016, the C:N ratio was significantly greater for FRC than for all other treatments; greater for MC than for SSOC and control treatments; and greater for FPMC than for the control treatment.

For particulate organic matter (POM), there was a significant effect of compost treatment in both years, and for both pre-plant and post-harvest sampling dates, on concentrations of POM-C, POM-N and on the POM C:N ratio (Table 3.5). The POM-C pre-plant in 2015 was significantly greater for FRC and SSOC than for the FPMC, MSC, and control treatments; greater for MC than for the MSC and control treatments; and greater for FPMC than for the control treatment. Post-harvest in 2015, POM-C was significantly greater for FRC than for the SSOC, MSC, FPMC and control treatments; greater for MC than for the FPMC and control treatments; and lower for the control treatment than all other treatments. Pre-plant in 2016, POM-C followed the pattern MC, FRC, SSOC > MSC, FPMC > control. Post-harvest in 2016, POM-C followed the pattern SSOC, MC > FRC > MSC, FPMC > control.

Pre-plant in 2015, POM-N was significantly greater for the SSOC treatment than for all other treatments; greater for MC than for FRC, MSC and control treatments; and greater for FPMC than for the control treatment (Table 3.5). Post-harvest in 2015, POM-N was significantly greater for SSOC than for all other treatments; greater for MC than for FRC, FPMC, and control treatments; greater for MSC than for FPMC and control treatments; and greater for FPMC than for the control treatment. Pre-plant in 2016, POM-N followed the pattern SSOC > MC > MSC, FRC, FPMC > control. Post-harvest in 2016, POM-N was significantly greater for SSOC than for all other treatments; greater for MC than for FRC, MSC, FPMC and control treatments; and greater for FRC and MC than for the control treatment.

The POM-C:N ratio pre-plant in 2015 followed the pattern FRC > MC, FPMC, MSC > control, SSOC (Table 3.5). The POM-C:N ratio post-harvest in 2015 was significantly greater for FRC than for all other treatments; greater for FPMC and MC than for the control and SSOC treatments; and greater for MSC than for the SSOC treatment. The pre-plant 2016 POM-C:N ratio was significantly greater for FRC than for all other treatments; greater for MC and FPMC than for the SSOC and control treatments; and greater for MSC than for the control treatment. The post-harvest 2016 POM-C:N ratio followed the pattern FRC, MC > FPMC, MSC, SSOC > control.

Permanganate oxidizable carbon (POX-C), a measure of active carbon, was significantly different among compost treatments in both years (Table 3.5). Pre-plant in 2015, POX-C was significantly greater for FRC and SSOC than for the FPMC and control treatments; and greater for MSC than for the control treatment. Post-harvest in 2015, POX-C was significantly greater for SSOC and FRC than for the MSC, FPMC and control treatments; and greater for MC than for the control treatment. Pre-plant in 2016, POX-C followed the pattern SSOC, FRC > MC, MSC > FPMC > control. Post-harvest in 2016, POX-C was greater for SSOC than for the MSC and control treatments; and greater for FRC and MC than for the control treatment.

The MBC (units of mg C per g of oven-dried soil) was not significantly influenced by compost treatment and averaged 997 and 766 mg kg^{-1} in 2015 and 2016, respectively (Table 3.6). The MBC$_{SOC}$ (units of mg C per g of SOC) was significantly different among compost treatments in 2016, but not in 2015 (Table 3.6). The MBC$_{SOC}$ was significantly greater for FPMC than for the MSC and FRC treatments; and greater for the control than for the FRC treatment.

Soil respiration, as a measure of mineralizable C, and 24h burst test were significantly different among compost treatments in both years (Table 3.6). Pre-plant soil respiration in 2015 was significantly greater for the FPMC, MSC and SSOC treatments than for all other treatments. Soil respiration post-harvest in 2015 was not significantly

Table 3.6 Comparison of microbial biomass carbon (MBC), soil respiration, 24 h Burst, CaCl$_2$-extractable NO$_3$-N and NH$_4$-N, and labile N measured pre-plant and post-harvest over two years following application of five compost treatments and an unamended control on a loamy New Brunswick soil.

Treatment	MBC (mg kg^{-1})	MBC$_{SOC}$ (mg g$_{SOC}^{-1}$)	Respiration (mg CO$_2$-C kg^{-1} h^{-1})	24 h Burst (mg CO$_2$-C kg^{-1})	CaCl$_2$: NO$_3$-N (mg kg^{-1})	CaCl$_2$: NH$_4$-N (mg kg^{-1})	Labile N (mg kg^{-1})
			Pre-plant 2015				
Control[1]	ND[2]	ND	0.79b	18.3c[3]	12.03a	1.59	22.0d
MSC	ND	ND	1.24a	34.6a	7.72a	1.58	25.3ab
MC	ND	ND	0.96b	22.0bc	7.77a	2.14	23.4bcd
FRC	ND	ND	0.80b	22.7bc	4.38b	1.61	22.3cd
SSOC	ND	ND	1.22a	27.8b	8.11a	2.08	26.9a
FPMC	ND	ND	1.24a	34.2a	6.63a	1.34	24.7bc
Average			1.04	26.6	7.77	1.72	24.1
			Post-harvest 2015				
Control	1008	52.2	0.83	22.0b	ND	ND	ND
MSC	978	45.7	1.36	34.9a	ND	ND	ND
MC	986	44.6	0.97	34.1a	ND	ND	ND
FRC	992	42.3	1.35	33.8a	ND	ND	ND
SSOC	960	40.6	0.95	33.7a	ND	ND	ND
FPMC	1059	52.2	1.02	29.6a	ND	ND	ND
Average	997	46.3	1.08	31.4			
			Pre-plant 2016				
Control	ND	ND	0.59c	22.1c	8.64bc	1.87	22.6b
MSC	ND	ND	1.21a	33.1ab	12.09a	1.77	26.6a
MC	ND	ND	0.68c	26.4bc	7.44cd	2.07	26.2a
FRC	ND	ND	0.85bc	35.4ab	6.03d	2.33	24.4ab
SSOC	ND	ND	0.73c	28.5bc	10.56ab	1.82	25.3a
FPMC	ND	ND	1.07ab	40.9a	10.45ab	1.58	25.8a
Average			0.86	31.1	9.20	1.91	25.2
			Post-harvest 2016				
Control	747	36.4ab	0.46c	15.1c	ND	ND	ND
MSC	653	29.4bc	0.76ab	20.4a	ND	ND	ND
MC	839	34.4abc	0.71ab	19.8ab	ND	ND	ND
FRC	640	27.0c	0.51bc	17.7b	ND	ND	ND
SSOC	826	32.6abc	0.63bc	20.6a	ND	ND	ND
FPMC	888	40.9a	0.77a	19.1ab	ND	ND	ND
Average	766	33.5	0.64	18.8			

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[1] Marine with shells compost (MSC), poultry manure compost (MC), forestry residues compost (FRC), municipal source separated organic waste compost (SSOC), and forestry waste and poultry manure compost (FPMC).

[2] Not determined

[3] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

affected by compost treatment and averaged 1.08 mg CO_2-C kg^{-1} h^{-1}. Pre-plant soil respiration in 2016 was significantly greater for MSC than for the FRC, SSOC, MC and control treatments; and greater for FPMC than for the SSOC, MC and control treatments. Post-harvest soil respiration in 2016 was significantly greater for FPMC than for the SSOC, FRC and control treatments; and greater for MSC and MC than for the control treatment.

The pre-plant 24 h burst test in 2015 was significantly greater for MSC and FPMC than for the SSOC and control treatments; and greater for SSOC than for the control treatment. The post-harvest 24 h burst test in 2015 was significantly lower for the control treatment than for all other treatments. The pre-plant 24 h burst test in 2016 was significantly greater for FPMC than for SSOC, MC and control treatments; and greater for FRC and MSC than for the control treatment. The post-harvest 24 h burst test in 2016 was significantly greater for SSOC and MSC than for the FRC and control treatments; and greater for MC and FPMC than for the control treatment.

Labile N and $CaCl_2$-extractable NO_3-N were significantly different among compost treatments in both years, whereas there was no significant effect of compost treatment on $CaCl_2$-extractable NH_4-N in either year (Table 3.6). The $CaCl_2$-extractable NO_3-N in 2015 was significantly lower for FRC than for all other treatments. In 2016, $CaCl_2$-extractable NO_3-N was significantly greater for MSC than for the control, MC and FRC treatments; greater for SSOC and FPMC than for the MC and FRC treatments; and greater for the control than for the FRC treatment. Labile N in 2015 was significantly greater for SSOC than for the FPMC, MC, FRC and control treatments; greater for MSC than for the FRC and control treatments; and greater for FPMC than for the control treatment.

Abundance of Collembola at the family level was significantly affected by compost treatment only for the pre-plant sampling in 2015 (Table 3.7). The abundance of Oncyhiurdiae was significantly greater for SSOC and MC treatments than for the FRC and control treatments. In addition, there was no significant effect of compost treatment on total abundance of Collembola on either sampling date in each year. There was, however, a significant effect of compost treatment richness of Collembola in the pre-plant sampling in 2015. The richness of Collembola families was significantly greater for SSOC and MC than for the FRC and control treatments.

3.3.4 Correlations

There were several statistically significant relationships ($P < 0.05$) between soil quality indicators and compost parameters. Soil extractable K was positively related with compost K concentration in both years ($R^2 = 0.89$ and 0.82 in 2015 and 2016, respectively) (Figure 3.5). Soil extractable Zn was positively related with compost Zn concentration in both years ($R^2 = 0.83$ and 0.93 in 2015 and 2016, respectively) (Figure 3.6). In post-harvest soils, the compost N concentration was positively related with soil TN ($R^2 = 0.99$ and 0.96 in 2015 and 2016, respectively) and with POM-N ($R^2 = 0.95$ and 0.87 in 2015 and 2016, respectively) (Figure 3.7). The 24h burst test release of CO_2 of pre-plant soils was negatively related to C concentration of compost ($R^2 = 0.98$ and 0.78 in 2015 and 2016, respectively) (Figure 3.8). The quantity of C added by compost was positively related with SOC ($R^2 = 0.68$ and 0.86 in 2015 and 2016, respectively) and POM-C ($R^2 = 0.88$ and 0.89 in 2015 and 2016, respectively) in post-harvest soils (Figure

Table 3.7 Comparison of the abundance and diversity of Collembola at the family level (number sample^{-1}) in the 0-15 cm soil depth measured pre-plant and post-harvest over two years following application of five compost treatments and an unamended control on a loamy New Brunswick soil.

Treatment	Onychiuridae	Hypogastruridae	Isotomidae	Entomobryidae	Sminthuridae	Total Abundance	Richness
Pre-plant 2015							
Control[1]	0.0b[2]	0.0	8.0	0.3	0.5	8.8	1.3b
MSC	0.3ab	0.0	31.3	0.3	3.8	35.5	2.3ab
MC	1.3a	0.3	21.5	0.8	2.8	26.5	2.8a
FRC	0.0b	0.3	16.0	0.0	4.3	20.5	1.8b
SSOC	1.3a	0.5	33.5	0.0	2.3	37.5	3.0a
FPMC	0.3ab	0.3	11.8	0.0	1.5	13.8	2.3ab
Post-harvest 2015							
Control	10.5	0.0	6.3	1.0	0.5	18.3	2.5
MSC	10.0	0.0	12.5	0.3	0.0	22.8	2.3
MC	7.5	0.0	4.0	0.0	0.5	12.0	2.5
FRC	16.0	0.0	12.0	0.0	0.0	28.0	2.0
SSOC	21.8	0.0	7.8	0.0	0.5	30.0	2.5
FPMC	7.3	0.0	9.5	0.0	0.0	16.8	2.0
Pre-plant 2016							
Control	3.0	0.0	1.8	0.0	3.3	8.0	2.3
MSC	5.5	0.0	2.8	0.0	3.0	11.3	2.3
MC	3.8	0.3	3.5	0.0	2.0	9.5	3.0
FRC	8.3	0.0	8.3	0.0	2.8	19.3	2.0
SSOC	7.5	0.8	6.0	0.0	4.8	19.0	2.8
FPMC	4.5	0.3	4.3	0.0	4.3	13.3	2.5
Post-harvest 2016							
Control	24.0	0.0	0.8	0.0	0.0	24.8	1.5
MSC	26.5	0.0	2.3	0.0	0.0	28.8	1.8
MC	25.0	0.0	6.0	2.3	0.3	33.5	2.3
FRC	31.8	0.0	1.5	0.5	0.8	34.5	2.0
SSOC	10.8	0.0	2.3	0.3	0.0	13.3	2.3
FPMC	7.8	0.0	3.3	0.0	0.3	11.3	2.0
Overall Average	9.8	0.1	9.0	0.2	1.6	20.7	2.3

[1] See Table 3.6 for definitions

[2] Means within columns for a given year followed by the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

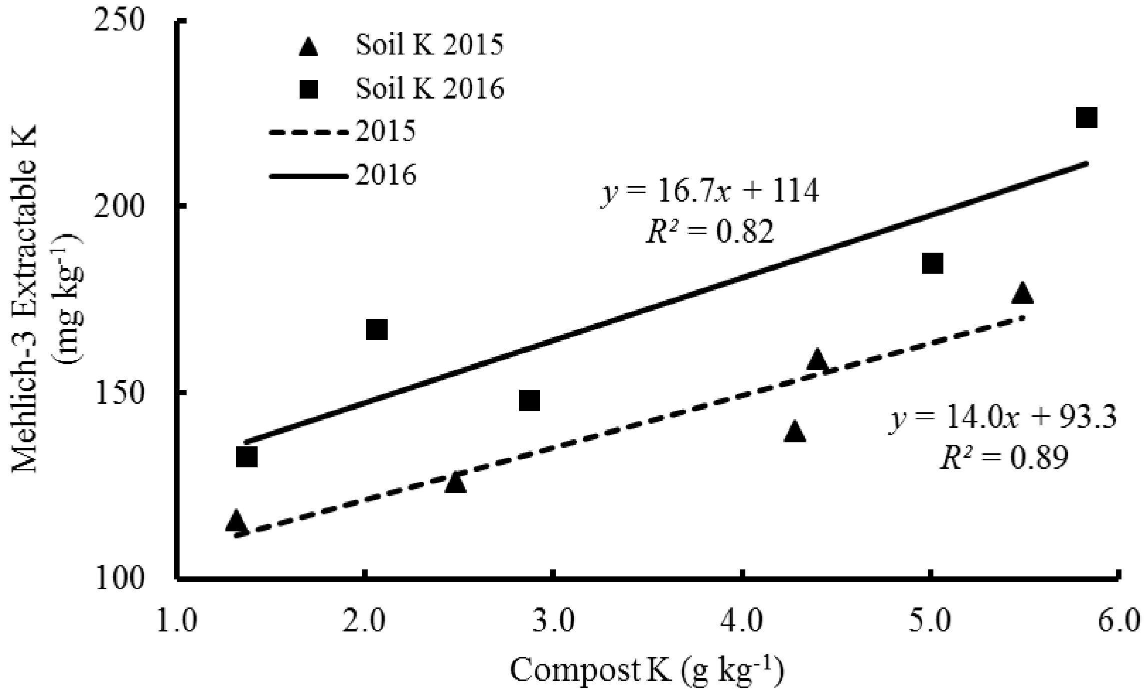

Figure 3.5 Linear regression between compost K concentration and Mehlich-3 extractable soil K measured pre-plant in two years.

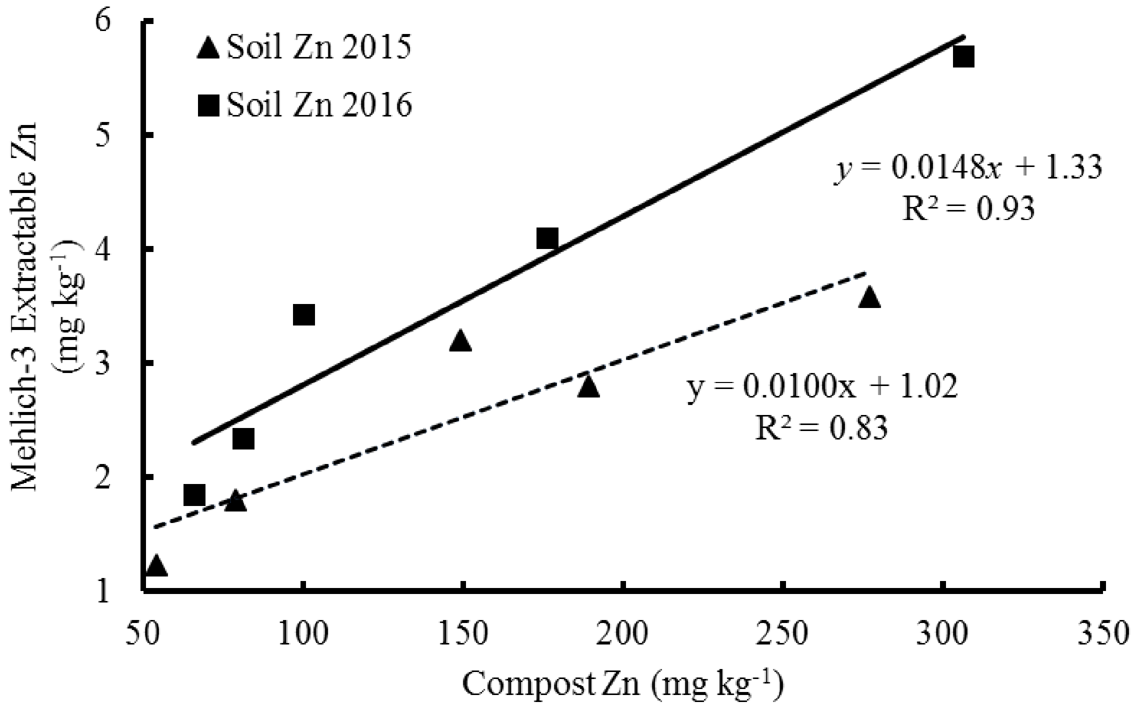

Figure 3.6 Linear regression between compost Zn concentration and Mehlich-3 extractable soil Zn concentration measured pre-plant in two years.

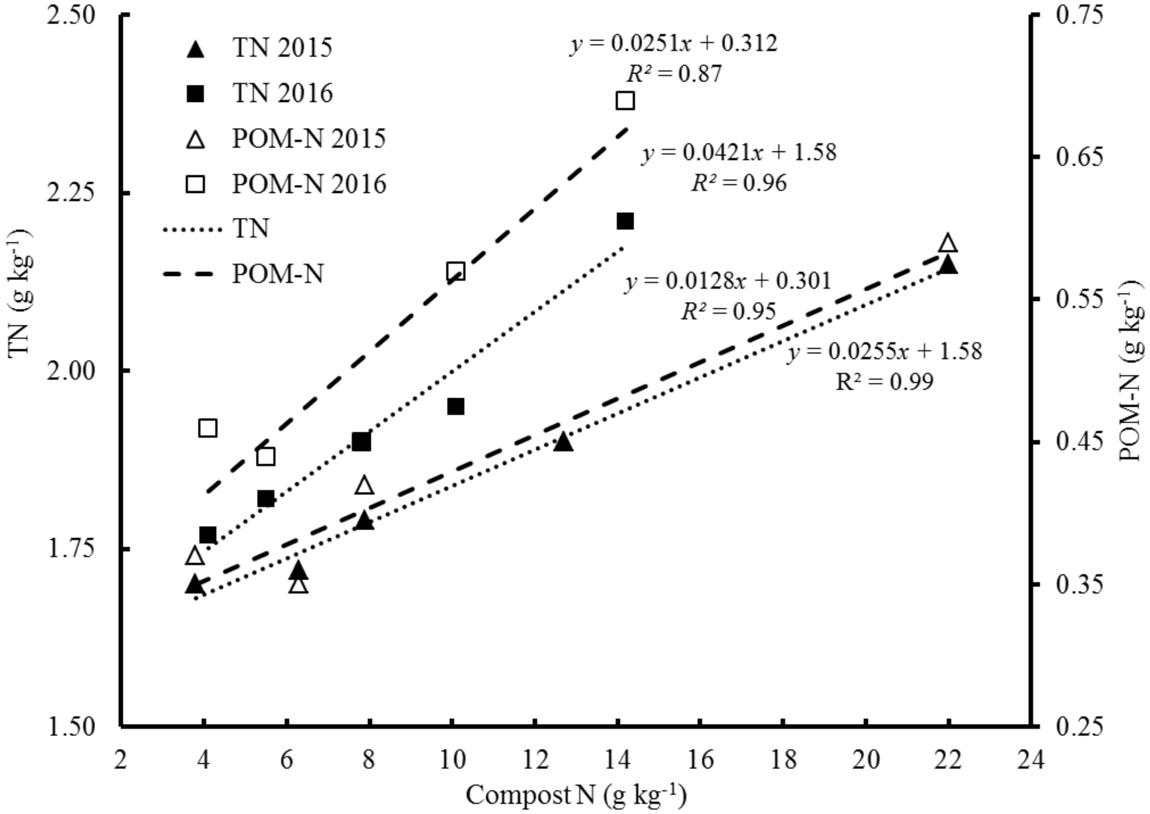

Figure 3.7 Linear regression between compost N concentration, soil total nitrogen (TN) and particulate organic matter nitrogen (POM-N) measured post-harvest in two years.

3.9). Compost parameters were able to account for over 80% of the variation all of aforementioned soil quality indicators, with the exception of SOC in 2015.

3.4 Discussion

The application rate of compost in this study was selected to rapidly build SOM and improve soil quality within the two years of the experiment. Compost products were applied at 45 Mg ha^{-1} on a dry weight basis, and addedbetween 5.9 and 12.2 Mg C ha^{-1} in two consecutive years. At this rate, products added between 171 and 990 kg ha^{-1} of N, and between 22 and 395 kg ha^{-1} of P in each year, although only a small fraction of these nutrients are readily available for plant uptake or loss, due to immobilization and sorption processes.

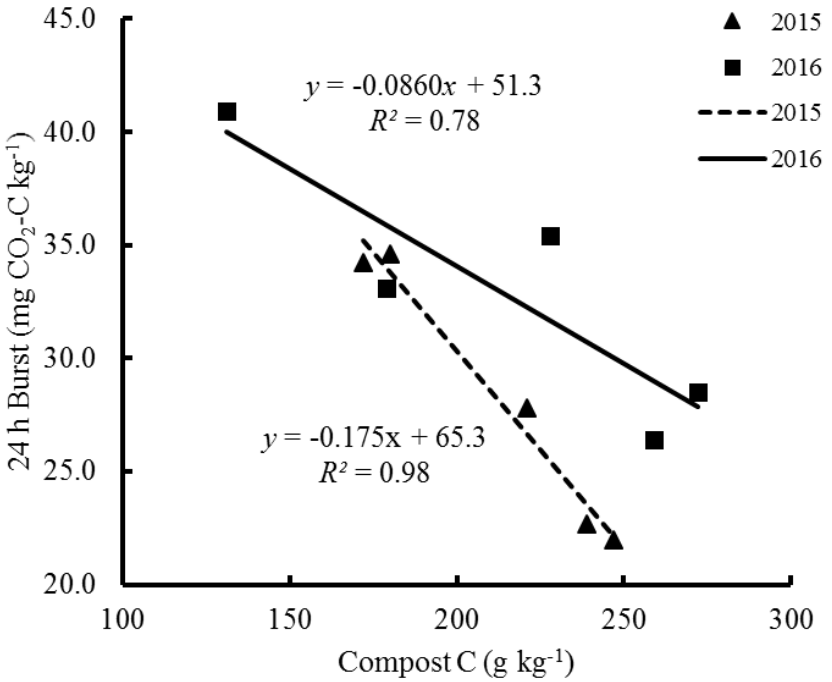

Figure 3.8 Linear regression between compost C concentration and 24 h burst test for pre-plant soils in two years.

The application rate in the current study was comparable with other agronomic studies in the region that applied compost as a soil conditioner (Gagnon et al. 2001; Lynch et al. 2005). Gagnon et al. (2001) applied composted pulp fibre waste at 45 and 90 Mg ha^{-1} (10.4 and 20.7 Mg C ha^{-1}) on a dry weight basis to soils under continuous potato production in New Brunswick. Lynch et al. (2005) applied three different types of compost at dry weight rates up to 37.5 Mg ha^{-1} (4.6 and 10.9 Mg C ha^{-1}) to soils under forage production in Nova Scotia. The composts were derived from crop residues, dairy manure or sewage sludge. Carter et al. (2004) applied compost derived from sawdust, manure and cull potatoes at 12.8 Mg ha^{-1} and 16.8 Mg ha^{-1} (dry weight basis) in 1992 and 1995, respectively, on a 3-year potato rotation in Prince Edward Island. Although Carter et al. (2004) applied only 0.3 Mg C ha^{-1}, measurable increases in SOC and other soil

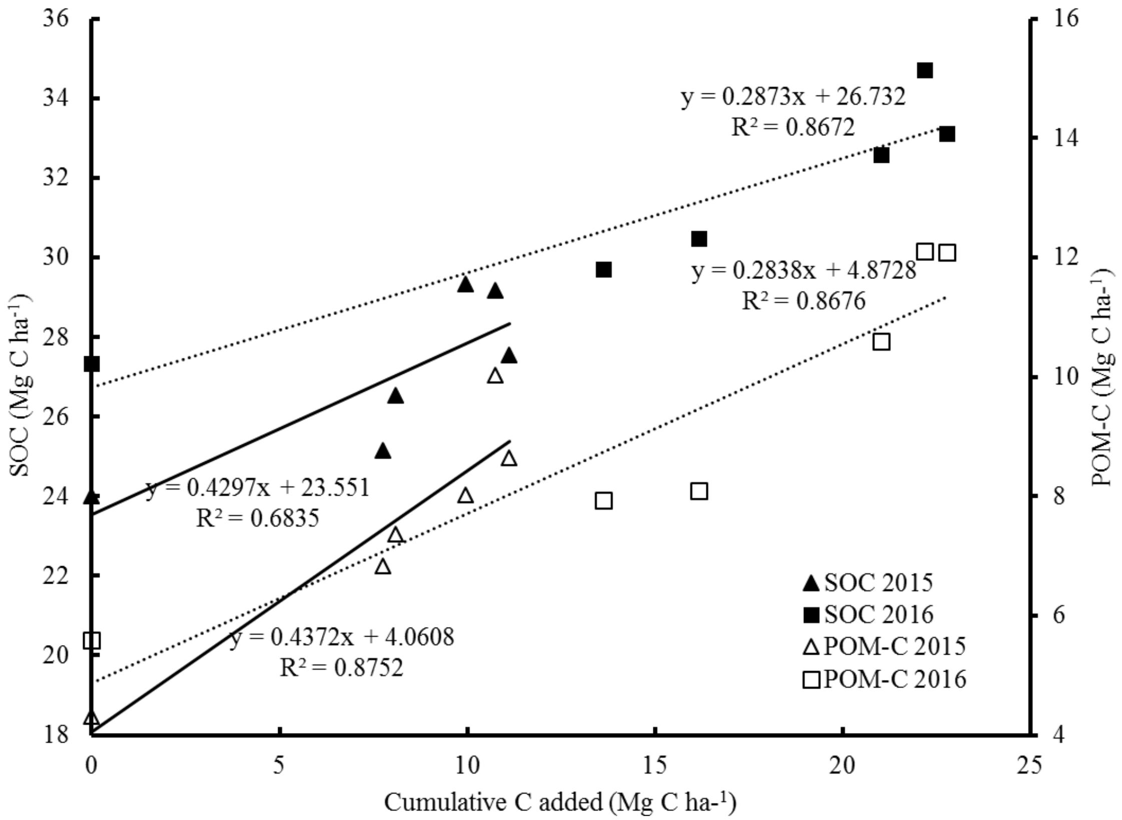

Figure 3.9 Linear regression between cumulative carbon added and quantity of soil organic carbon (SOC) and particulate organic matter carbon (POM-C) at 0-15 cm depth measured post-harvest in two years, calculated from the average soil bulk density because there was no significant effect on treatment on soil bulk density.

properties were observed in 1996. In this study, annual compost application of 45 Mg dry weight ha^{-1} yr^{-1}, (5.9 to 12.2 Mg C ha^{-1}), were able to significantly increase SOC and improve several key soil functions under New Brunswick potato production.

3.4.1 Supply of Plant Nutrients

High rates of inorganic fertilizers are typically required to optimize potato yield in New Brunswick production (Zebarth et al. 2012). Therefore, improvements in soil nutrient supply and storage in potato production soils would reduce fertilizer requirements. In this study, compost application increased the concentration of Mehlich-3 extractable K, Ca, Mg, S, B, Zn, and Mn in both years of the experiment. This was not unexpected: the application of compost has increased extractable nutrient concentrations, such as that of K, Mg and Ca, in other studies (Porter et al. 1999; He et al. 2001).

Compost application had a substantial effect on availability of K, which plays a critical role in plant energy status and water transport (Hawkesford et al. 2012). Previous studies showed K in composts to have similar availability to inorganic K fertilizer and that more than 85% of K in compost was readily available for plant uptake (He et al. 2001; Lynch et al. 2004). In this study, the MC treatment resulted in the greatest increase in soil extractable K, and this reflected the greater concentration of K in the initial compost product. In general, the more K added with compost, the greater the increase in extractable K. An increase in plant K uptake was also observed in 2015 following the application of SSOC to field plots receiving no inorganic fertilizers (Chapter 2). However N-limiting conditions, and high spring soil test K at this site, limited the usefulness of plant K uptake as a measure of soil K availability.

Despite substantial additions of P in compost, there were no significant differences in Mehlich-3 extractable P in either year of the experiment. This is not surprising: the availability of P in compost is estimated at only 20 to 40% in the year following application due to immobilization and sorption processes (He et al. 2001). In addition, Miller et al. (2009) also observed low apparent P recovery by a barley crop following nine years of annual compost applications in Alberta. However, an increase in plant P uptake was observed in 2015 following application of SSOC (Chapter 2). This was unexpected, given the lack of difference in Melich-3 extractable P. However, the increased plant P uptake may be more of a reflection of increased crop growth due to increased soil N supply for the SSOC treatment (Chapter 2) resulting in increased plant P uptake than of increased soil P availability.

All compost treatments significantly increased soil pH in this study. Increases in soil pH were observed following the application of all compost products in 2015 and the MSC, FPMC, SSOC and MC treatments in 2016. Compost application increased soil pH in several other studies when applied to acidic soil (Zebarth et al. 1999; Baziramakenga et al. 2001: Eghball 2002; Camberato et al. 2006) and the magnitude of increase in soil pH in these studies reflected the initial pH of the compost applied. All compost products applied in this study had pH greater than 7. With a soil pH less than 6, it follows that the application of these compost products would thereby exhibit a liming effect on soil. Due to the acidic nature of soils in eastern Canada, a compost-induced liming effect would be beneficial for many crops and would reduce the requirement for lime application somewhat.

Compost treatments increased soil TN in this study. The most substantial increases were observed in POM-N. Participate organic matter serves as readily decomposable substrate and is associated with high microbial activity and respiration in soils (Gregorich et al. 1994). Most POM is unprotected and exhibits a short turnover rate (Gregorich et al. 1994). As POM-N is mineralized, N becomes available for plant uptake in years following compost application. In this study, POM-N represented between 16-31% of soil TN, with the greatest increases in POM-N observed following the application of the SSOC. In particular, the SSOC resulted in increases in POM-N of 78-119% when compared with the untreated control. These results suggest that compost-derived organic matter can contribute substantially to the POM-N soil fraction. Furthermore, the magnitude of increases in POM-N and soil TN following compost application tended to reflect the initial total N concentration of added compost products. Increases in POM-N following compost application in potato production systems have been observed by Carter (2007), who reported increases in POM-N from 41 to 56 g N m^{-2} after four cycles of a 3-year potato-barley-red clover rotation.

Increased soil TN did not, however, necessarily translate into short-term increases in plant available N. Little to no increases in pre-plant $CaCl_2$ extractable NO_3-N or labile N, as estimated by N mineralization during a 14 day aerobic incubation, were observed in compost-amended plots. In a study of manure compost application to forage grass in Nova Scotia, Sharifi et al. (2014) also found that compost tended to contribute more to stable organic N pools than more labile N fractions.

A reduction in plant N availability was also observed following the application of the FRC treatment in this study. This product exhibited a negative apparent N recovery (Chapter 2), decreased pre-plant $CaCl_2$ extractable NO_3-N relative to the control, and did not significantly affect pre-plant labile N. This product had high C:N and NH_4-N:NO_3-N ratios, which is consistent with an immature product undergoing net soil N immobilization during the decomposition process (Bernai et al. 1998; Sánchez-Monedero et al. 2001; Sharifi et al. 2014). Reducing N availability during the growing season is unfavourable and may result in a yield limitation. However, fall application of organic amendments with high C:N ratios (>30) to soils high in residual soil mineral N may induce short-term N immobilization and reduce over-winter N losses. In Prince Edward Island, the incorporation of straw following potato harvest was able to reduce NO_3-N in tile drainage discharge by up to 30% (Milburn et al. 1997).

The application of SSOC, MC and MSC treatments also resulted in a small increase in the concentration of Mehlich-3 extractable Na in 2015. Excess Na can have adverse effects on crop growth (stress due to salinity) and soil structure, by displacing plant nutrients on cation exchange sites. However, soil Na qualities measured in this study are low and unlikely to be of a concern. These concentrations may reflect the fact that compost was applied in the fall. Fall application reduces of risk of salinity effects on the subsequent crop, as Na can be leached out of root zone over fall and winter months.

In this study, only the short-term effects of compost application on nutrient availability were assessed. Compost resulted in an increase in nutrient supply by increasing several Mehlich-3 extractable nutrients (K, Ca, Mg, S, B, Zn and Mn), as well as increasing soil pH. There was little to no increase in plant available N or P, whereas net N immobilization was observed for the FRC treatment in the two years of this study. However, compost significantly contributed to total organic N and POM-N fractions, and it is likely that increases in N and P availability may be observed in the longer-term as the organic matter decomposes.

3.4.2 Storage of Plant Nutrients

Many potato production soils of eastern Canada are medium or coarse in texture with inherently low CEC. Increasing the CEC of medium and coarse textured soils through the addition of compost has been widely demonstrated (Porter et al. 1999; Zebarth et al. 1999; Forge et al. 2016). For example, Forge et al. (2016) observed increases in soil CEC from 3.5 meq/100g in unamended plots to 15.2 meq/100g in treated plots under raspberry production following spring application of compost derived from poultry layer manure, greenhouse waste and yard waste at 88.8 Mg ha^{-1}, on a dry matter basis.

In this study, the CEC of soil was not significantly affected by compost application. This was unexpected. The CEC of organic amendments is associated with carboxylic acid groups in highly decomposed organic fractions present in composted organic materials (Zebarth et al. 1999). Accordingly, as organic amendments decompose, the CEC generally increases (Harada and Inoko 1980; Jokova et al. 1997). Composted paper mill sludge waste has been shown to double or triple soil CEC compared to uncomposted product (Camberato et al. 2006). In contrast, following annual application of commercially produced poultry and food waste compost to sandy soils of British Columbia, significant increases in CEC were only observed in the fourth year of the experiment (Zebarth et al. 1999).

The CEC of composted organic amendments also depends on the initial feedstock. Harada and Inoko (1980) determined CEC values to be 47 meq/100g for compost derived from city refuse, 91 meq/100g for rice straw compost, and 123 meq/100g for a commercial compost product derived from tree bark. Two composts applied in Zebarth et al. (1999) had CECs of 94 and 47 meq/100g for composted hog solids and poultry and food waste compost, respectively. A lack of a significant increase in CEC in this study may therefore be due to inherently low CEC of the compost products applied. In addition, changes in CEC may only be observed in the long-term as a result of continued degradation of these products.

3.4.3 Soil Permeability and Rootability

Soil degradation and erosion are major issues hindering potato productivity in eastern Canada (Rees et al. 2014). Soil compaction reduces porosity and results in lower rootability and microbial activity (Hatley et al. 2005). Slow rainfall infiltration due to a lack of soil pore-connectivity can increase soil erosion and result in substantial re-distribution or off-site losses of soil, nutrients and organic materials (Boiteau et al. 2014). In this study, compost application increased saturated hydraulic conductivity (2015), decreased bulk density (2015 and 2016) and decreased resistance to penetration at some depth intervals in the potato hill (2016). Reductions in soil bulk density following the application of compost have been observed in other studies (Zebarth et al. 1999; Carter et al. 2004; Forge et al. 2016). Because compost is generally much less dense than soil, it follows that compost application will cause a reduction in soil bulk density and translate into increased permeability and rootability benefits.

Despite the aforementioned improvements in soil structure, there was no significant effect of compost on soil aggregate stability in this study. This is not unexpected: several studies did not observe a significant effect of compost on water stable aggregates in the first or second year after compost application (Carter et al. 2004; Forge et al. 2016). Furthermore, studies have shown that mature compost is generally less effective at stabilizing aggregates than immature compost or other raw organic materials (Roldán et al. 1996; Annabi et al. 2007). The composts applied in this study were generally derived from forestry-based wastes and, therefore, would be slower to degrade than composts derived from more labile C bulking agents, such as straw. As these products break down over time, the increased stimulation of microbial activity may result in increased aggregate stabilization. A delay in aggregate stability response to compost application was observed by Forge et al. (2016) who found no significant difference in mean weight diameter (MWD) between compost and control plots in 2010, but did see a significant increase in MWD four years later in 2013. Despite earlier results from the same study indicating no changes in MWD (Carter et al. 2004), Carter (2007) observed increased MWD in the final potato phase of four, 3-year rotations, following application of compost. Carter (2007) had applied compost (potato, sawdust and manure mixture) once every three years.

In contrast, other studies reported increases in aggregate stability in the year following compost application. Grandy et al. (2002) observed increases in medium- (1-2 mm) and large-sized (2-6.5 mm) aggregates following the spring application of both manure and compost to potato production soil in Maine. Whalen et al. (2003) observed increases in the proportion of water stable aggregates (WSA) greater than 4 mm following one application of composted manure at 15, 30 and 45 Mg ha^{-1} (wet weight basis) in Quebec to silage corn. Accordingly, the proportion of smaller sized WSA was decreased or unchanged. Both Grandy et al. (2002) and Whalen et al. (2003) applied products containing manure (either raw manure and/or composted). It appears that greater microbial stimulation following the application of manure and immature compost (compared to mature composts) may explain some of the rapid improvements in aggregate stability (Annabi et al. 2007). Alternatively, these studies both examined larger sized fractions than in this current study. In this study, only stable aggregates from 1-2 mm in size were determined. Determining the percentage of stable aggregates at larger size diameters may provide additional insight into the effect of compost on structural stability and significant differences among compost treatments may be observed. Spring application of these amendments may have also shown more benefits, as labile C would have been available immediately following application.

Compost products resulted in benefits to soil structure, but it appears that compost-induced improvements were more a reflection of the properties of the compost product applied, rather than of any major compost-induced soil stabilization. Of all the products examined, the FRC, SSOC and MC products resulted in the greatest improvement in soil structure. These products contained the highest concentrations of C.

3.4.4 Soil Water Holding

During the growing season in eastern Canada, potatoes are subjected to variable precipitation including dry conditions alternating with periods of heavy rainfall associated with severe weather systems. Compared with many other crops, potatoes are especially sensitive to water stress due to a shallow, surface root system (Porter et al. 1999; Carter et al. 2007). Reducing soil moisture stress should therefore, be associated with greater canopy growth and yield (Porter et al. 1999). In this study, compost application increased water content at FC and PWP; but resulted in no net change in soil available water. This is commonly observed in medium- to coarse-textured soils (Carter 2007). After observing only increases in water content at FC during the potato phase of the experiment, Carter (2007) postulated that changes in soil water retention may be the result of reactions between the compost and soil matrix which cause slight stabilization of tillage-induced aggregates. Of all the compost products, the SSOC had the greatest effect on water content, consistently increasing GWC. This product resulted in the greatest increase in SOC.

Compost products had a significant effect on the water holding properties of soil in 2016. Although significant effects were only observed after two consecutive years of compost application, it is unclear whether this was the result of cumulative compost applications, decomposition of compost, or different environmental conditions in the second year of the study. In 2016, trends in VWC collected from permanent soil moisture probes indicated greater VWC for FRC than for the control at both depths throughout the growing season. When all treatments are compared, increases in GWC were observed in post-harvest soils held at FC (-33 kPa) and PWP (-1500 kPa), and from samples collected from the 2 to 6 cm depth in late-July. The increase in GWC at both FC and PWP negated effects on water holding capacity indicating that although the soil was wetter following compost application, it did not necessarily hold more plant available water.

The effect of compost on soil water holding capacity in the current study are similar to Zebarth et al. (1999), Carter et al. (2007) and Forge et al. (2016). Zebarth et al. (1999) observed increases in soil water retention following application of compost at 45 Mg ha^{-1} on a dry weight basis to sandy soils in British Columbia. However, this did not result in increased soil water holding capacity as water content increased at both FC and PWP under compost application. Carter et al. (2007) observed increases in water content at several matric potentials in soil following four compost applications over a 12 year period. The water contents at FC and PWP were significantly correlated with soil C concentration; however, total available water remained unchanged. Despite finding significantly greater soil water content under compost-treated plots, Forge et al. (2016) found reduced soil available water-holding capacity relative to control and other treatments, a finding attributed to increased water content at PWP.

3.4.5 Soil Organic Matter

Soil organic matter plays a major role in the maintenance of soil quality (Carter 2007). Because changes in SOM may be difficult to measure against the relatively large background mass in soil, other indicators of SOM can be used to indicate directions of change in total mass: particulate organic matter or light fraction organic matter (Gregorich et al. 1994; Carter 2007). Not surprisingly, all compost products applied in this study influenced soil organic matter quality and quantity. By fall of 2016, compost application increased SOC concentration by 9 to 27% relative to the unamended control. The strong positive relationship between SOC and cumulative C applied indicated that the more compost C that was applied, the greater the corresponding increase in SOC. Similarly, two applications hog waste compost and poultry and food waste compost increased SOM from 17.6 to 24.6 and 28.8 g SOM kg^{-1}, respectively (Zebarth et al. 1999). Carter (2007) did not observe increases in SOC or POM-C after 12 years of 3-year rotation cycling with four compost applications; however, limited C additions were made each year and the rotation included both a barley and red clover phase which also contributed to background soil C.

The particulate organic matter (or macroorganic matter) fraction of soil has a turnover rate of approximately 1 to 8 years in Canada (Carter 2002). Particulate organic matter is typically not protected by organo-mineral complexes and, therefore, serves as a readily available substrate and nutrient source for soil micoroorganisms (Gregorich et al. 1994). In this study, all products increased POM-C concentrations in the soil. The C:N ratio of the compost was positive correlated with the C:N of the POM. Based on this evidence, the organic matter applied by the compost directly contributed to increases in the POM fraction. In previous studies, compost has been shown to significantly increase POM-C. Grandy et al. (2002) found that soil C increase in potato rotations following compost application were largely the result of increases in C unprotected by complexes with the soil matrix. Gagnon et al. (2001) reported significant increases in POM-C following three applications of composted pulp waste at 45 Mg ha^{-1}, on a dry weight basis, to a continuous potato production system in Quebec. In this study, the greatest increases in POM-C were observed following application of the FRC, SSOC and MC treatments, the products with the greatest C concentrations.

Changes in permanganate oxidizable carbon (POX-C) also reflected changes in POM-C and SOC. In other studies, the POX-C, or active carbon, fraction has been correlated with SOC, POM-C total N and other 'less active' carbon pools in the soil, and serves as a sensitive, accurate, and cost effective indicator of overall soil quality (Morrow et al. 2016). The SSOC and FRC treatments produced the greatest increases in POX-C.

3.4.6 Biological Activity

Biological activity in soils is associated with a number of benefits. Microbial biomass is sensitive to soil management, nutrient availability and toxicities (Gregorich et al. 1994). In this study, compost application had little to no effect on MBC. However, compost was applied in the fall and MBC was determined one year later, in the subsequent fall after potato harvest. Given this time between application and MBC analysis, it is possible that labile sources of carbon were depleted. Sampling for MBC in the spring prior to planting (after fall application of compost) may show a greater response to compost application. Similarly, Carter et al. (2004) also did not see a change in MBC following application of compost to a potato rotation in PEI.

Mineralizable C, as measured by respiration rate, affects nutrient dynamics within growing seasons (Gregorich et al. 1994). In this study, respiration rate was affected by compost treatment, with consistently greater rates observed for MSC and FPMC treatments. The negative relationship between respiration rate and the compost NH_4:NO_3 ratio suggests that mature products tend to exhibit greater respiration rates. This was unexpected, as respiration rates typically decrease as compost products mature and labile sources of carbon are degraded. The greater mineralization rates may also be related to particle-size of compost, where greater mineralization rates are associated with finer particle fractions (Miller et al. 2009). However, the lack of a consistent relationship between particle-size of compost and respiration rate suggests that there were other factors controlling soil respiration rates in this study.

The 24 h burst test was also significantly different among compost treatments. Originally developed as an indicator of potential N mineralization (Haney et al. 2008), the results of the 24 h burst test were not significantly correlated with labile N in this study. This was unexpected. In addition, the 24 h release of CO_2-C following re-wetting in pre-plant soils was negatively correlated with compost C concentration. Despite having lower NH_4-N:NO_3-N ratios, consistent with mature products, and lower C concentrations, the MSC and FPMC treatments tended to produce the greatest response in respiration rate and the 24 h burst test. This results suggests that perhaps quality, in addition to quantity, of compost-derived C effects changes in soil properties.

Soil microarthropods, such as springtails (Class: Collembola), are sensitive to soil quality and changes in management (Parisi et al. 2005). Similar to other studies, the dominant families in this study were Onychiuridae and Isotomidae (Carter and Noronha

2007). However, there was little to no increase in the abundance and diversity of Collembola following compost application. The overall low abundance of Collembola in both years of experiment was consistent with the absence of a surface litter and the high frequency of soil disturbance in the potato production system (Boiteau et al. 2014).

3.5 Conclusions

In this study, all compost products increased soil quality in an intensive potato production system. Following the application of compost, soils exhibited improvements in nutrient supply, permeability and rootability, and soil organic matter quality and quantity. However, not all products behaved in the same way and, in many cases, the effect of compost on soil properties reflected the initial composition of the compost. For example, composts with greater concentrations of C generally resulted in greater increases in SOC. Similarly, the application of compost with greater concentrations of plant nutrients, such as K, generally resulted in greater increases in nutrient concentrations in the soil.

This study suggests that mature composts with greater C concentrations (i.e. low ash) and greater dry matter (DM) concentrations were most suitable for use in New Brunswick potato production systems. High DM is an important economic consideration as a substantial cost is associated with handling, transportation and application of compost products. However, there remain several practical limitations to compost application in the region including cost (i.e., no guaranteed return on investment), compost variability, and contaminants such as heavy metals or plastic debris. To optimize use of compost in potato production systems, specific soil properties should be targeted in an effort to select an appropriate compost product.

CHAPTER 4.0 EFFECT OF DIVERSE COMPOST PRODUCTS ON SOIL-BORNE DISEASES OF POTATO

4.1 Introduction

Soil-borne diseases result in important economic losses for potato (*Solanum tuberosum* L.) producers in eastern Canada. Common scab alone was estimated to cause approximately 17 million dollars in losses annually in Canada (Hill and Lazarovits 2005). Necrotic lesions and surface blemishes resulting from pathogen infection reduce the marketability of table and seed varieties and may hinder potato processing. Two persistent diseases in the humid agricultural soils of eastern Canada are black scurf and common scab, caused by *Rhizoctonia solani* and pathogenic *Streptomyces* species, respectively (Larkin and Tavantzis 2013). Other tuber-diseases of economic importance include powdery scab and silver scurf, caused by *Spongospora subterranea* and *Helminthosporium solani*, respectively. Current control measures include cultural practices and chemicals, such as seed treatments and fumigants; however, these practices are often impractical and ineffective, necessitating the application of alternative or supplemental control measures (Larkin and Tavantzis 2013; Mehta et al. 2014). One alternative control method is the application of composted organic amendments (Hoitink et al. 1997).

The application of compost has been associated with a reduction in potato soil-borne disease incidence and severity in field and greenhouse experiments (Entry et al. 2005; Al-Mughrabi et al. 2008; Bernard et al. 2014; Molina et al. 2014; El Khaldi et al. 2016). Visible reductions in wilt caused by *Verticillium dahliae* were observed following application of composted beef cattle manure (Molina et al. 2014) and vegetable waste compost (Entry et al. 2005). Reductions in the severity of *Streptomyces scabiei* were observed following foliar application of compost and compost tea drenches (Al-Mughrabi et al. 2008). Compost application also reduced the incidence and severity of black scurf (Bernard et al. 2014; El Khaldi et al. 2016). In several of these studies, indigenous microbes and biological communities were recognized for their role in compost-induced disease suppression (Entry et al. 2005; El Khaldi et al. 2016).

El Khaldi et al. (2016) observed zones of lyses and mycoparasitism of *R. solani* hyphae under a compost treatment. Filtered or autoclaved compost lost its suppressive activity against *R. solani*; therefore, researchers attributed the suppressive activity to biotic factors (El Khaldi et al. 2016). Previous studies suggest that hyperparasites from the genus *Trichoderma* may be responsible for compost-induced suppression of *R. solani* (Nelson and Hoitink 1983; Chung and Hoitink 1990; Hoitink et al. 1997). Other mechanisms of disease suppression, as reviewed by Hoitink et al. (1997) and Mehta et al. (2014), include competition and/or antibiosis between microbes and induction of system acquired resistance (SAR) in the plant.

Despite evidence of compost induced disease suppression, compost application may also exhibit a negligible or stimulating effect on plant disease (Termorshuizen et al. 2006). Generally, the composition of the initial feedstock, maturity of compost, and the potential for microbial recolonization during the curing process significantly affect the disease suppressive ability of compost in plant systems (Hoitink et al. 1997). El Khaldi et al. (2016) observed disease suppression of *R. solani* of potato following application of composted date palm mixed with cattle manure, but a sheep manure plus date palm compost with similar C:N ratio and other properties did not. This finding was attributed to the differing feedstock that likely affected the diversity of the suppressive population (El Khaldi et al. 2016).

Chemical properties of compost affect soil-borne disease. Highly acidic, basic or saline products may alter the soil environment and can result in changes in microbial communities in some cropping systems (Hoitink et al. 1997). Immobilization of nutrients following application of composts from high carbon materials may suppress certain soil-borne diseases, such as *Fusarium* (Hoitink et al. 1997).

Disease suppression in the field also varies with environmental conditions, particularly soil moisture (Larkin et al. 2011; Bernard et al. 2014). Following annual application of dairy manure compost, Larkin et al. (2011) observed a reduction in black scurf only under non-irrigated conditions. Bernard et al. (2014) also observed a significant reduction in black scurf, but only during one year (the driest) of a three year study.

In order to better understand the effect of compost on soil-borne disease suppression in potato production systems, the objective of this study was to evaluate the effect of diverse compost products on the severity and incidence of soil-borne diseases including common scab (CS), powdery scab (PS), black scurf (BS), and silver scurf (SS) after one application and after two successive applications under field conditions in a humid temperate climate and under growth room conditions.

4.2 Materials and Methods

4.2.1 Field Experiment

A two-year field experiment was established in the fall of 2014 at the Fredericton Research and Development Centre of Agriculture and Agri-Food Canada, Fredericton, New Brunswick, Canada (Lat. $45^0 55'N$; Long. $66^0 36'W$) and was previously described (Chapter 2). The experiment used a randomized complete block design with six treatments and four replicates. Treatments included five compost products and a no compost control as previously described (Chapter 2).

Potato tubers were harvested by hand on September 28, 2015 and September 26, 2016. Thirty tubers from each plot were stored in the dark at 15^0C in mesh bags under high relative humidity of 90-95% for 6-8 weeks to better visualize fungal diseases. Disease severity (approximate percentage of tuber surface covered with visible symptoms) and incidence (percentage of tubers with visible disease symptoms) were assessed.

Statistical analysis was performed separately for years 2015 (after one compost application) and 2016 (after two consecutive years with compost application). Data from each year were analyzed using the General Linear Model procedure in Minitab 17 Statistical Software (Version 17, Minitab Inc., USA) as a randomized complete block designs with six treatments and four replicates. Normality and constant variance were tested, and transformations were used as appropriate. When a significant effect was identified in the analysis, Tukey's HSD test for multiple means comparisons was computed ($\alpha = 0.05$). Pearson correlations between compost parameters and diseases were determined using treatment means. Pearson correlations between soil parameters (0-15 cm depth sampled pre-planting) and diseases were also determined using treatment means.

4.2.2 Growth Room Experiment

The growth room experiment quantified the effect of diverse compost products on disease severity of tubers in a controlled environment. The experiment was designed as a randomized complete block design experiment with eight compost treatments and eight replicates. Compost treatments included the six treatments described in the field experiment plus two additional compost products: lobster shell compost (LC) composted from a 2:1 volumetric ratio of lobster processing wastes to softwood bark, and sea compost (SEAC) obtained from a mixture of composted manure, seaweed, shellfish flour, and peat moss feedstock (Table 4.1). The experiment was repeated once.

Table 4.1 Additional composts applied in growth room experiment: lobster shell compost (LC) and sea waste compost (SEAC).

	LC	SEAC
Dry matter (%)[1]	53.8(0.9)[2]	40.4(0.2)
Ash g kg^{-1}	567(10)	255(2)
C:N	15.2(0.1)	12.8(0.2)
pH	8.00(0.00)	6.70(0.10)
C (g kg^{-1})	247(1)	398(9)
N (g kg^{-1})	16.2(0.0)	31.0(0.8)
P (g kg^{-1})	10.43(0.10)	7.89(2.55)
K (g kg^{-1})	1.60(0.04)	19.08(5.37)
Ca (g kg^{-1})	123.2(2.7)	31.5(9.3)
Mg (g kg^{-1})	7.55(0.13)	5.06(1.46)
Fe (g kg^{-1})	3.8(0.1)	2.3(0.8)
Cu (mg kg^{-1})	19.6(0.5)	67.8(19.8)
Zn (mg kg^{-1})	62.3(1.2)	212.9(60.3)
B (mg kg^{-1})	9.2(0.4)	31.5(10.3)
Mn (mg kg^{-1})	553.5(11)	258.2(69)
Nitrate-N (mg kg^{-1})	497.3(17.9)	1024.7(183.0)
Ammonium-N (mg kg^{-1})	28.6(1.2)	58.7(13.7)

[1] With the exception of DM and pH, all values expressed on dry matter basis.

[2] Standard deviation expressed in parenthesis.

Field soil naturally infected with common scab (*Streptomyces scabies*), powdery scab (*Spongospora subterranea*), black scurf (*Rhizoctonia solani*), and silver scurf (*Helminthosporium solani*) was collected and hand-sieved to pass through a 4.75 mm sieve. Each compost treatment (sieved to pass through an 8 mm sieve to remove large debris) was mixed with soil at 5% w/w ratio (dry weight compost to dry weight soil). This compost rate is approximately equivalent to twice the rate used in the field experiment, assuming a soil bulk density of 1.2 g cm^{-3} and a 0.15 m depth of compost incorporation. One seed piece per pot of hand-cut Shepody seed (57.0 ± 0.3 g) was planted in the soil/compost mix in 15-cm clay pots on September 3-4, 2015 (Experiment 1). For the first two months, the photoperiod was 16 h with 20^{0}C during the day or 18^{0}C at night. Pots were watered by hand. Fertilizer (20-20-20) was applied at a concentration of approximately 1 g L^{-1} at time of watering for the first two months, a recommended rate for constant watering. For the last two months, the photoperiod was decreased to 12 h and fertilization was stopped to induce tuberization.

Tubers were harvested approximately 16 weeks after planting to assess disease incidence and severity, as described for the field experiment. Rotted tubers were counted, recorded and discarded because symptoms of common scab, powdery scab, and black scurf could not be assessed. Tubers < 4 g in size (approximately < 2 cm in diameter) were discarded because it was difficult to obtain an accurate disease assessment, and due to late tuber initiation, these tubers may have delayed infection compared with larger, earlier-formed tubers. Tubers with surfaces covered with $> 40\%$ sunburn or browning were also discarded; these tubers sat above the soil surface and, therefore, were not subject to same conditions as tubers covered with soil. Tuber disease assessments were corrected for the area of tuber not exposed to soil.

The growth room experiment was repeated from February to May, 2016 (referred to as growth room experiment 2). Seed pieces were planted on February 4, 2016. The photoperiod was the same as previous experiment. However, the fertility was reduced to encourage the development of disease. As recommended for intermittent feeding, plants received 0.67 g pot^{-1} (20-20-20) every two weeks following seedling emergence. After two months, fertilization was reduced to once every four weeks until harvest.

Data were analyzed using the General Linear Model procedure in Minitab 17 Statistical Software (Version 17, Minitab Inc., USA) as a randomized complete block design with eight treatments and four replicates. Normality and constant variance were tested, and transformations were used as appropriate. When a significant effect was identified in the analysis, Tukey's HSD test for multiple means comparisons was computed ($\alpha = 0.05$). Pearson correlations between compost parameters and diseases were determined using treatment means.

4.3 Results

4.3.1 Field Experiment

Common scab (CS), black scurf (BS), powdery scab (PS), and silver scurf (SS) were observed on tubers harvested from the field experiment in 2015. There was no significant effect of compost treatment on severity or incidence of individual diseases assessed (Table 4.2). Disease severity averaged 1.66%, 0.17%, 0.02%, and 3.47% for control plots, and 0.83%, 0.39%, 0.05%, and 3.34% for compost treated plots for CS, BS, PS, and SS, respectively. Disease incidence averaged 41.0%, 10.1%, 2.5%, and 74.6% for

Table 4.2 Effect of different compost treatments on the severity and incidence of common scab (CS), powdery scab (PS), black scurf (BS) and silver scurf (SS) in the field experiment in 2015 and 2016.

Treatment	CS		BS		PS		SS		Total disease	
	Severity[1]	Incidence[2]	Severity	Incidence	Severity	Incidence	Severity	Incidence	Severity	Incidence
					2015					
Control	1.66	41.0	0.17	10.1	0.02	2.5	3.47	74.6	5.31	78.9ab[3]
MSC	0.76	33.3	0.26	13.3	0.14	5.8	3.39	77.5	4.55	85.0ab
MC	0.79	28.8	0.39	7.6	0.00	0.0	2.66	74.1	3.84	79.1ab
FRC	0.73	25.1	0.92	16.8	0.02	2.5	3.73	75.7	5.41	84.1ab
SSOC	0.37	19.5	0.17	8.6	0.01	2.5	2.80	56.6	3.35	65.2b
FPMC	1.50	34.2	0.23	9.2	0.07	4.2	4.10	85.0	5.90	90.0a
					2016					
Control	0.88a	57.9	3.26a	69.8	0.06	9.3	3.24	65.0	7.43	94.0
MSC	2.09a	85.8	1.37ab	48.3	0.30	14.2	4.81	79.2	8.57	100.0
MC	0.93a	60.0	0.90b	46.7	0.46	10.0	4.32	62.5	6.62	96.7
FRC	0.87a	62.5	1.37ab	65.8	0.13	7.2	5.84	74.2	8.21	95.8
SSOC	2.07a	78.3	1.10ab	36.7	0.31	15.0	3.65	69.2	7.10	95.8
FPMC	2.88a	77.5	1.00ab	33.3	0.06	4.2	2.81	62.5	6.75	92.5

[1] Severity is the percentage of surface coverage.

[2] Incidence is the percentage of tubers with detectable disease.

[3] Means within columns for each year followed by the same letter are not significantly different according to Tukey's HSD test ($P < 0.05$).

control plots, and 28.2%, 11.1%, 3.0%, and 74.0% for composted treated plots for CS, BS, and SS, respectively. However, there were significant differences in total disease incidence among compost treatments with significantly greater disease observed in FPMC (90.0%) compared with SSOC (65.2%). Total disease severity averaged 5.3% for the control plots and 4.6% for compost treated plots and was not significantly different among treatments.

In 2016, there was a significant effect of compost treatment only on the severity of CS and BS (Table 4.2). The BS severity of the control (3.26%) was significantly greater than for the MC treatment (0.90%). Although there was a significant treatment effect of compost on the severity of CS, mean values were not significantly different according to the Tukey HSD test. Disease severity averaged 0.88%, 3.26%, 0.06%, and 3.24% for control plots, and 1.77%, 1.15%, 0.25%, 4.28% for compost treated plots, for CS, BS, PS, and SS, respectively. Disease incidence averaged 57.9%, 69.8%, 9.3%, and 65.0% for control plots, and 72.8%, 46.1%, 10.1%, and 69.5% for compost treated plots, for CS, BS, PS, and SS, respectively. Total disease severity averaged 7.43% and 7.45% for control and composted treated plots, respectively. Total disease incidence averaged 94.0% and 96.2% for control and composted treated plots, respectively.

Significant correlations were identified among disease and compost parameters in 2015 (Table 4.3). Black scurf incidence was negatively correlated with compost K concentration (r = - 0.99). Powdery scab severity was positively correlated with the concentration of ash in the compost (r = 0.91) and PS incidence was negatively correlated with compost carbon content (r = -0.88). Silver scurf incidence (r = - 0.89), total disease

Table 4.3 Pearson correlations between the severity (sev) and incidence (inc) of soil-borne diseases in 2015 and 2016 and compost parameters for the field experiment.

Compost Parameter	CS		BS		PS		SS		Total disease	
	Sev[1]	Inc[2]	Sev	Inc	Sev	Inc	Sev.	Inc.	Sev.	Inc.
					2015					
Ash	0.43	0.67	-0.63	-0.06	**0.91**	0.88	0.41	0.39	0.27	0.40
C	-0.58	-0.66	0.55	0.03	-0.83	**-0.88**	-0.60	-0.46	-0.46	-0.47
N	-0.62	-0.67	-0.58	-0.65	-0.41	-0.34	-0.78	**-0.89**	**-0.88**	**-0.94**
K	0.12	-0.01	-0.66	**-0.99**[3]	-0.38	-0.50	-0.53	-0.20	-0.47	-0.34
					2016					
Fe	0.27	-0.30	-0.44	-0.21	-0.66	**-0.95**	-0.44	-0.68	-0.53	**-0.91**

[1] Severity is the percentage of surface coverage.

[2] Incidence is the percentage of tubers with detectable disease.

[3] Values in bold are significant ($P < 0.05$).

severity (r = - 0.88), and total disease incidence (r = - 0.94) were negatively correlated with compost total N concentration. In effect, the total N concentration of compost was able to account for 88% of variation in total disease incidence and 78% of variation in total disease severity in 2015 (Figure 4.1). In addition, there were significant correlations among other properties; however in each case, the correlation was significant due to the influence of a single treatment mean and as a result the correlation was difficult to interpret. In 2016, the Fe concentration of compost was negatively correlated with the PS incidence (r = -0.91) and total disease incidence (r = -0.91) of compost applied prior to the 2016 growing season (Table 4.3). There were no other significant correlations with compost properties as observed in 2015.

Significant correlations were identified among disease and soil properties in 2015 (Table 4.4). Silver scurf severity was negatively correlated with soil P concentration (r = -0.90). Total disease severity was negative correlated with soil Na concentration (r = -0.91) and soil P concentration (r = -0.92). Common scab severity was negatively correlated with the soil cation exchange capacity (r = - 0.89), soil C concentration (r =

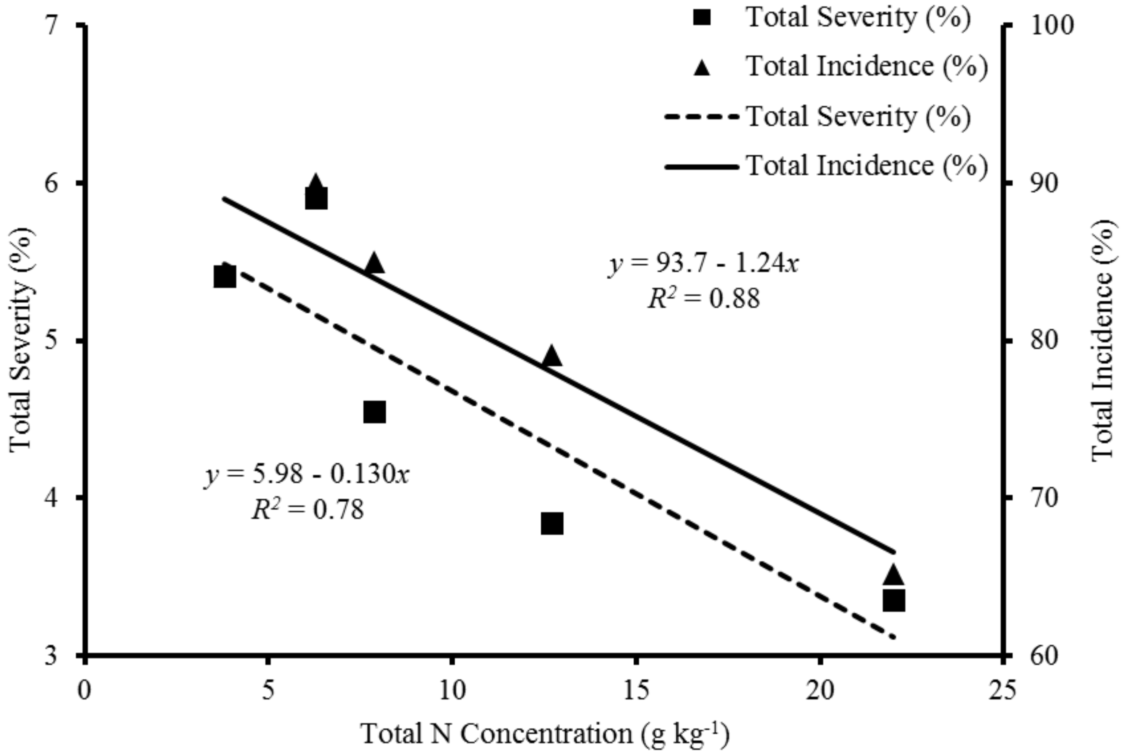

Figure 4.1 Linear regression between compost total N concentration and total disease severity and incidence for the field experiment in 2015.

0.85), and POM-C concentration (*r* = -0.86). Common scab incidence was negatively correlated with soil C concentration (*r* = -0.98), and POM-C concentration (*r* = -0.99). In effect, the POM-C concentration of soil was able to account for 98% of variation in CS incidence and 74% of variation in CS severity (Figure 4.2). Additional correlations were significant due to the influence of a single treatment mean and as a result the correlation was difficult to interpret and not presented here.

Significant correlations were identified among disease and soil properties in 2016 (Table 4.4). Soil Ca concentration was positively correlated with CS severity (*r* = 0.83) and CS incidence (*r* = 0.96). Soil Al concentration was negatively correlated with CS incidence (*r* = -0.85). Black scurf incidence was negatively correlated with soil Zn

Table 4.4 Pearson correlations between the severity and incidence of soil-borne diseases in 2015 and 2016 and soil properties for the field experiment.

Soil	CS		BS		PS		SS		Total disease	
Property	Severity[1]	Incidence[2]	Severity	Incidence	Severity	Incidence	Severity	Incidence	Severity	Incidence
					2015					
C	**-0.85**	**-0.98**	0.17	-0.06	-0.37	-0.26	-0.49	-0.79	-0.67	-0.70
POM C	**-0.86**	**-0.99**	0.34	-0.01	-0.38	-0.34	-0.47	-0.63	-0.61	-0.53
CEC	**-0.89**	-0.77	0.47	0.48	-0.11	-0.06	-0.43	-0.66	-0.56	-0.52
P	-0.62	-0.52	-0.32	-0.62	-0.25	-0.46	**-0.90**	-0.57	**-0.92**	-0.61
Na	-0.75	-0.56	-0.33	-0.41	0.09	-0.09	-0.79	-0.58	**-0.91**	-0.55
					2016					
pH	**0.88**	**0.94**	-0.53	-0.71	0.10	0.17	-0.13	0.36	0.19	0.32
P	0.15	0.16	-0.67	-0.67	**0.87**	0.34	-0.11	-0.31	-0.56	0.27
Ca	**0.83**	**0.96**	-0.48	-0.65	0.12	0.27	-0.07	0.46	0.29	0.41
Fe	-0.81	-0.72	0.37	**0.84**	-0.28	-0.27	0.61	0.17	0.35	-0.09
Zn	0.67	0.33	-0.68	**-0.86**	0.14	-0.36	-0.50	-0.56	-0.71	-0.38
Al	-0.59	**-0.85**	0.38	0.38	-0.18	-0.31	-0.20	-0.65	-0.53	-0.64

[1] Severity is the percentage of surface coverage.

[2] Incidence is the percentage of tubers with detectable disease.

[3] Values in bold are significant ($P < 0.05$).

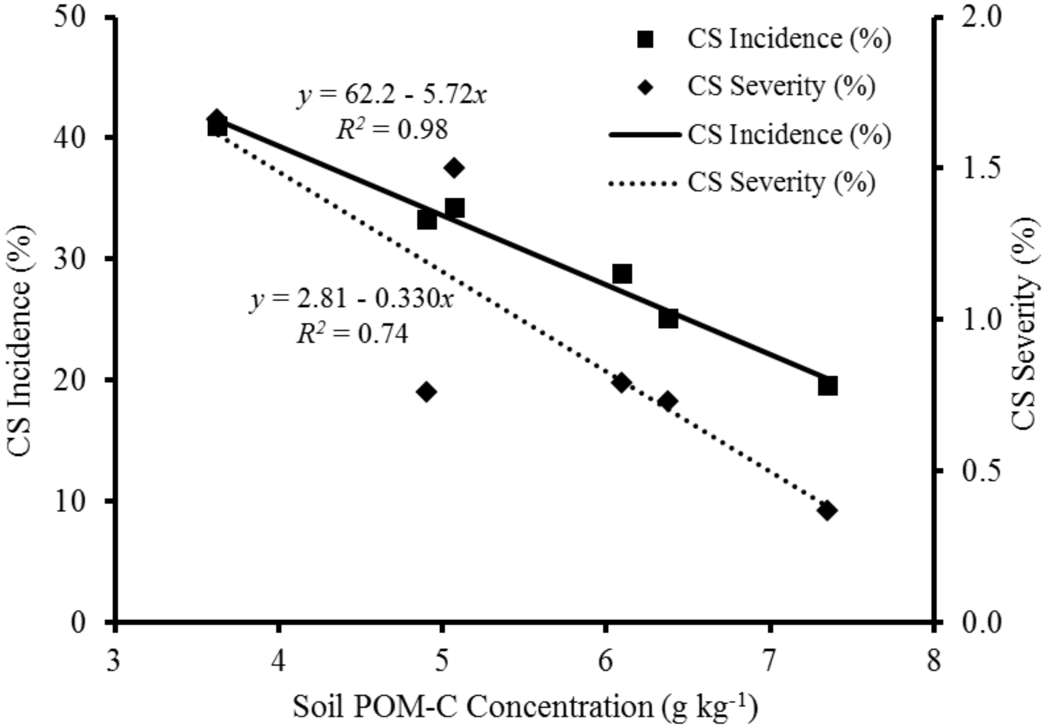

Figure 4.2 Linear regression between soil particulate organic matter carbon (POM-C) concentration and common scab (CS) severity and incidence for the field experiment in 2015.

concentration (r = -0.86) and positively correlated with soil Fe concentration (r = 0.84). Powdery scab severity was positively correlated with soil P concentration (*r* = 0.87). Soil pH was positively correlated with CS severity (*r* = 0.88), and CS incidence (*r* = 0.94). In effect, the soil pH was able to account for 89% of variation in CS incidence and 77% of variation in CS severity (Figure 4.3).

4.3.2 Growth Room Experiment

In growth room experiment 1, there was an average of 4.2 tubers per pot and CS, PS, and BS were observed (Table 4.5). Compost treatments resulted in significant differences in CS severity and incidence. The severity of CS under the control treatment (8.98%) was significantly greater than that under the SSOC (1.72%) or the SEAC

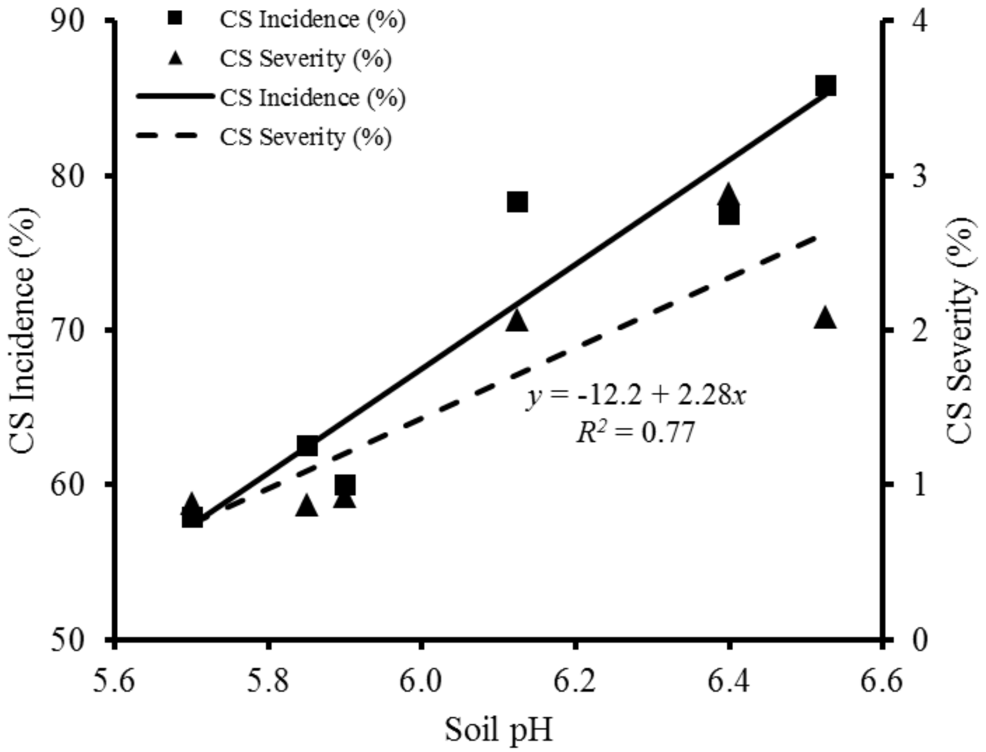

Figure 4.3 Linear regression between soil pH and common scab (CS) severity and incidence for the field experiment in 2016.

(2.47%) treatments. Although there was a significant treatment effect of compost on the incidence of CS, mean values were not significantly different according to the Tukey HSD test and averaged 97.5% for the control and 88.0% for compost treated pots. There was no significant effect on PS or BS. The severity of PS and BS averaged 0.36% and 0.00%, respectively, for control pots, and 0.22% and 0.25%, respectively, for compost treated pots. The incidence of PS and BS averaged 4.3% and 0.0%, respectively, for control pots, and 8.6% and 5.6%, respectively, for composted treated pots.

Growth room experiment 2 had fewer tubers to analyze due to poor tuber growth, averaging 1.5 tubers per pot, a result attributed to poor seed quality. The diseases CS, PS and BS were observed (Table 4.5). There was no significant effect of compost treatment on severity or incidence of any of the diseases observed in this experiment. However, CS

Table 4.5 Effect of different compost treatments on the severity (sev) and incidence (inc) of soil-borne diseases common scab (CS), black scurf (BS) and powdery scab (PS) in two growth room experiments (Expt. 1 and Expt. 2).

Treatment	CS		BS		PS		Total disease	
	Sev[1]	Inc[2]	Sev	Inc	Sev	Inc	Sev	Inc
			Growth Room Expt. 1					
Control	8.98a[3]	97.5a	0.00	0.0	0.36	4.6	9.34	97.5
MSC	5.80ab	88.8a	0.44	17.1	0.10	9.9	6.34	90.4
MC	3.12ab	92.9a	0.00	0.0	0.02	2.1	3.14	92.9
FRC	3.84ab	77.1a	0.05	2.5	0.53	21.7	4.43	79.6
SSOC	1.72b	79.4a	0.63	16.7	0.33	5.6	2.68	79.4
FPMC	8.51ab	94.3a	0.00	0.0	0.23	10.4	8.74	96.4
LC	5.71ab	98.2a	0.78	3.1	0.21	6.7	6.70	98.2
SEAC	2.47b	82.0a	0.00	0.0	0.10	3.9	2.57	82.0
			Growth Room Expt. 2					
Control	1.37	73.3	0.50	10.0	0.20	20.0	2.07	73.3
MSC	3.00	83.3	0.33	16.7	1.58	66.7	4.92	100.0
MC	0.13	16.7	1.17	16.7	0.25	16.7	1.54	41.7
FRC	0.79	38.1	0.95	33.3	1.29	40.5	3.03	81.0
SSOC	0.43	46.7	0.40	20.0	1.46	56.7	2.29	66.7
FPMC	4.63	61.1	0.06	5.6	2.54	50.0	7.22	66.7
LC	0.80	50.0	0.10	10.0	0.75	50.0	1.65	70.0
SEAC	0.53	36.5	0.44	12.5	0.50	34.4	1.46	63.5

[1] Severity is the percentage of surface coverage.

[2] Incidence is the percentage of tubers with detectable disease.

[3] Means within columns followed by the same letter are not significantly different according to Tukey's HSD test ($P < 0.05$).

severity and incidence were numerically greater in the control pots at 1.58% and 66.7%, respectively, compared with compost-treated pots at 1.13% and 41.4%, respectively. The severity of PS and BS averaged 0.20% and 0.50% for control pots, and 1.20% and 0.49%, for compost treated pots, respectively. The incidence of PS and BS averaged 20.0% and 10.0% for control pots, and 45.0% and 16.4% for composted treated pots, respectively.

Significant correlations were observed between disease symptoms and compost parameters in both growth room experiments (Table 4.6). In growth room experiment 1, the compost C concentration was negatively correlated with CS severity (r = -0.79) and total disease severity (r = -0.81). This is consistent with the positive correlation of

Table 4.6 Pearson correlations between the severity (sev) and incidence (inc) of soil-borne diseases common scab (CS), black scurf (BS), and powdery scab (PS) and compost parameters in two growth room experiments.

Compost Parameter	CS		BS		PS		Total disease	
	Sev[1]	Inc[2]	Sev	Inc	Sev	Inc	Sev	Inc
			Growth Room Expt. 1					
Ash	**0.78**[3]	0.40	0.16	0.31	0.13	0.40	**0.81**	0.50
C	**-0.79**	-0.41	-0.07	-0.18	-0.19	-0.43	**-0.81**	-0.51
Mg	0.60	**0.82**	0.07	-0.59	-0.37	-0.28	0.58	**0.81**
NH_4-N	**-0.76**	**-0.78**	-0.06	0.03	0.41	-0.03	-0.74	**-0.84**
			Growth Room Expt. 2					
DM	**0.79**	**0.87**	-0.55	-0.44	0.59	0.68	0.72	0.57
Ash	**0.77**	0.68	-0.30	-0.11	0.74	0.56	**0.81**	0.49
C	**-0.76**	-0.56	0.24	0.10	-0.76	-0.44	**-0.82**	-0.37
Mg	0.28	0.03	-0.51	**-0.77**	-0.03	-0.12	0.11	-0.25

[1] Severity is the percentage of surface coverage.
[2] Incidence is the percentage of tubers with detectable disease.
[3] Values in bold are significant (*P* < 0.05).

compost ash concentration with CS severity (*r* = 0.78), and total disease severity (*r* = 0.81). The Mg concentration was positively correlated with the CS incidence (*r* = 0.82) and total disease incidence (*r* = 0.81). The ammonium-N concentration was negatively correlated with CS severity (*r* = -0.76), CS incidence (*r* = -0.78) and total disease incidence (*r* = -0.84). Compost ammonium-N concentration was able to account for 61% of the variation in CS incidence and 58% of the variation in CS severity in growth room expt. 1 (Figure 4.4).

In growth room experiment 2, CS severity (*r* = 0.79) and incidence (*r* = 0.87) were positively correlated with compost dry matter (DM) (Table 4.6). Black scurf incidence was negatively correlated with the compost Mg concentration (*r* = 0.77). The C concentration was negatively correlated with CS severity (*r* = -0.76), and total disease severity (*r* = -0.82). Correspondingly, the compost ash concentration was positively correlated with CS severity (*r* = 0.77), and total disease severity (*r* = 0.81). Compost C

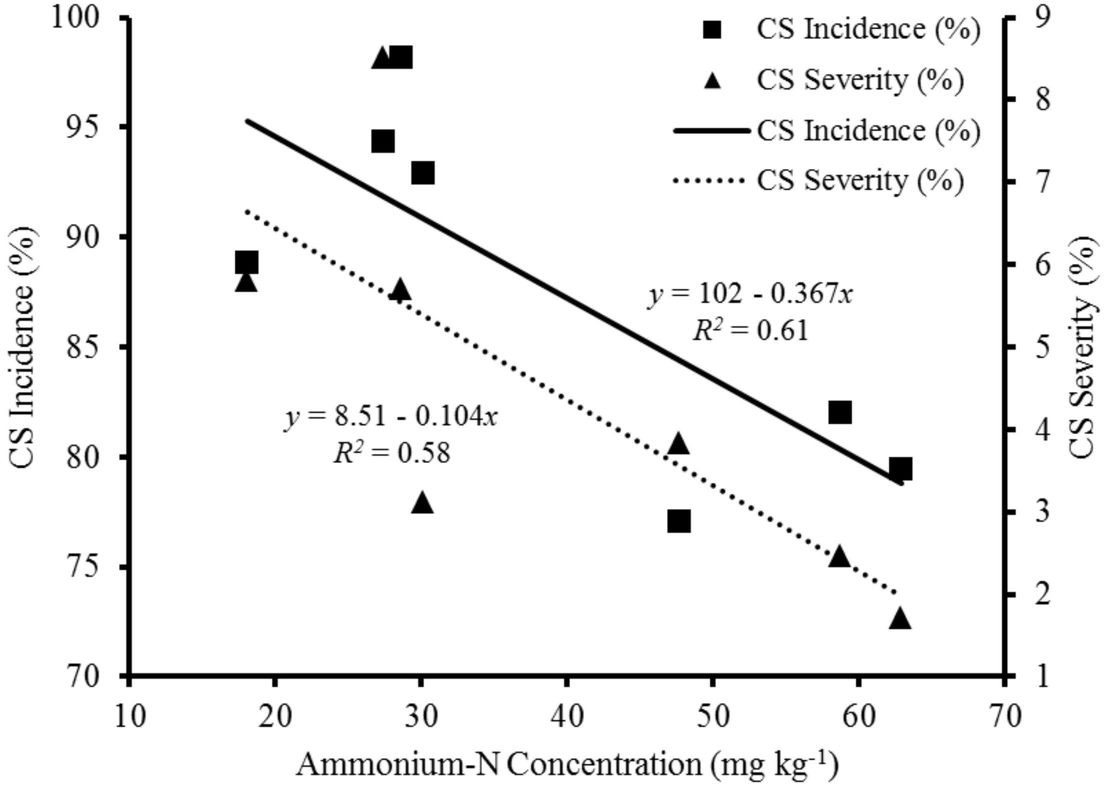

Figure 4.4 Linear regression between compost ammonium-N concentration and common scab (CS) severity and incidence in growth room experiment 1.

concentration explained 58% of the variation in CS severity in growth room experiment 2 and 62% of the variation in CS severity in growth room experiment 1 (Figure 4.5).

4.4 Discussion

Surface lesions and blemishes caused by soil-borne pathogens can significantly reduce the marketability of potato tubers. In this study, symptoms of CS, BS, PS and SS were detected under field conditions, and (with the exception of SS) under growth room conditions. The potato cultivar, Shepody, was selected for its susceptibility to common scab and its ease in disease identification. Considering all treatment means, CS severity ranged from 0.73% to 2.88% in the field and from 0.13% to 8.98% in the growth room. These values were similar to CS severity reported in other potato field studies in New

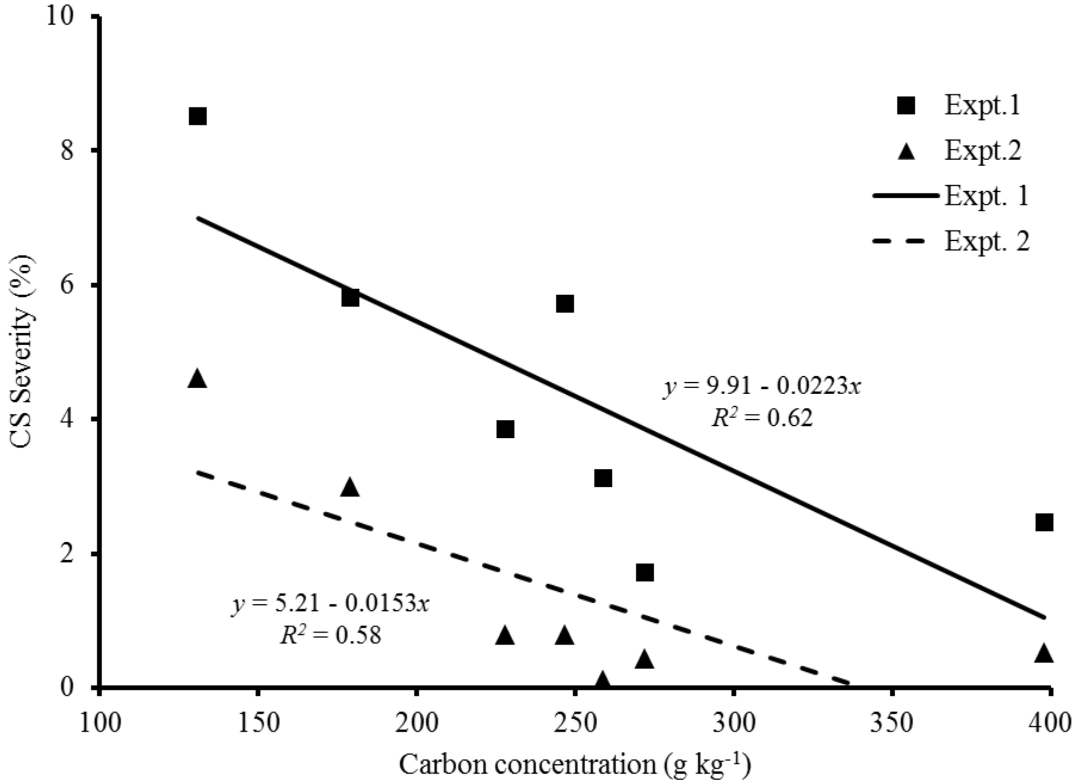

Figure 4.5 Linear regression between compost C concentration and common scab (CS) severity in two growth room experiments.

Brunswick (Al-Mughrabi et al. 2008) and Maine (Larkin et al. 2011). Black scurf severity was greater in 2016 than 2015 and severity was greater than those reported by Al-Mughrabi et al. (2008) and Larkin et al. (2011). Silver scurf was detected over the two years of the field experiment, but was not detected on tubers from the growth room. Total disease severity and incidence increased in the second year of the field experiment. However, it is unclear if this increase was due to repeated potato cropping and build-up of pathogen levels in soil or other factors that favour disease development, such as seasonal differences in precipitation and temperature.

Symptoms of CS are caused by several species of pathogenic *Streptomyces* that colonizes the lenticels of growing potato tubers. Suppression of CS was observed under SEAC and SSOC treatments in the growth room experiment 1. Similar trends in suppression were observed in growth room experiment 2, as well as in the field experiment in 2015; although these were not statistically significant responses. Suppression of CS following the application of compost has been observed in other studies (Al-Mughrabi et al. 2008); but the mechanism of suppression has not been identified. Significant negative correlations between CS and the carbon content of compost in the field and growth room experiments of the current study indicate a role for OM quantity in disease suppression. Organic matter can affect soil-borne disease by stimulating antibiosis, hyperparasitism, competition between microorganisms, systemetic induced resistance (SIR) or changes in soil nutrient and physical properties (Stone et al. 2004; Mehta et al. 2014). In this study, products applied up to 23 tonnes C ha^{-1}. Because compost was applied on a constant dry matter basis in this study, the C concentration of a product could be used as a direct indicator of the quantity of C applied. This suggests general disease suppression, where suppression is related to the total sum of activities of the overall biological population, rather than the action of a particular few (Stone et al. 2004).

There were, however, deviations from the regression line of CS severity against compost C concentration and a strong negative correlation between CS and soil POM-C concentration, which support a role for OM quality in disease suppression. In other studies, compost maturity and the extent of OM decomposition were shown to influence disease suppression in compost-amended soils (Hoitink et al. 1997; Bonanomi et al. 2010; Pane et al. 2013). Particulate organic matter serves as a readily available food and energy source for microorganisms (Gregorich et al. 1994). In soil amended with higher-quality compost, rapidly growing zymogenous (r-selected) organisms are favoured and can outcompete slower growing autochthonous (k-selected) organisms, such as fungi or actinobacteria. Soil-borne pathogens of potato typically fall in the latter group, and therefore may be suppressed by competition in compost-amended soils.

Chemical compost properties can also influence the development of soil-borne disease (Hoitink et al. 1997). In growth room experiment 1, a negative correlation was observed between ammonium-N concentration and CS severity and incidence. It is hypothesized that N-rich products may alter the nutritional status of the plant, thereby affecting plant N availability and influencing microbial communities (Huber and Watson 1970). Poor nutrient status is often associated with increased disease symptoms (LaMondia et al. 1999) and it is possible that the high-N products increased plant N availability and resulted in an increase in vegetative growth that reduced disease severity.

In the field experiment, compost had a significant liming effect on the soil and resulted in increased soil pH relative to the un-amended control (Chapter 3). In 2016, the soil pH was positively correlated with CS incidence and severity. Common scab symptoms are known to increase with increasing soil pH (Larkin et al. 2011).

Rhizoctonia solani, the causal agent of BS of pathogen, is a competitive fungal pathogen (Stone et al. 2004; El Khaldi et al. 2016). In this study, greater severity and incidence of BS was observed in the field experiment in 2016 than in 2015. This is likely the result of cool, wet weather following planting in May and early June which favours pathogen development. Very little BS was observed under growth room conditions. One compost treatment (MC) significantly reduced the severity of BS relative to the control in 2016 in the field. Compost application has been shown to reduce BS in potato production; although this response is often inconsistent and difficult to predict (Larkin et al. 2011). The literature points to biological control of *R. solani* in soils treated with compost by ‘specific suppression’, or more specifically, parasitism, antibiosis and other suppressive mechanisms by *Trichoderma* spp. and/or other biocontrol agents (Hoitink et al. 1991; Hoitink et al. 1997; Stone et al. 2004, El Khaldi et al. 2016). Although the diversity of microbial communities were not evaluated in this study, it is possible that the MC compost was colonized by a population suppressive to *R. solani* and was able to effectively reduce BS symptoms on the tubers. In previous studies, compost products derived from conifer bark and other lignin-rich wastes exhibited greater disease suppression (Bailey and Lazarovits 2003). The MC treatment included lignin-rich conifer-based waste in the feedstock, which may have resulted in a reduction in plant N availability (Hoitink et al. 1997; Stone et al. 2004).

Despite evidence of CS and BS suppression in the current study, not all compost products behaved similarly. In 2015 of the field experiment, FPMC exhibited significantly greater total disease incidence than the SSOC treatment. A negative correlation between the total N concentration of compost products and total disease incidence was observed. The total N concentration of compost reflects the initial feedstock, the extent of decomposition, and composting process (Wu et al. 2010). These two compost products were very different in original feedstock and chemical properties, which likely affected the biological communities.

4.5 Conclusions

In this study, there was some evidence that compost products had a significant suppressive effect on soil-borne potato diseases in a loam soil of New Brunswick. In some cases, the SSOC, SEAC and MC significantly reduced BS or CS severity relative to an un-amended control. Symptoms of CS severity were negatively correlated with compost C concentration, compost ammonium-N concentration, soil C concentration, soil POM-C concentration, and soil CEC, and positively correlated with compost ash concentration, compost DM concentration, soil pH, and soil Ca concentration. These correlations suggest that the quantity and quality of OM play roles in compost-induced CS suppression in this system. Despite some evidence of disease suppression, the overall results of this study were inconsistent and were not reproducible between field seasons or within growth room experiments.

Based on these results, the use of compost to suppress diseases is likely not a reliable strategy in potato production systems. However, the lack of a negative response of these products when compared to the unamended control does provide initial reassurance to producers that compost, as applied in this study, did not significantly increase disease. In addition, when applied as an amendment to improve soil quality, these products may result in the added benefit of disease suppression. Prior to applying compost to soils under potato production, the chemical properties of the product should be considered. Although increases in soil pH are often desirable in the acidic soils of New Brunswick, increases in soil pH following the application of some compost products can result in increases in CS severity.

CHAPTER 5.0 CONCLUSION

In this study, one and two applications of five compost products, applied at 45 Mg ha^{-1} on a dry weight basis, were able to enhance overall quality of potato production soil, as measured by improvements in soil chemical, physical and biological properties. There were significant differences among compost treatments: some products were more beneficial than others and specific improvements in soil properties reflected the initial composition of the compost. However, despite significant improvements in quality of the soil, there was no effect on tuber yield in this study.

In an effort to capture the variability in compost across the region, five commercially available products were selected for this thesis. This included composts derived from diverse sources of feedstock with different C:N ratios. Despite variability in C:N ratio and C concentration, these products, with the exception of SSOC, were primarily derived from forestry-waste and were rich in recalcitrant C molecules. In future studies, evaluation of compost products derived from additional C sources and bulking agents, for example plant residues or manures, may be insightful. Differences in the quality of C in such alternative compost products may exhibit a greater effect on soil aggregate stability, labile C pools, and CEC.

In this study, compost products affected soil chemical properties, including the supply of nutrients. Evidence of a marginal, but significant, increase in N-supply was demonstrated by SSOC, and to a lesser extent MSC and FPMC treatments (Chapter 2). Increases in petiole nitrate-N, plant N uptake, and soil mineral N were observed following application of these treatments. Increases in soil labile N were observed for all compost products (Chapter 3). However, some of the compost products showed evidence of N immobilization, primarily the FRC treatment, and to a lesser extent, the MC treatment (Chapter 2). The FRC product exhibited decreased petiole nitrate-N, plant N uptake, and soil mineral N. This product also exhibited a negative apparent nitrogen recovery.

In addition to influencing N availability, compost products increased soil pH and the supply of plant nutrients. Specifically, several compost products increased Melich-3 extractable nutrients K, Ca, Mg, S, B, Zn, and Mn (Chapter 3). Increases in soil extractable K were strongly correlated with K added in compost, with the greatest increases observed following the application of the FPMC treatment. Increases in soil pH were also observed. Therefore, when applying compost, producers may need to adjust K fertilizer application rates, as well as rates of lime application. Despite the addition of large quantities of OM with the compost, there was no significant effects on soil CEC (Chapter 3). This was unexpected, but likely reflected the nature of the products applied in this study.

Compost products improved several soil physical properties. Compost application resulted in reductions in bulk density and resistance to penetration at some depth intervals, as well as improvements in permeability as measured by saturated hydraulic conductivity (Chapter 3). The greatest improvements in soil physical properties were observed following the application of the SSOC, FRC and MC treatments. For a given dry weight application of compost, these products applied greater quantities of C to the soil, which presumably resulted in greater physical benefits. However, compost application did not affect other physical properties in this study, including aggregate stability and water holding capacity. This was not unexpected: soil aggregates are often more stabilized by immature composts or raw manures (Annabi et al. 2007). Also, compost products often increase water content at both FC and PWP, which negates an effect on overall water holding capacity (Carter 2007; Forge et al. 2016).

Compost products improved soil biological properties and increased organic matter in this study. Increases were observed in SOC, POM-C, and POX-C, and to a lesser extent, the 24 h burst test, mineralizable C, and abundance of Collembola (Chapter 3). It is not surprising that compost products had a greater effect on more stable pools of C: compost is dominated by recalcitrant forms of C as labile substrates are catabolized during the composting process (Rynk 1992; Dumontet et al. 1999). Some compost products were also able to suppress soil-borne disease, namely CS and BS, although suppression was inconsistent between years and between field and growth room experiments (Chapter 4). Based on the correlations obtained, the quantity of carbon supplied by the compost may play a major role in the improvement of soil biological properties. The three compost products containing greater C concentrations, SSOC, MC and FRC, resulted in the most significant improvements in soil biology. However, the quality of C added may have influenced some of these changes, in particular the more labile C pools, as demonstrated by significant responses to MSC and FPMC treatments.

Compost-induced yield benefits in potato production in this region have often been attributed to increases in soil moisture retention, especially under drier conditions (Carter et al. 2004; Lynch et al. 2008; Bernard et al. 2014). However, despite improvements in soil quality and an increase in water content at FC, there was no significant effect on yield (Chapter 2). This may be the result of moisture conditions in the two years of the field experiment. The growing season in 2015 was wetter than 30-

year normal (Environment Canada 2017), and following planting in 2016, there was a period of cool and wet weather which resulted in persistence of rainwater between potato hills.

In this study, only short-term effects of compost application were quantified. The residual benefits of compost application on soil physical, biological and chemical properties have been documented (Eghball et al. 2004; Moore et al. 2011; Reeve et al. 2012). Increases in soil P and crop P uptake were observed at least four years after application of composted beef cattle manure on corn production (Eghball et al. 2004). Significant increases in total tuber yield and U.S. #1 yield were observed three years after the previous application of dairy manure compost (Moore et al. 2011). Greater microbial biomass, total organic C, and enzyme activity were observed at least 16 years following the application of dairy manure compost at 50 Mg ha^{-1} on a dry weight basis to organic dryland wheat in western United States (Reeve et al. 2012). As micro-organisms catabolise compost derived POM-C, plant nutrients are mineralized and microbial exudates are released, possibly contributing to long-term nutrient yield-benefits and soil aggregate stabilization, respectively. Humification of SOM and compost-derived-C may contribute to increased soil water retention and CEC. Continued monitoring of soil quality and productivity of the field trials examined in this thesis would help quantify the longer term, residual benefits of compost application in this system.

Future studies comparing diverse compost products and their effect on quality and productivity in New Brunswick should also consider applying compost to a range of soil textures, soil C concentrations, and fertility levels. Soils in this study were loamy in texture with high levels of Melich-3 extractable P and K. Applying compost products to coarser textured soils with lower inherent water holding capacity or to less fertile sites may have provided greater responses in soil quality indicators and potato productivity.

From the changes in soil quality observed in this study, it was possible to identify some properties of compost most suitable for use in New Brunswick potato production. Key compost properties to consider include:

1) Dry matter content – A compost product with greater dry matter would be more economical, as a major portion of costs associated with compost use are for transportation and application of the product;
2) Carbon or ash concentration – A compost product with greater OM or C concentration (or low ash content) has more benefits for producers. In this study, compost C concentration was strongly related to soil-borne disease suppression, to benefits in soil physical properties and structure, and to increases in SOC and other C fractions;
3) Nutrient concentrations – A compost product with greater concentrations of plant nutrients may reduce fertilizer nutrient requirements. Many inorganic nutrients applied in compost are readily available for plant uptake (He et al. 2001). In this study, Melich-3 extractable K was significantly affected by compost treatment and in general, the more the K that was applied, the greater the increase in soil extractable K. Additionally, products containing more N exhibited a greater impact on total soil N, but also on plant N uptake and labile N. Prior to application of compost with high-nutrient concentrations, it is important to consult with soil test levels to ensure that application will not result in exceeding those recommended;

4) Compost pH – The compost pH should be considered prior to application. In effort to reduce the pH of acidic soils of eastern Canada, application of neutral-to-slightly basic compost ($pH > 6.5$) may be desirable. However, excessive liming should be avoided as common scab development is favoured at higher soil pH;
5) Compost maturity – A mature compost will reduce the risk of N immobilization. In this study, mature compost products were consistent with lower C:N ratios (<30), and lower NH_4-N:NO_3-N ratios (<3). Alternatively, if residual soil mineral N levels are excessive after potato harvest, fall application of an immature compost product may result in favourable N immobilization for prevention of overwinter mineral N losses;
6) Contaminants - Contaminants were a major issue for potato production in the region and there is no tolerance for physical debris. Heavy metal contamination should also be avoided. Despite demonstrating some of the most favourable results in this study, the SSOC product contained plastic debris and other waste materials, making it unusable in current potato production systems in New Brunswick.

In conclusion, over the last few decades, the quality and productivity of New Brunswick potato production soils has been declining (Saini and Grant 1980; Rees et al. 2014). The future of the potato industry in the province is contingent upon improving soil quality and functioning. In this study, the application of compost was able to significantly increase SOC and improve soil properties in one or two years. Despite these significant improvements, it is unlikely that widespread compost application will be readily adopted by producers because, currently, there is no guaranteed economic return on investment from application of compost. In addition, high variably in compost quality is a major issue for producers. Either applying high rates of compost to address specific issues in smaller regions of fields, or applying lower rates of compost within longer crop rotations with reduced tillage may be more economical and practical strategies to improve soil quality and productivity. In addition, adequate compost testing must be performed. As this study strongly supports: the quality of compost will directly affect the quality of the soil.

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