PROPERTIES OF AN ORTHIC BLACK CHERNOZEM AFTER 5 YEARS OF LIQUID AND SOLID PIG MANURE APPLICATIONS TO ANNUAL AND PERENNIAL CROPS

by

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ABSTRACT

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Soil physical and chemical properties determine a soil's crop production potential and the sustainability of a production system. The objective of this study was to determine the effect of solid and liquid pig manure application on the physical and chemical properties of soil after 5 years of manure application. Solid pig manure increased saturated hydraulic conductivity (Ksat) by 110%, aggregate stability by 30%, available and total phosphorus by 471% and 52% respectively, available nitrogen by 38%, organic carbon by 29% and exchangeable K by 308%, and reduced soil bulk density by 14%. Liquid pig manure (LPM) also increased aggregate stability by 21%, exchangeable K by 45%, available P and total P by 258% and 27%, respectively and, reduced bulk density by 6%. An important finding was the 33% decrease in the concentration of exchangeable Ca in LPM-amended soils. Significant manure by cropping system interaction was also obtained for water retention parameters and available water, total nitrogen and electrical conductivity. There was no effect of pig manure on pH and exchangeable Mg concentrations. Soils under perennial vegetation had 31% greater Ksat, 26% increase in available N, 31% greater available P, 15% greater total P and 12% lower bulk density compared with those under annual crops. Our results show that SPM has a potential as a better organic amendment in improving physical and chemical properties of surface soils.

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1. INTRODUCTION

1.1 Manure and manure benefits

Animal manure is a valuable organic fertilizer that can be added to the soil to improve the physical and chemical properties of soils. Although manure is added to the soil primarily as a source of plant nutrients, it is rich in organic carbon. The soil organic carbon strongly influences the physical, biological and chemical properties of soils and soil quality (Liang et al., 2012). Manure addition to soil can affect soil physical, chemical and biological properties, either directly or indirectly (Wienhold, 2005). Manure promotes soil aggregation, increases nutrient availability and retention, determines cation exchange capacity and influences the development of a good soil structure (McSheehy and Rawlings, 1973). It also improves soil water retention (Miller et al., 2002b), aggregate stability (Dunjana et al.,2012) and lowers bulk density (Fares et al., 2008, Miller et al., 2002b). Seguel et al. (2013) reported a decrease in bulk density with the application of manure to fine textured haplocambid soil. Sommerfeldt and Chang (1985) reported a decrease in soil bulk density at the rate of 0.0002 Mg/m^3 per megagram of manure applied annually. They also reported an effect of solid beef cattle manure on soil aggregate size distribution in irrigated soil. Although the effect of beef cattle manure on soil structure was not as large as they expected, they attributed this to the fact that the soil originally had a good structure with good aggregate size distribution and stability (Sommerfeldt and Chang, 1985). Whalen and Chang (2002) reported an increase in wet aggregate stability in a dark brown Chernozem after 25 annual manure applications, with greater increase in an irrigated soil compared to a dryland which was related to the higher moisture content in irrigated plots than in dryland plots during the growing season.

Animal manure is also a source of plant nutrients (Schoenau and Davis, 2006). Manure application increases pH, mineral N (ammonium-N and nitrate-N), available phosphorus and potassium (Limon-Ortega et al., 2009), extractable potassium (Olson and Papworth, 2006), calcium and magnesium (Whalen et al., 2000).

The inappropriate use of manure can lead to eutrophication of freshwater, surface water or lakes (Correll, 1998). Land application is the most environmentally friendly and accepted means of using manures. However, excess application of manures to land can result in leaching of nitrogen and phosphorus into groundwater and runoff into surface waters (Bailey and Buckley, 1998). As such, effective management of manure becomes necessary for the protection of adjacent environments. The optimal amount of manure to be applied to an agricultural field depends on the manure composition, soil nutrient availability, the type of crop grown and environmental conditions (Eghball et al., 2002).

1.2 Pig Manure

Pig production has grown at a rapid rate in western Canada (Novek, 2003). Manitoba is the third largest pig producing province in Canada, after Ontario and Quebec. From July 1,2012 to January, 2013, Manitoba pig industry contributed 23% of total Canada pig production of 12.9 million pigs and 22.8% of the total Canada pig production of 13.1 million pigs in the first 6 months of 2014 (Statistics Canada, 2014). On a global scale, pigs excrete up to 1.7 billion tonnes of liquid manure annually (Choudhary et al., 1996). A pig, on the average excretes 2 tonnes of manure per year (Larson, 1991). As a result of the high pig production rate in Manitoba, large quantities of manure are generated yearly in Manitoba (Sri Ranjan et al., 2005). Pig manure can be an asset to a pig producer when it is properly managed (Choudhary et al., 1996). Spreading the manure as solid or liquid has been the most common form of manure application (Khakbazan et al., 2004).

1.2.1 Solid versus Liquid Pig Manure

Pig manure is generally handled as liquid, solid or semi-solid (slurry). The solid and semi-solid manure have higher organic carbon content than the liquid because of the beddings that forms a part of the solid manure. The solid manure has more residual straw/fibre content and hence more organic carbon than the liquid manure (Magdoff, 1993; Fares et al., 2008). The liquid, semi-solid and solid manure can be differentiated using their respective moisture content. The solid manure has less than 80 percent moisture content, the liquid has more than 90 percent moisture content and the semi-solid has between 80-90 percent moisture content (Manure Application and Uses Guidelines, 2004). Most pig farms in Manitoba adopt the liquid manure storage system (Clean Environment Commission, 2007). However, in recent years, a few producers in Manitoba have experimented with the solid manure handling system.

The manure handling system influences the nutrient content of pig manure (Agricultural Guidelines Development Committee, 2007). For example, fresh solid pig manure from finishing operation contains an average of 6.3 kg $tonne^{-1}$ total N, 1.4 kg $tonne^{-1}$ ammonium-N, 2.14 kg $tonne^{-1}$ available N and 2.83 kg $tonne^{-1}$ total P. The liquid manure from pig fed with phytase supplemented diet contains an average of 3.2 kg $tonne^{-1}$ total N, 2.4 kg $tonne^{-1}$ ammonium-N, 1.8 kg $tonne^{-1}$ available N and 0.7 kg $tonne^{-1}$ of total P (Agricultural Guidelines Development Committee, 2007).

1.2.2 Factors affecting the composition of pig manure

The chemical composition of pig manure depends on a number of factors among which is the feed composition, the age of the animal, manure storage system, and the type of bedding used (Bernal et al., 1993, MAFRI, 2009). Sutton et al. (1984a) reported an increase in the sodium content of manure from pigs fed 0.5% salt when compared to that of a pig fed 0.2% salt. Also Kornegay et al. (1976) reported an increase in the Cu concentration of manure from pigs fed 250-300 ppm Cu diets compared to pigs fed with diets that contained no Cu. In a study by Racz and Fitzgerald (2001), a wide number of pig manure samples were collected and analysed for nutrient content. The authors reported that the total N content of manure samples varied with the barns and concluded that this could be due to differences in the protein content of the feed. The manure from the sow barn had the smallest mean total N and the feed of sows had low total protein content (Racz and Fitzgerald 2001).

Manure composition also depends on the pig growth stage. On average, total N content of liquid pig manure from farrow, nursery, finisher, farrow-finish is 1.7, 2.7, 3.4, 2.8 kg m^{-3} (without phytase supplemented diet), respectively (Agricultural Guidelines Development Committee, 2007). This shows that the age or stage of development can affect pig manure composition.

1.2.3 Pig manure as a plant nutrient source

Plant nutrients can be grouped into macro- and micro-nutrients based on the quantity needed for plant growth. Nitrogen and phosphorus are among the major nutrients needed for crop growth. There are potential problems associated with the use of N and P either from inorganic fertilizers or from manures as N can be lost from the soil through leaching, volatilization, denitrification, run off and surface erosion. Phosphorus, on the other hand, can also be transported by surface runoff and erosion.

The use of manure for fertilization of farmlands can reduce associated costs of inorganic fertilizers (Van Wieringen et al., 2005). Pig manure can be an effective source of plant nutrients (Allen and Mallarino, 2008; Wienhold, 2005) as it is rich in P (Von Wandruszka, 2006) and contains all essential plant nutrients. Racz and Fitzgerald (2001) reported that potassium (K), calcium (Ca) and chloride (Cl) were, on average, the most abundant elements in pig manure while magnesium (Mg), sodium (Na) and sulphur (S) were present in moderate concentrations in 145 pig manure samples collected from 38 pig operations. Pig manure is rich in ammonium-N and total N (Ndayegamiye and Cote, 1989). The total amount of N and P in pig manure produced in Manitoba is approximately 22,500 to 24,000 tonnes of N and 5,000 to 7,000 tonnes of P (Clean Environment Commission, 2007). As a result of the nutrient elements in pig manure, studies have shown that pig manure can be a source of plant nutrients as its addition to soil increased total phosphorus (Royer et al. 2003), available phosphorus and total nitrogen (Bernal et al., 1993), and available nitrogen (Bork et al. 2013; Mooleki et al. 2002; Olson and Papworth 2006; Woli et al. 2013).

1.3 Effect of Pig Manure on Soil Physical Properties

In addition to providing essential nutrients to plants, pig manure also affects soil physical properties. Some important soil physical properties which have great influence on soil and crop productivity include bulk density, aggregate stability, water retention and saturated hydraulic conductivity.

Bulk density is the ratio of the mass of soil to its total volume. Fares et al. (2008) reported a decrease in bulk density of a highly weathered tropical soil amended with pig manure and concluded that the decrease could be as a result of adding a less dense material (organic matter) to the soil or as a result of organic matter improving aggregate stability. Asefa et al. (2004) reported a decrease of 8-9% in the bulk density of a black chernozemic soil that received four annual applications of liquid pig manure. Sommerfeldt and Chang (1985) observed a decrease in bulk density in the 0-15 cm depth of an Orthic Black Chernozem after 5 years of annual cattle manure application.

The aggregate stability of soils is also an important physical property as stable soil aggregates reduce the susceptibility of soil to erosion and provide good soil tilth. An improvement in the quality and quantity of soil organic matter is expected to increase soil aggregation and stability (Whalen and Chang, 2002) as such; aggregate stability can be improved by the addition of organic amendment to the soil (Sun et al., 1995, Wortmann and Shapiro, 2007). Asada et al. (2012) reported an increase in the soil porosity, soil water retention at 0-1000 kPa and enhanced aggregation in soils amended with high rates of pig manure. Comin et al. (2013) also studied the effect of pig slurry and pig litter on the physical properties of a typic hapludult. The authors reported that pig litter increased macroporosity, aggregation, aggregate stability, decreased bulk density and penetration resistance. The addition of pig manure and litter also decreased the proportion of aggregates with diameters >4 mm. In a study by Miller et al. (2002b), bulk density was significantly reduced after 24 years of solid beef manure application. A significant increase in the saturated hydraulic conductivity with increasing rate of cattle manure application was reported by Fares et al. (2008). Limited research exists on the effect of pig manure on soil physical properties. Some studies have been carried out on the effect of liquid pig manure (Fares et al. 2008; Asada et al. 2012; Comin et al. 2013) and pig manure compost (Seguel et al., 2013) on soil properties, however, limited information exists on the effect of solid pig manure on the selected properties. As well, studies of the comparative effect of solid and liquid pig manure on the physical properties of the soil are few. This study attempts to fill this gap.

1.4 Effect of pig manure on soil chemical properties

Both physical and chemical properties of the soil are important for soil productivity. Some chemical properties that can affect the growth of crops as well as the productivity of the soil include available nitrogen, available phosphorus, total nitrogen and phosphorus, organic carbon, pH, electrical conductivity and cation exchange capacity of the soil.

Studies have been carried out on the effect of liquid pig manure on soil chemical properties. For example, Mooleki et al. (2002), Nikiema et al. (2013), Woli et al. (2013) studied the effect of liquid pig manure (LPM) on available nitrogen and found that manure increased soil available N and yield. Qian et al. (2005) reported that after 7 annual applications of liquid pig manure, extractable K was significantly increased in the soils with high manure application rate compared to the control. McAndrews et al. (2006), used solid pig manure and concluded that it resulted in an increase in Bray P and exchangeable K. High rates of pig slurry (120 m^3 ha^{-1}) increased soil organic carbon and potentially mineralizable nitrogen (Ndayegamiye and Cote, 1989).

Phosphorus is another major plant nutrient whose concentration in soils can be influenced by pig manure additions. A study by Royer et al. (2003) showed that 8 annual applications of liquid pig manure at high rates increased soil total phosphorus and other labile P forms. In another detailed study of the effect of pig manure on soil chemical properties of forage land by Olson and Papworth, (2006) an increase in nitrate-N with manure rate, electrical conductivity (EC), orthophosphate phosphorus and extractable potassium was reported. Turner et al. (2010), in a study on effect of annual applications of animal manure on semi-arid soils, reported that pig effluent contributed greater quantities of potassium and total dissolved salts than beef manure. An increase in soil total N and exchangeable K was observed following the application of 300-400 m^3 ha^{-1} of pig slurry in a study by Bernal et al. (1993). An increase in available P was also reported at the smallest rate (100 m^3 ha^{-1}) of pig slurry addition (Benal et al. 1993). Liquid pig manure reduced soil pH by 5% on a sandy loam soil after four annual applications (Assefa et al., 2004).

Miller et al., (2002b) reported a significant increase in the organic carbon content of a Dark Brown Orthic Chernozem after 24 years of solid beef manure application. Also, in a study by Qian et al., (2004), total P increased following 5 annual applications of solid cattle manure to a loam Black Chernozem while no significant effect on total P was detected in soils to which liquid pig manure was added. This was attributed to the fact that a smaller quantity of P was added by the liquid pig manure than the cattle manure.

Soil cation exchange capacity influences plant nutrient uptake and ion movement in soil (Gao and Chang,1996). Ndayegamiye and Cote (1989) observed that pig slurry and solid cattle manure increased cation exchange capacity in soils to which these manures were added, however, the increase was significantly higher in soils amended with cattle manure. This was attributed to the higher organic carbon content in solid cattle manure. Gao and Chang, (1996) reported an increase in the soil cation exchange capacity, total nitrogen and soil organic carbon content with the addition of increasing rates of cattle manure to a dark brown chernozemic clay loam after 18 annual applications.

Limited information exist on the effect of solid pig manure on soil chemical properties, also no direct comparison has been made between the solid and liquid manure and their effect on soil physical and chemical properties. This study will attempt to fill such gap.

1.5 Effect of cropping system on soil properties

Perennial crops persist for multiple growing seasons while annual crops complete their lifecycle in one growing season as all the parts of the annual crop (the root, stem and leaves) die annually. Perennial crops can be harvested multiple times during their life time. Annual crops usually have a shallow root while the perennial crops have deeper roots and as a result can extract water from deeper layers of soil (Wallace, 2000). Perennial crops, due to their deep root can create biopores, improve soil structure and drainage and reduce soil acidity (Cransberg and McFarlane, 1994).

Franzluebbers et al. (2014) concluded that soil under perennial forages have high organic matter content which can lead to improved soil quality in later years. Subsurface nutrient losses (nitrate) from soils cropped to annual vegetation is higher than losses in soils cultivated to perennial crops (Randall and Mulla, 2001; Tomer and Liebman, 2014). Pugesgaard et al. (2014) reported that the nitrate losses in perennial grass clover were smaller than nitrate leached in winter wheat (annual crop). His study recommended that the use of willow or grasses as a replacement for annual crops in nitrate leaching sensitive areas will lead to a significant reduction in nitrate leaching. Also, the establishment of perennial vegetation is known to sequester C from soil organic matter and vegetation (Wienhold and Tanaka, 2001). The sequestered C is important in building soil fertility, protect soil from compaction, and nurture soil biodiversity (Franzluebbers et al., 2014). As such, soil cultivated to perennial vegetation will have less compaction. Also since soil organic C can improve soil physical and chemical properties, soils cultivated under perennial grasses can have improved soil physical and chemical properties (such as greater plant nutrients) when compared to soils under annual crops. Culman et al. (2010) reported a significant increase in total nitrogen, water stable aggregate and soil organic carbon in perennial grasslands than in soils cropped to annual crops in a study to compare the impacts of high-input annual cropping and unfertilized perennial grass production on soil properties. Soils within a perennial grass hedge system produced significantly lower bulk density and higher saturated hydraulic conductivity compared to soils within row crops area (Rachman et al., 2004a; Rachman et al., 2004b; Seobi et al., 2005). Studies on the effect of perennial and annual cropping system on the selected physical and chemical properties are limited.

1.6 Research Objectives

A review of literature showed that several studies have been carried out on the effect of liquid pig manure on soil physical and chemical properties, crop growth and yield. However, the corresponding information on the effect of solid pig manure on the physical and chemical properties of the soil is limited. To our knowledge, there is no study that directly compared the effect of solid pig and liquid pig manure on the physical and chemical properties of soil. Such studies are needed to provide us with information on the impact that a shift from liquid to solid manure management system can have on the soil that receives these manures. Therefore, the objectives of this study are to determine the effect of five years application of N based liquid pig manure and N based solid pig manure on selected soil physical and chemical properties and to determine the effect of cropping system on changes in soil physical and chemical properties following 5 years of manure application.

Chapter 2 of this thesis will focus on the effect of 5 years of repeated pig manure application on the soil physical properties such as bulk density, saturated hydraulic conductivity, water retention at field capacity (0.2 bar) and at permanent wilting point (15 bar), available water capacity and aggregate stability. Chapter 3 will examine the effect of both liquid and solid pig manure on soil chemical properties such as nitrate-N and ammonium-N, available phosphorus, total nitrogen and phosphorus, organic carbon, total carbon, pH, electrical conductivity, exchangeable cations and the cation exchange capacity of the soil. Chapter 4 gives the overall synthesis of the research project.

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2. PHYSICAL PROPERTIES OF AN ORTHIC BLACK CHERNOZEM AFTER 5 YEARS OF LIQUID AND SOLID PIG MANURE APPLICATION

2.1 Abstract

Pig (*Sus scrofa*) manure is added to the soil to supply nutrients and improve soil properties. The choice of a cropping system also has an effect on soil properties. To our knowledge, no direct comparison has been made on the effect of liquid pig manure (LPM) and solid pig manure (SPM) on physical properties of a prairie soil.

The study was established in 2009 at the Ian Morrison Research Station of the University of Manitoba at Carman, Manitoba, on an Orthic Black Chernozem. The experimental design was a split plot with cropping system (annual and perennial) as the main plot and manure treatment (N-based LPM, N-based SPM, and a control) as the subplot. Soil samples were collected at two depth intervals (0-10 cm and 10-20 cm) in the spring of 2014 for bulk density, saturated hydraulic conductivity (Ksat) and soil water retention at field capacity (20 kPa) and at permanent wilting point (PWP) (1500 kPa). For aggregate stability, samples were collected from the 0-5 cm depth. Land application of SPM produced a soil with a significantly smaller bulk density (14% decrease), a significantly greater Ksat in the 0-10 cm depth interval and a significantly greater aggregate stability. The LPM also produced soils with a significantly smaller bulk density (6% decrease) compared with the control. No significant difference in Ksat between soils amended with LPM and the control. Soils that were under perennial grasses had significantly smaller bulk density and greater Ksat than soil under annual cropping. We conclude that SPM has the potential as an organic amendment to improve the physical properties of the topsoil.

2.2 Introduction

Animal manure can improve soil physical properties by improving soil structure (Barbosa et al., 2015), reducing soil bulk density and compaction and by improving soil aeration and water retention (especially in sandy soils) (Schoenau and Davis, 2006). Pig manure is commonly applied to soil and it is a valuable organic fertilizer and soil amendment (Ahmed et al., 2013). Manitoba is the third largest pig producing province in Canada, after Ontario and Quebec, contributing 22.5% to the total Canadian pig production (13.0 million pigs) in the first six months of 2014 (Statistics Canada, 2014). The large scale pig production in Manitoba leads to high production of pig manure in the province (Sri Ranjan et al., 2005). Pig manure can be handled as liquid, solid or semi-solid. The liquid manure handling system is the most common among livestock farmers (Beaulieu, 2004). A number of research studies have been carried out on the effect of liquid pig manure on soil properties while a few studies exist on solid pig manure. Due to the dearth of information on the effect of solid pig manure on soil physical properties, this review will contain literature on the effect of solid beef cattle manure on soil physical properties. The assumption is that solid pig manure and solid beef cattle manure will have similar effects on the soil physical properties as they both contain bedding materials such as straw.

Soil physical properties are important for maintaining soil quality (Rachman et al., 2003). Soil physical properties that influence crop growth include bulk density, saturated hydraulic conductivity, aggregate stability and water retention. Bulk density is the ratio of the mass of soil solid to the total volume of soil. It is a measure of the state of soil compaction (Blanco-Canqui et al., 2015). Soil bulk density can be used to estimate some soil physical properties including water retention, porosity and compressibility (Ruehlmann and Körschens, 2009). It also affects the relationship between water content, air-filled porosity and penetration resistance (Quiroga et al., 1999). Manure is rich in organic matter: as such, its addition to soil can alter soil bulk density and compressibility (Prévost, 2004; Ruehlmann and Körschens, 2009). Fares et al. (2008) reported a decrease in bulk density of a highly weathered tropical soil and concluded that the decrease could be due to adding less dense organic matter to the soil or due to the added organic matter improving aggregate stability. Assefa et al. (2004) also reported a decrease of 8-9% in the bulk density of a Black Chernozemic soil that received four annual applications of liquid pig manure. A study by Miller et al. (2002b) showed that bulk density was significantly reduced after 24 years of solid beef cattle manure application. The bulk density of a fine sandy loam soil was also reduced after 71 years of beef cattle manure application in a study by Blanco-Canqui et al. (2015).

Soil water retention is another important physical property. The plant available water capacity of a soil can be estimated from soil water retention at field capacity and at permanent wilting point. Field capacity is defined as the water remaining in the soil after internal drainage has ceased (Hillel 1980). Manure has been known to improve soil water retention at field capacity and permanent wilting point. Miller et al. (2002a), in his study on the effect of cattle manure on hydrological properties of a clay loam, reported increased soil water retention between 0 and 1500 kPa by 5-48% in soils amended with cattle manure. Asada et al. (2012) also reported that soil water retention at 1000 kPa increased with the application of high rates of liquid pig manure but no increase in water retention of soils amended with standard rates of liquid pig manure was observed. Blanco-Canqui et al.(2015) observed an increase of up to 18% in water retention at field capacity and 21% in water retention at permanent wilting point in soils that received beef cattle manure for 71 years.

Soil aggregate stability is an indicator of soil quality (Nakajima et. al, 2015). Aggregate stability measures the stability of the soil structure and a reduction in aggregate stability implies an increase in soil degradation (Mbagwu, 2003). This property can be improved by the addition of organic amendment such as manure to the soil (Sun et al., 1995; Wortmann and Shapiro, 2007). Barbosa et al. (2015) reported that the application of liquid pig manure improved aggregation in an oxisol. A study by Dunjana et al. (2012) on the effect of solid cattle manure on soil properties, showed an increase in macro-aggregate stability of clay soils following 7 years of cattle manure application. This improvement was associated with an increase in soil organic carbon content of the soil resulting from the addition of cattle manure.

Soil saturated hydraulic conductivity is an important property which affects water flow, infiltration and transport of dissolved substances in soil (Jiang and Shao, 2014). Saturated hydraulic conductivity can be used as a key indicator of soil quality (Nakajima et. al, 2015). Miller et al. (2002a) investigated the effect of cattle manure on the saturated hydraulic conductivity of a clay loam and reported an increase of 76-128% after 24 years of manure application.

Crop rotations or the type of cropping system adopted on a farm can affect soil quality (Limon-Ortega et al., 2009; Rachman et al., 2003). Perennial crops have deeper roots than annual crops. As a result, they can extract water from greater depths in the soil profile (Wallace, 2000) and improve soil structure and drainage (Cransberg and McFarlane, 1994). A study by Rachman et al. (2003) showed that soil cropped to perennial grass (Timothy) produced soil aggregates that were three times more stable than soil under annual crops after over 100 years of cropping. Culman et al. (2010) reported a significant increase in water stable aggregates and soil organic carbon concentrations in perennial grasslands than in soils cropped to annual crops. Soils within a perennial grass hedge system produced significantly lower bulk density and higher saturated hydraulic conductivity than soils under row crops (Rachman et al., 2004a; Rachman et al., 2004b; Seobi et al., 2005)

This review shows that while several studies have been carried out on the effect of pig manure on soil physical properties, there have been very few studied on the effect of solid pig manure on soil physical properties. We are also not aware of any study that made a direct comparison between liquid and solid pig manures for their effect on the physical properties of prairie soils. Therefore the objective of this study were

1) To determine the effect of liquid and solid pig manure on soil physical properties following 5 years of manure application, and
2) To determine the influence of annual and perennial cropping system on soil physical properties.

2.3 Materials and Methods

2.3.1 Site information and experiment overview

The study was established in 2009 at the University of Manitoba's Ian Morrison Research Station in Carman, Manitoba. The soil at the site is of the Orthic Black Chernozem order and Hibsin soil series, which is characterized as coarse loamy surface soils underlain by clayey deposits. The soil is moderately well-drained. The site was seeded to annual and perennial crops from the start of the experiment in 2009 and maintained till 2013. The site consists of 40 plots of dimensions 10 m x 10 m.

Each plot was separated by a distance of 2 m and a distance of 5 m between replicates to serve as a buffer.

The experimental design was a split plot (Figure 2.1) with cropping system as the main plot and manure treatment as the sub-plot, replicated four times. For the annual cropping system, a canola-barley crop rotation was maintained till fall of 2013. For the perennial crop, a mixture of timothy and orchard grass was maintained till fall of 2012, then ploughed under and seeded with canola in 2013 (Akinremi et al., 2014).

The manure treatments were N-based liquid pig manure (T1) - plots to which liquid pig manure was applied in 2009- 2013 at rates targeted to meet the N needs of the crops; N-based solid pig manure (T3) - plots to which solid pig manure was applied in 2009-2013 at rates of application that targeted the N needs of the crops; Control (T5) - plots to which no manure or synthetic fertilizer was applied.

The liquid pig manure was applied as a slurry while the solid was applied through surface broadcast in all five years of the study. Incorporation of manure was done on annual plots alone while manure was not incorporated into the soil on perennial plots (except in 2013 when the plots were seeded to canola). The characteristics of liquid and solid pig manure applied during the five years study is shown in Table 2.1.

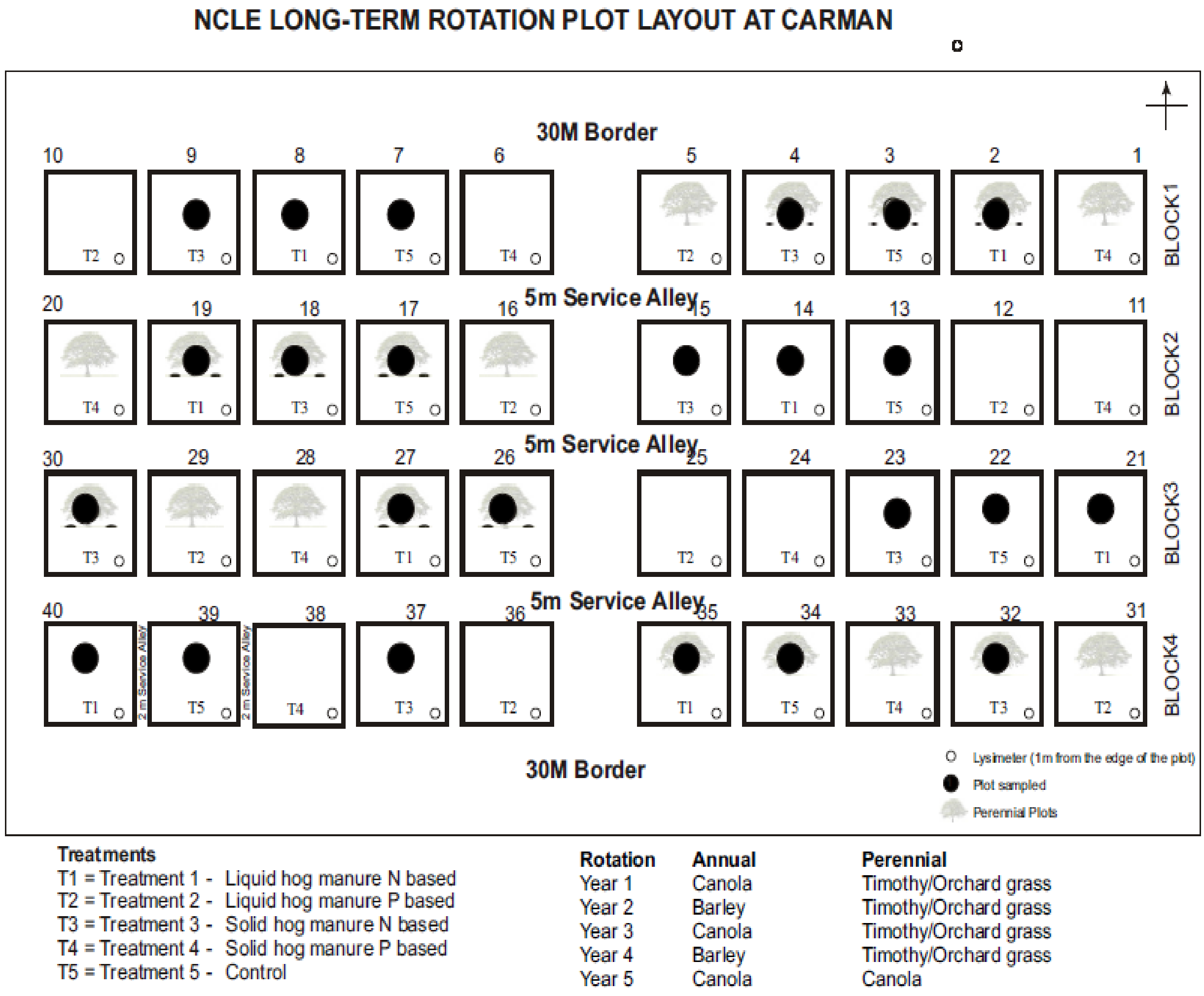

Figure 2.1. Plot layout at Carman

Table 2.1 Manure characteristics in all five years of the study

Year	Solid pig manure			Liquid pig manure		
	Moisture	Dry matter	Total C (dry basis)	Moisture	Dry matter	Total C (dry basis)
	%			%		
2009	70	30	9	93	7	4
2010	70	30	16	98	2	4
2011	78	22	20	98	2	2
2012	76	24	23	97	3	5
2013	75	25	22	98	2	4

2.3.2 Sample collection

Soil samples were collected in the spring of 2014 before manure application. Undisturbed soil samples for bulk density and saturated hydraulic conductivity were collected using soil core (diameter of 5 cm and 5 cm in height). Soil samples for water retention were collected using soil cores of 3 cm height and 5 cm diameter. Soils for aggregate stability measurement were collected using an aggregate stability shovel (a square shaped shovel tip). The shovel ensured that little disturbance was applied to the soil during collection. All soil samples were collected at 0-10 cm and 10-20 cm depth intervals with two random samples collected per plot. For aggregate stability, two random soil samples were collected at the 0-5 cm depth.

2.3.3 Laboratory Analysis

Saturated hydraulic conductivity was determined first on the cores, using the falling head method (Klute and Dirksen, 1986). Bulk density was then determined using the core method on the same soil that was used for saturated hydraulic conductivity measurement, as the ratio of oven dry weight of soil to the total volume of soil (Blake and Hartge, 1986). Soil samples for aggregate stability were air-dried and crushed by hand, then passed through a 6.3 mm sieve. Wet aggregate stability was measured using the wet sieving technique (Yoder, 1936) and mean weight diameter was calculated following the method of Kemper and Rosenau (1986). Aggregate mass of 50 g with diameter $\leq$6.3 mm was used in the measurement of mean weight diameter. Saturated soil within the core of height 3 cm was placed on a ceramic plate in a pressure chamber. These were then equilibrated with pressures of 20 kPa and 1500 kPa to determine water retention at field capacity and permanent wilting point, respectively. At equilibrium, samples were taken out of the chamber and gravimetric moisture content was determined on the samples using the thermo gravimetric method (Gardner, 1986). The product of gravimetric moisture content and bulk density of the samples gave the volumetric moisture content.

2.3.4 Calculations

Saturated hydraulic conductivity was calculated using Darcy's equation for saturated flow,

$$K = \frac{A_1 L}{A_2 t} \ln \frac{H_1}{H_2} \tag{1}$$

Where K is the saturated hydraulic conductivity in cm/hr

A_1 is the cross sectional area of the standpipe (cm^2)
A_2 is the area of the soil core (cm^2)
L is the length of the soil in the core (cm)
t is time taken for 200 ml of water to pass through the soil (hr)
H_1 is the height from initial water level to the base of the core (cm)
H_2 is the height from final water level in standpipe to the base of the core (cm).

The volume of soil was calculated using the formula for volume of a cylinder, $\pi r^2 h$.

Bulk density was calculated as the ratio of the total mass of the dry soil (*Ms*) to the total volume of the soil (*Vt*).

$$\rho b = \frac{M_s}{V_t} \qquad (2)$$

Mean weight diameter was determined using the method by Kempau and Rosenau, (1986)

$$MWD = \sum_{i=1}^{n} X_i W_i \qquad (3)$$

where X_i is the mean diameter of any particular size range of aggregates separated by sieving
W_i is the weight of aggregates in that size range as a fraction of total dry weight of sample, with the summation, carried out over all *n* (6) size fractions
n is the number of size fractions = number of sieves used plus one = 6

The sieve diameters were 4, 2, 1, 0.5 and 0.25 mm respectively.

The volumetric water content (θ_v)of water retention samples were calculated as the product of the pre-calculated bulk density (ρ_b) of soil samples and gravimetric moisture content(θ_g).

$$\theta_v = \left(\frac{M_w}{M_s}\right) X \left(\frac{\rho_b}{\rho_w}\right) \qquad (4)$$

2.3.5 Statistical Analysis

Data were analysed using PROC GLIMMIX in SAS 9.4 (SAS Institute, 2014). Analysis of variance was performed separately for each depth interval (0-10 cm, 10-20 cm) for all soil physical property measured as depth was not of primary interest in the study. Means were compared using the Tukey-Kramer multiple comparison test at a probability level of 0.05. PROC UNIVARIATE was used to test for normality and a Gaussian distribution was assumed for the response variables in the model for analysis. Samples collected per plot were treated as independent samples in the model.

2.4. Results

2.4.1. Saturated Hydraulic Conductivity

Analysis of variance showed significant effect of cropping system and manure treatment on the Ksat (Table 2.2). Soils to which SPM was applied had a significantly greater Ksat than soil that received LPM or the control that received no manure or fertilizer in both soil depth intervals (0-10 cm, 10-20 cm). There was no significant difference in Ksat between soil amended with LPM and the control (Fig. 2.2). Soils sown to perennial grasses had a significantly greater saturated hydraulic conductivity compared with annual plots. There was no significant interaction between cropping system and manure treatment for Ksat in both soil depth intervals (Table 2.2).

Table 2.2. Effect of manure and cropping system on soil physical properties in the 0-10 cm and 10-20 cm depth intervals

Group means	**Ksat (cm hr^{-1})**		**Bulk density (g cm^{-3})**		**Aggregate stability (mm)**	**Water retention at field capacity (cm^3 cm^{-3})**		**Water retention at PWP (cm^3 cm^{-3})**		**AWC (cm^3 cm^{-3})**	
	0-10 cm	**10-20cm**	**0-10 cm**	**10-20 cm**	**0-10 cm**	**0-10 cm**	**10-20 cm**	**0-10 cm**	**10-20 cm**	**0-10 cm**	**10-20 cm**
Cropping system											
Annual	4.32**b**	0.55	1.26**a**	1.50	2.07	0.17	0.20	0.07	0.09	0.10	0.11
Perennial	5.66**a**	0.83	1.11**b**	1.49	1.68	0.21	0.20	0.085	0.08	0.12	0.12
Model						**P value [a]**					
Cropping system	**0.04**	0.08	**0.02**	0.76	0.19	**0.03**	0.97	**0.11**	0.27	**0.001**	0.21
Manure	**<0.0001**	**0.01**	**<0.0001**	**0.002**	**0.0002**	**<0.0001**	**0.004**	**<0.0001**	0.24	**<0.0001**	**0.02**
Cropping system × manure	0.99	0.69	0.27	0.09	0.36	**<0.0001**	0.37	**0.001**	0.64	**0.001**	0.57

[a] Probability value is significant at 0.05 and highlighted in bold

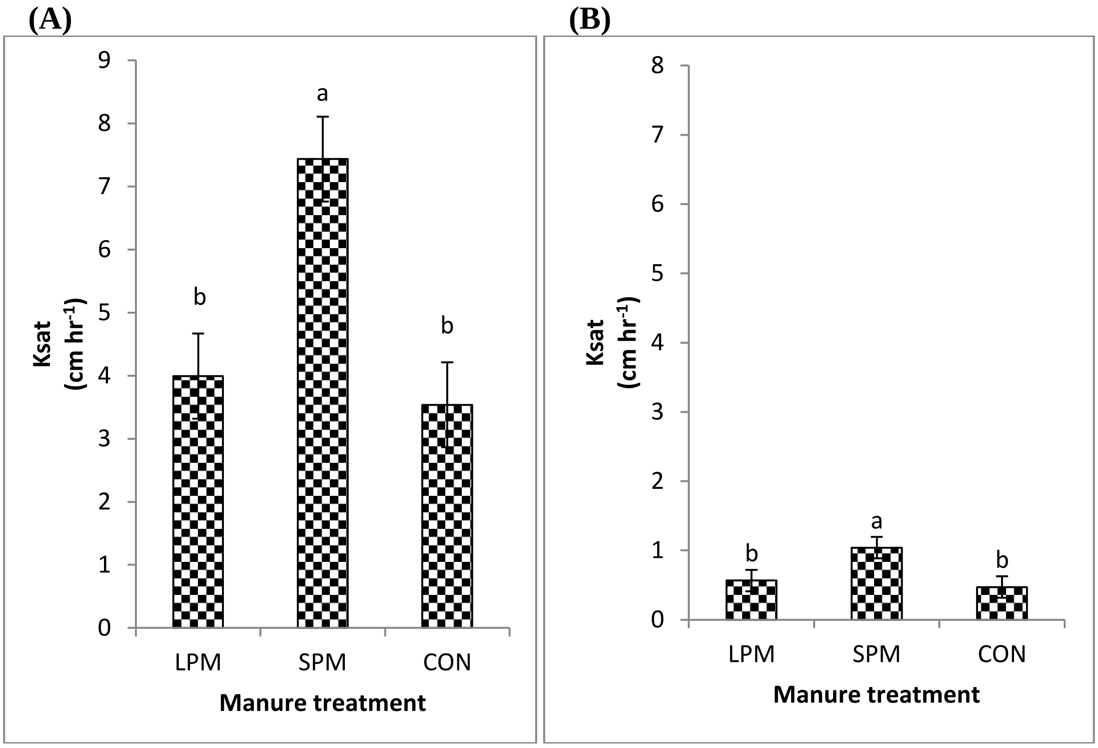

Figure 2.2 Effect of manure treatment on saturated hydraulic conductivity in the (A) 0-10 cm depth (B) 10-20 cm depth. Error bars represent standard errors of the means. Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test

2.4.2 Bulk Density

All manure treatment means were significantly different from each other in the 0-10 cm layer (Fig. 2.3a). The bulk density of soils amended with manure decreased from liquid to solid pig manure.In the 10-20 cm depth interval, only manure treatment was significant, with soils amended with SPM having the smallest bulk density. Soils amended with liquid pig manure and the control were not significantly different in the 10-20 cm depth (Fig. 2.3b)

Soils under perennial grasses had a smaller bulk density than those under annual crop in the 0-10 cm depth (Table 2.2). There was no significant cropping system effect on bulk density in the 10-20 cm depth interval (Table 2.2).

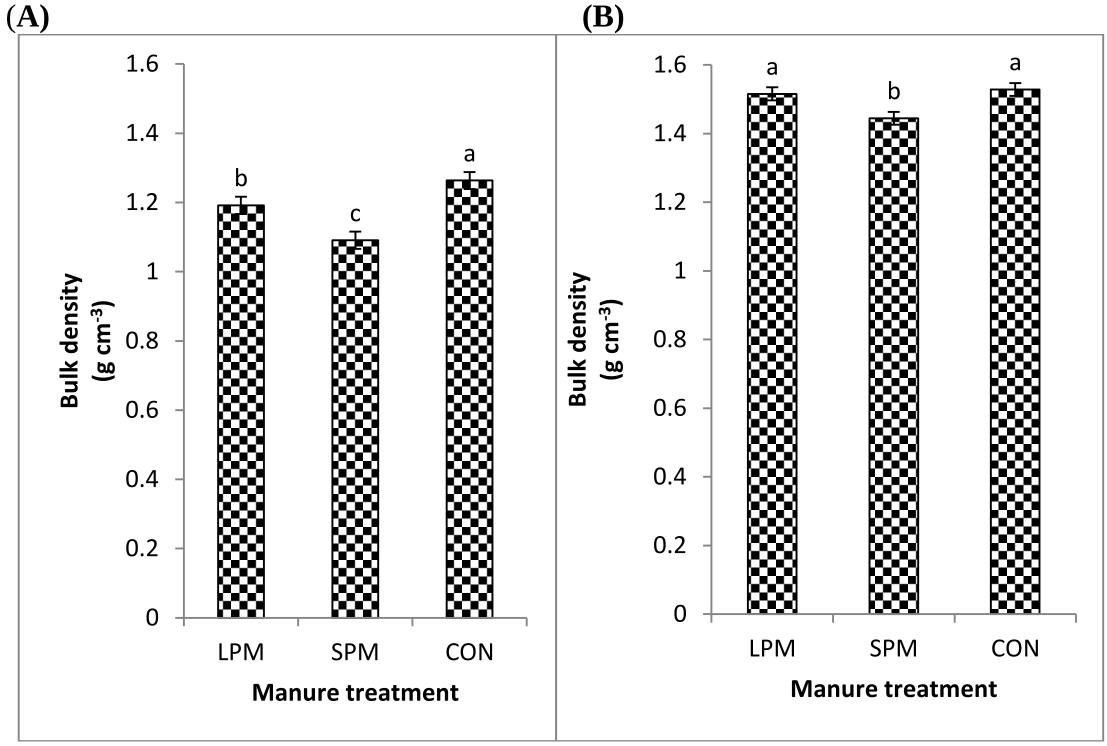

Figure 2.3 Manure treatment effect on soil bulk density in the (A) 0-10 cm depth (B) 10-20 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different (P ＞ 0.05) according to the Tukey-Kramer multiple comparison test

2.4.3 Aggregate Stability

Soils amended with manure had aggregate stability values that were significantly greater than the control. However, there was no significant difference between soil aggregate stability for LPM and SPM amended soils (Figure 2.4). Aggregate stability for soils cropped to annual crops and perennial grasses were not significantly different from one another (no cropping effect) (Table 2.2).

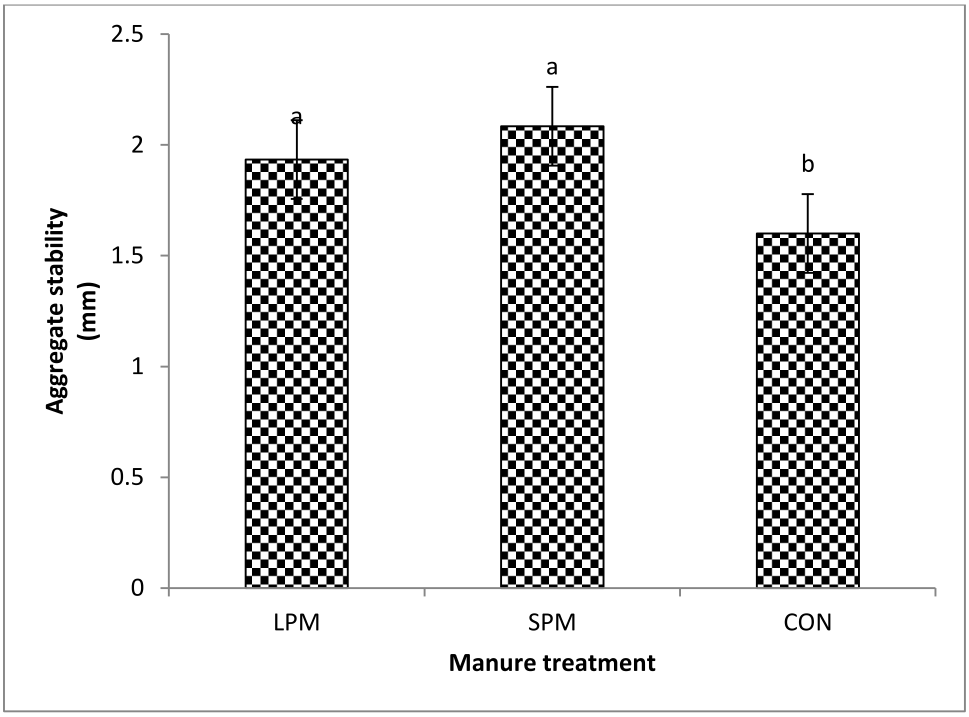

Figure 2.4 Effect of manure treatment on aggregate stability. Error bars represent standard error of the means. Bars with the same letter are not significantly different (P >0.05) according to the Tukey -Kramer multiple comparison test

2.4.4 Water retention at Field Capacity

The treatment by cropping system interaction was significant (P <0.05) for water retention at field capacity in the 0-10 cm depth interval (Table 2.2). In annual plots, water retention at field capacity was greater in pig manure-amended soils. No difference was observed between water retention at field capacity in SPM and LPM amended soils. On perennial plots, SPM-amended soils was had the highest water retention (0.2914 cm^3 cm^{-3}), while LPM did not significantly affect this property (Figure 2.5). In the 10-20 cm depth interval, there was no treatment by cropping system interaction; however manure effect was significant in soils amended with SPM having greater moisture content at field capacity compared to the control and LPM (Fig 2.6).

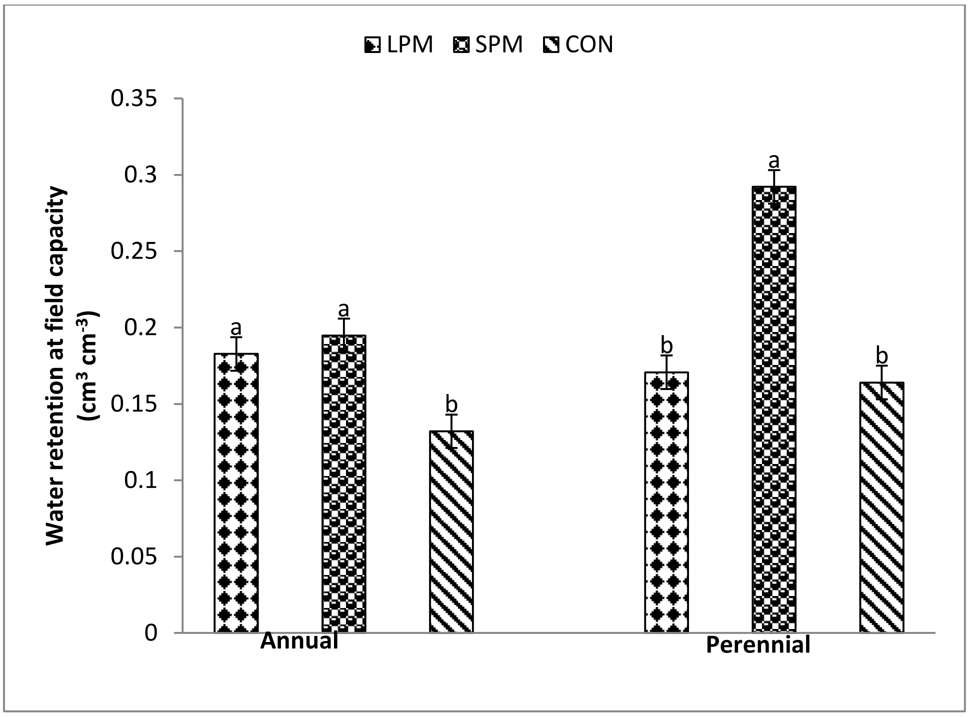

Figure 2.5 Effect of cropping system by manure treatment interaction on soil water retention at field capacity in the 0-10 cm depth. Error bars represent standard error of the means Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey -Kramer multiple comparison test

Note: Tukey-Kramer multiple comparison was done within each cropping system

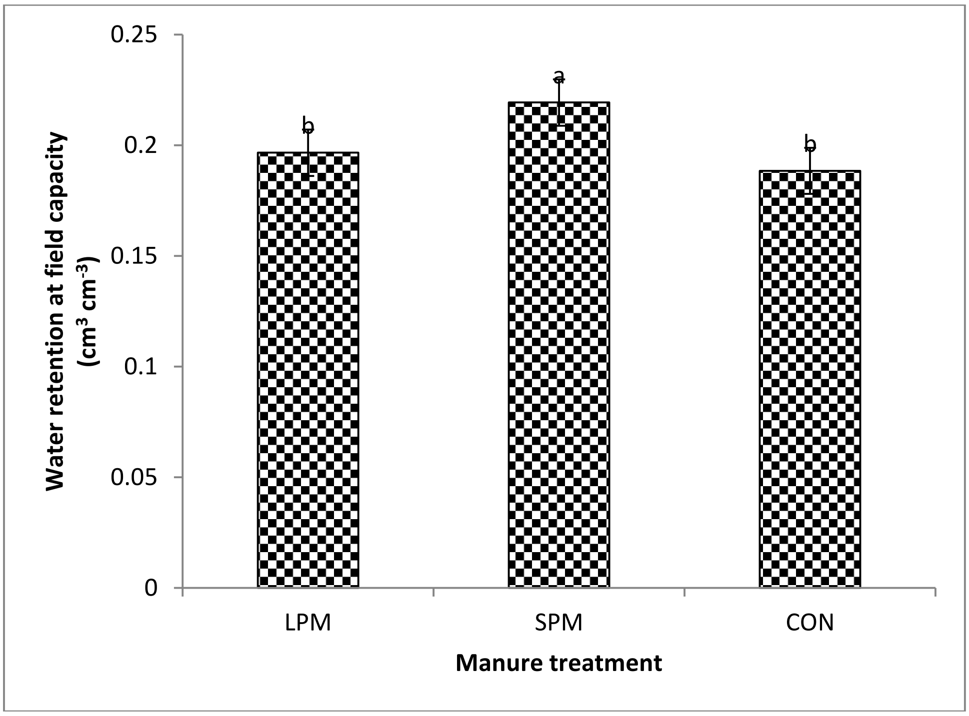

Figure 2.6 Effect of manure treatment on soil water retention at field capacity in the 10-20 cm depth. Error bars represent standard error of the means Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test

2.4.5 Water retention at Permanent Wilting Point

The manure treatment by cropping system interaction was significant (P=0.0001) for water retention at permanent wilting point in the 0-10 cm depth interval (Table 2.2). On perennial plots, soils to which SPM was applied had the greatest water retention at PWP (0.1145 cm^3 cm^{-3}) while pig manure-amended soils (SPM and LPM) significantly increased water retention relative to the control at permanent wilting point in annual plots (Figure 2.7). For the 10-20 cm depth interval, both cropping system and manure treatment effects were not significant. The manure treatment by cropping system interaction was also non-significant in the 10-20 cm depth interval (Table 2.2).

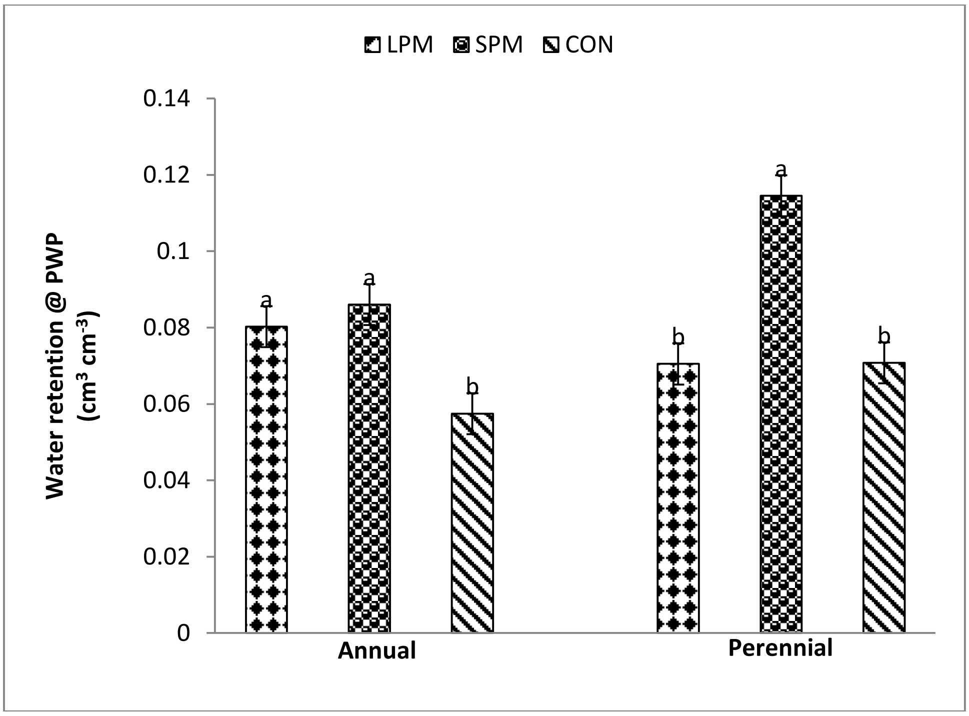

Figure 2.7 Effect of cropping system by manure treatment interaction on soil water retention at PWP in the 0-10 cm depth. Error bars represent standard error of the means Bars with the same letter are not significantly different (P > 0.05) according to the Tukey-Kramer multiple comparison test
Note: Tukey-Kramer multiple comparison was done within each cropping system

2.4.6 Available Water

In the 0-10 cm depth interval, the manure treatment by cropping system interaction was significant (P< 0.05) for available water (Table 2.2). Perennial plots amended with SPM had the greater available water than LPM amended soils or the control on perennial plots. On annual plots, SPM significantly increased available water compared to the control (Fig 2.8).

In the 10-20 cm depth interval, similar to results from water retention at field capacity, the manure treatment effect was significant with SPM-amended soils having greater available water content than control or LPM amended soils, however, the available water in SPM amended soils was not significantly different from soils to which LPM was applied (Fig 2.9).

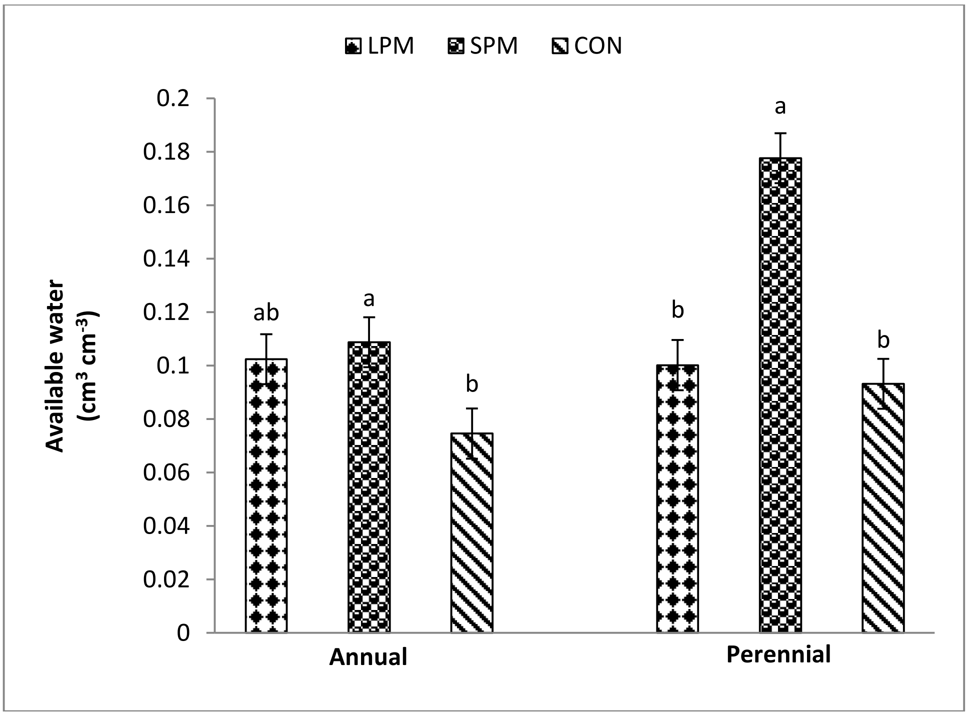

Figure 2.8 Effect of cropping system by manure treatment interaction on available water at the 0-10 cm depth. Error bars represent standard error of the means Bars with the same letter are not significantly different (P >0.05) according to the Tukey-Kramer multiple comparison test Note: Tukey-Kramer multiple comparison was done within each cropping system

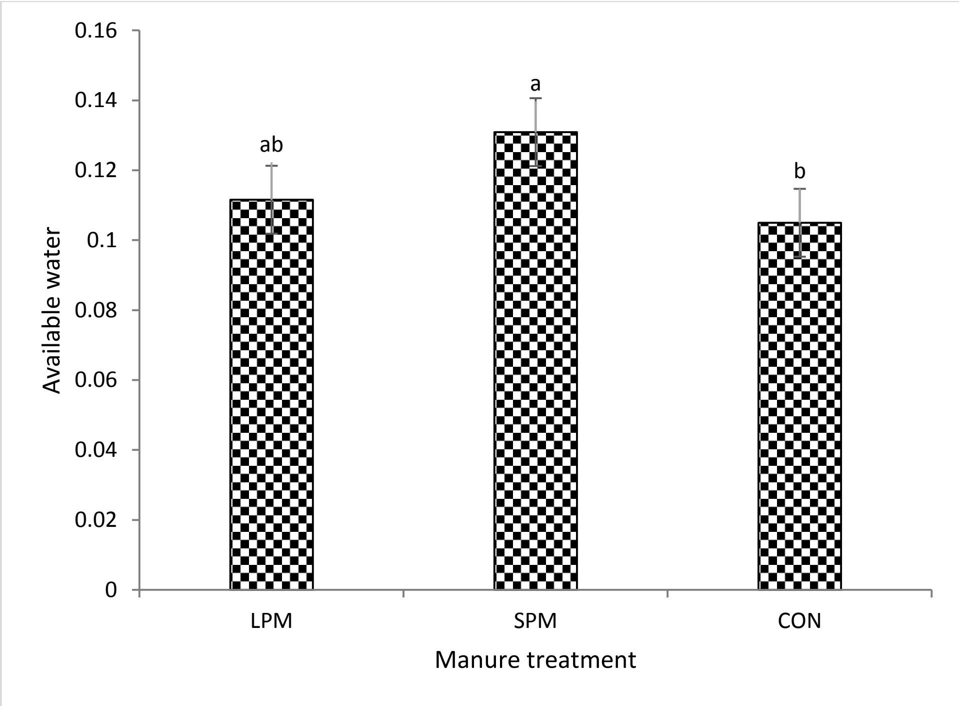

Figure 2.9 Effect of manure treatment on available water at the 10-20 cm depth. Error bars represent standard error of the means Bars with the same letters are not significantly different (P >0.05) according to the Tukey-Kramer multiple comparison test.

2.5 Discussion

2.5.1 Saturated Hydraulic Conductivity

The improvement in saturated hydraulic conductivity in soils amended with SPM could be a result of increase in soil organic matter due to manure addition and the stimulation of soil aggregation (Celik et al., 2004). It could also be due to the presence of bedding materials with high C: N ratio in the manure which is a source of organic carbon (Fares et al., 2008; Veiga et al., 2009). The high C: N ratio of these bedding materials causes a slower rate of manure decomposition leading to greater long term effect on soils (Comin et al., 2013).

The lack of a significant difference in Ksat for soils in control plots and soils amended with LPM is consistent with results by Fares et al. (2008), who reported no significant differences in the saturated hydraulic conductivity of a tropical soil amended with liquid pig manure and the control. They likened this to a ponded manure situations, where the particulate materials in LPM which could result in sealing of pores, thereby reducing Ksat (Rowsell et al, 1985; Asada et al, 2012). The behaviour of the soils amended with LPM may also be due to lower organic carbon content of LPM compared to the solid manure and differences in the quality of the organic carbon of the two manures (Ndayegamiye and Cote, 1989).

The effect of cropping system on the saturated hydraulic conductivity is similar to the result obtained by Rachman et al. (2004a) and Seobi et al. (2005) in which soils cropped to perennial vegetation had greater saturated hydraulic conductivity compared to row crops. The creation of new pores from the active and decaying roots of the perennial grasses or expansion of old pores might have resulted in the increase in saturated hydraulic conductivity (Rachman et al., 2004a). Also, the presence of larger and deeper roots, and greater root biomass of perennial grasses in the 0-10 cm depth interval compared to annual crops is another reason for increased Ksat in perennial plots (DuPont et al., 2014). Cropping effect was observed only in the 0-10 cm depth interval due to this depth being the region containing majority of the plant root biomass (DuPont et al., 2014).

2.5.2 Bulk Density

The decrease in bulk density of pig manure amended soils is attributed to the addition of organic material (pig manure) to the soil (Haynes and Naidu, 1998; Celik et al., 2004; Fares et al., 2008) or an increase in soil organic carbon (Miller et al., 2002b). The result obtained from this study is consistent with those of Asefa et al. (2004), Celik et al. (2004), Fares et al. (2008) who also reported decrease in bulk density with pig manure addition to soil. The greater decrease in bulk density was in soils to which solid pig manure was added. This was due to the presence of straw bedding material with high C:N ratio in solid pig manure (Magdoff, 1993; Comin et al., 2013). In our study, a decrease of 6-14% in bulk density at the 0-10 cm depth was observed. This result corroborates that of Fares et al. (2008) who reported that cattle and dairy manure produced a greater effect on soil properties due to the presence of bedding materials in the solid manures (dairy and beef manure). Liquid pig manure is low in organic carbon when compared to solid manures (Ndayegamiye and Cote, 1989). An inverse relationship exists between soil organic carbon and bulk density (Comin et al., 2013). Manures with higher organic carbon content have significantly greater effect on soil properties compared to low SOC manures (Ndayegamiye and Cote, 1989), hence the smallest bulk density observed for SPM amended soil is attributed to its greater soil organic carbon compared to LPM.

Bulk density was lower at the surface soil than in the 10-20 cm layer. This is due to the over burden pressure of the overlaying soil layer(s) and also the decrease in organic matter content with depth (Franzluebbers, 2002; Prévost, 2004; Perie and Ouimet, 2008; Comin et al., 2013). Solid pig manure significantly reduced the bulk density of the lower depth soil by 5%. The effect of SPM on bulk density in the lower layer could also be attributed to better soil aggregation with pig manure addition, which increased soil total porosity and by implication, reduced soil bulk density (Fares et al., 2008; Asada et al., 2012).

The decrease in bulk density of soils cropped to perennial grasses may be due to the creation of new pores from the active and decaying roots of the perennial grasses or expansion of old pores (Rachman et al., 2004a), which by implication, increased the total porosity. The increased porosity thereby decreased bulk density. It could also be because of greater organic carbon content from the residues of perennial forages and root biomass (Magdoff, 1993; Wienhold and Tanaka, 2001; Rachman et al., 2004a) and better soil aggregation under perennial grasses compared to annual cropping. This is consistent with a study by Rachman et al. (2004a) in which soil within perennial hedges had a significantly lower bulk density than those with row crop hedges.

2.5.3 Aggregate Stability

The increase in aggregate stability of pig manure-amended soils could be attributed to an increase in organic carbon content of soil (Dunjana et al., 2012) and binding agents from the added manure (Tisdall and Oades, 1982). Bedding materials in solid manures contain hemicellulose and lignin, which decomposes slowly (Magdoff, 1993; Prescott, 2005), and thus have a long lasting effect as binding agents of soil aggregates (Celik et al., 2004). The time frame of the study (5 years) could be the reason why LPM and SPM behaved similarly (Carter and Campbell, 2006). It is possible that greater effect of SPM would be recorded with time as the mineralization of organic carbon in manure is time dependent. Carter and Campbell (2006) reported no change in aggregate stability of a soil to which LPM was added after 3 years of manure application but differences in aggregate stability as a result of manure application has been observed after 7 years (Dunjana et al., 2012).

The effect of cropping system on aggregate stability reported in our study is in contrast to the investigation by Rachman et al. (2003) in which soils cropped to perennial timothy after 100 years had higher mean weight diameter compared to annual fields. The non-significance of the cropping system could be a result of the short term nature of our study (5 years).

2.5.4 Water Retention

2.5.4.1 Water retention at Field Capacity

In the 0-10 cm depth interval, the effect of manure type on water retention at field capacity varied with cropping system. In annual plots, the increase in water retention of pig manure amended soils could be attributed to better aggregation and increase in micro porosity with manure addition (Benbi et al., 1998). Solid pig manure amended soils in perennial plots had significantly greater soil water retention at field capacity than the control or LPM. This may be due to the combined effect of cropping system and manure contributing organic carbon to the soil. Perennial grasses have been known to sequester carbon (Wienhold and Tanaka, 2001, Franzluebbers et al., 2014); as a result, a greater percentage of organic carbon is added to the soil by perennial grasses compared to annual crops. The organic carbon sequestered by perennial grasses combined with organic carbon from SPM could have resulted in the larger effect of SPM on water retention at field capacity on perennial plots. This shows that the manure in conjunction with the type of cropping system employed can improve soil water retention at field capacity, resulting from a synergistic effect.

In the lower layer (10-20 cm), the increase in water retention at field capacity with SPM addition could be attributed to the increase in organic carbon content, better soil aggregation and greater micro-porosity because of the manure applied (Benbi et al., 1998; Moskal et al., 2001; Zhang et al., 2006).

2.5.4.2 Water retention at Permanent Wilting Point

In the 0-10 cm soil layer, the effect of manure and cropping system on SWR at permanent wilting point was similar to that observed for water retention at field capacity. The increase in water retention at permanent wilting point in pig manure amended soils in annual plots could be attributed to better aggregation with manure addition to the soil (Benbi et al., 1998). The significant interaction of cropping system by manure type could be attributed to the synergistic effect of perennial cropping system and solid pig manure, contributing organic carbon to the soil which increased water retention at permanent wilting point. Perennial grasses sequesters carbon (Wienhold and Tanaka, 2001; Franzluebbers et al., 2014), as a result, a greater quantity of organic carbon is added to the soil by perennial grasses compared to annual crops (Culman et al., 2010; DuPont et al., 2014). Solid pig manure has also been shown to increase soil water retention at permanent wilting point (Asada et al., 2012).

The non-significance of manure or cropping system on water retention at PWP in the 10-20 cm layer may be due to the 0-10 cm layer being the region of manure application and greater accumulation of the root biomass (DuPont et al., 2014)

2.5.4.3 Plant Available Water

The effect of manure and cropping system on plant available water in the 0-10 cm layer, was similar to manure and cropping system effects on water retention at field capacity. The addition of solid manure to the soil can increase soil water retention at field capacity and/or permanent wilting point (Asada et al., 2012), which may lead to an increase in plant available water. The increase in available water of SPM amended soils in both annual and perennial plots could be attributed to better soil aggregation and greater organic carbon content of these soils due to manure addition

In the 10-20 cm layer, results from our study on available water of SPM-amended soils are in accord with those of Blanco-Canqui et al. (2015), who reported an increase in soil available water in the 15-30 cm layer with the addition of solid beef cattle manure. The increase in available water in our study can be attributed to an increase in soil organic carbon (Blanco-Canqui et al., 2015; Miller et al., 2002a), better aggregation and increased micro-porosity with manure addition (Benbi et al., 1998).

The non-significance of the cropping system effect on available water may be due to the 0-10 cm depth being the region of abundant root biomass (Culman et al., 2010; DuPont et al., 2014).

2.6 Conclusion

The application of pig manure improved physical properties of an Orthic Black Chernozem after five years. The improvement in these properties was attributed to the increase in organic carbon of the manure-amended soil.

Solid pig manure had the greatest effect on soil physical properties because of the recalcitrant straw bedding materials. The greatest effect was observed in the 0-10 cm layer and this is because the top soil is the region of manure application, and the region of biological activities such as decomposition and release of nutrients and organic carbon. Bulk density was significantly reduced and aggregate stability was significantly greater with pig manure application. Manure addition did not greatly impact soil physical properties in the 10-20 cm layer. Though soils amended with SPM had a significantly higher saturated hydraulic conductivity, water retention and smaller bulk density, LPM did not affect properties in the 10-20 cm layer.

The effect of cropping system was only significant for saturated hydraulic conductivity and bulk density and was restricted to the top soil (0-10 cm layer). This was attributed to the topsoil being the region of abundant root biomass and biological activity and may also be due to the fact that the soil was ploughed only in the fourth year of the study. Soils under perennial cropping had a significantly higher saturated hydraulic conductivity and lower bulk density than soils in annual plots.

We conclude that SPM has the potential as an organic amendment to improve surface soil physical properties. Results from our study also suggest that soils under perennial cropping can have increased saturated hydraulic conductivity and lower bulk density with time.

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3. CHEMICAL PROPERTIES OF AN ORTHIC BLACK CHERNOZEM AFTER 5 YEARS OF LIQUID AND SOLID PIG MANURE APPLICATION

3.1 Abstract

Pig (*Sus scrofa*) manure is a good source of plant nutrients and can influence soil chemical properties. Limited information exists on the effect of solid pig manure and cropping system on chemical properties of prairie soils.

The study was established in 2009 at the University of Manitoba's Ian Morrison Research Station in Carman, Manitoba. The treatment design was a split plot with cropping system (annual and perennial) as the main plot and manure treatment (N-based LPM, N-based SPM, and a control) as the subplot. Soil samples were collected from two depth intervals (0-15 cm and 15-30 cm) in the spring of 2014 for determination of total N and P, available N and P, pH, electrical conductivity (EC), organic carbon (C), cation exchange capacity (CEC), and exchangeable cations. In the 0-15 cm layer, SPM increased CEC by 9%, and concentrations of available P by 60%, total P by 19%, organic C by 18%, available N by 25%, and exchangeable K by 218% relative to LPM-amended soils ($P < 0.05$). Exchangeable Ca concentration in the 0-15 cm depth interval decreased by 33% with LPM than with SPM application. Soils under perennial grasses had significantly greater available N concentration in both soil layers compared with soil under annual cropping. Cropping effect was not significant for other properties measured. We conclude that SPM has the potential as to positively influence chemical properties of the top soil

3.2 Introduction

Pig production has increased rapidly in western Canada (Novek, 2003). Manitoba pig industry contributed over 2.9 million pigs, of the total Canada pig production (13 million pigs) in the first 6 months of 2014 (Statistics Canada, 2014). On a global scale, the pig industry generates up to 1.7 billion tonnes of liquid manure annually (Choudhary et al., 1996). A pig, on the average, excretes 2 tonnes of manure per year (Larson, 1991) and due to the high pig production rate in Manitoba, large quantities of manure are generated yearly in Manitoba (Sri Ranjan et al., 2005). The Manitoba pig industry produce an estimated 5 million tonnes of manure annually (Nikiema et al., 2013).

Pig manure is a valuable fertilizer and organic amendment. It contains the essential nutrients needed for plant growth and crop production and can influence soil chemical properties (Lourenzi et al., 2011; Penha et al., 2015), which are important in determining soil productivity (Magdoff, 1993). The chemical fertility of a soil is dependent on its chemical properties, some of which are, the organic matter content, soil organic carbon, available phosphorus, available nitrogen, total nitrogen and phosphorus, pH and electrical conductivity.

Pig slurry is rich in total N and ammonium-N (Ndayegamiye and Cote, 1989; Schoenau and Davis, 2006). Land application of liquid pig manure increased soil available N concentration in studies by Mooleki et al. (2002), Nikiema et al. (2013), Woli et al. (2013). In a study by Ndayegamiye and Cote (1989), high rates of pig slurry (120 m^3 ha^{-1}) increased soil organic carbon and potentially mineralizable nitrogen of an acidic silty loam soil. Mooleki et al. (2004) reported an increase in available N concentrations of a Black Chernozem sandy loam following 4 years of cattle manure application at high rates (400 kg ha^{-1}). Chantigny et al. (2001) also reported an increase in soil mineral N concentration of pig slurry amended soils during a 28 days field experiment to evaluate short term carbon and nitrogen dynamics. Nikiema et al. (2013) observed that pig manure significantly increased the soil nitrate-N level of a loamy sand after 3 consecutive years and suggested that the application of pig manure at high rates can lead to a higher soil residual nitrate level. Smanhotto et al. (2013) also reported an increase in nitrate-N and potassium concentrations following pig slurry application to a typic Rhodic Hapludox soil.

An increase in soil total N after 19 successive applications of pig slurry was reported by Lourenzi et al. (2013). The extractable K of a Black Chernozem was significantly greater in the soils amended with high rates of liquid pig manure compared to the control (Qian et al., 2005). An increase in soil total N and exchangeable K was also observed after application of 300-400 m^3 ha^{-1} of pig slurry to two calcareous soils (Bernal et al., 1993).

Phosphorus is another major nutrient whose concentrations can be influenced by pig manure application (Khakbazan et al., 2013). Pig manure is rich in P (Von Wandruszka, 2006). A study by Royer et al. (2003) showed that eight annual applications of liquid pig manure at high rates increased soil total P concentrations and other labile P forms. McAndrews et al. (2006) concluded that the application of solid pig manure resulted in an increase in Bray P and exchangeable K concentrations of soils amended with this manure. In another detailed study on the effect of pig manure on soil chemical properties of forage land by Olson and Papworth (2006), an increase in nitrate-N, orthophosphate phosphorus and extractable potassium concentration with manure rate was reported. Turner et al. (2010) reported that pig effluent contributed greater quantities of K concentration and total dissolved salts than beef manure. An increase in soil available P was also reported after pig manure application at the lowest rate (100 m^3 ha^{-1}) to a calcareous soil (Bernal et al., 1993). Penha et al. (2015) reported an increase in soil available P levels with increasing pig slurry rate, following nine years of pig slurry application. This increase in soil P was only observed at the soil surface (Penha et al., 2015). Also, in a study by Qian et al., (2004), total P increased following 5 annual applications of solid cattle manure to a Black Chernozem loam while no significant result was detected in soils to which liquid pig manure was added. This was attributed to the fact that a lower quantity of P was added by the liquid pig manure than the cattle manure (Qian et al., 2004).

The electrical conductivity of a soil sample estimates the salinity of the soil (Carter and Gregorich, 2008), which is the concentration of soluble salts in the soil sufficient to affect crop production adversely (Soil Science Society of America, 2001). A saline soil has an electrical conductivity of its extract exceeding 4 ds/m (Ashraf et al., 2008). Soil pH indicates the acidity of a soil solution (Carter and Gregorich, 2008). Manure can influence the electrical conductivity and pH of a soil. Plaza et al. (2002) reported an increase in EC and pH following pig slurry application. A study by Olson and Papworth, (2006) also showed an increase in EC of soils amended with pig manure. Liquid pig manure reduced the pH of a sandy loam by 5% after four annual applications (Assefa et al., 2004). No significant effect of liquid pig manure on soil pH was observed after 6 consecutive years of manure application (Ahmed et al., 2013). Smanhotto et al. (2013), however, reported an increase in soil pH after pig slurry application to a typic Rhodic Hapludox soil.

Pig manure addition to soil can increase the quantity and quality of soil total organic C, depending on manure composition, frequency of application and amount of manure applied (Brunetto et al., 2012). Brunetto et al., (2012) reported that pig slurry application at high rates (180 kg Nha^{-1}) and pig deep litter increased soil organic carbon contents to a depth of 30 cm. This improvement was attributed to be a result of high crop biomass on these plots and the application of pig manure, which is an organic amendment (Brunetto et al., 2012). Miller et al. (2002) reported a significant increase in soil organic carbon of a Dark Brown Orthic Chernozem after 24 years of solid beef manure application.

Soil CEC is important for plant nutrient uptake and ion movement in soil (Gao and Chang,1996, Akinremi and Cho, 1991 a,b). Ndayegamiye and Cote (1989) observed that pig slurry and solid cattle manure increased CEC in soils, however the increase in CEC was significantly larger in soils amended with cattle manure. This result was attributed to the higher organic carbon content in solid cattle manure (Ndayegamiye and Cote, 1989). An increase in CEC of a soil following nine years of repeated pig slurry application was reported by Penha et al. (2015). They concluded that the increase in the CEC may be attributed to the humic matter input because of increase in soil organic matter and changes in soil pH. Smanhotto et al. (2013) concluded that pig slurry application to a typic Rhodic Hapludox resulted in a significant increase in CEC. However, Brunetto et al., (2012) reported no change in the CEC of a soil following eight years of pig slurry application, but observed an increase in CEC in soils amended with pig deep litter. Gao and Chang, (1996) reported an increase in soil cation exchange capacity, total nitrogen and soil organic carbon content with increasing rates of cattle manure application to a Dark Brown Chernozem clay loam after 18 annual applications.

Pig manure contains Ca and Mg which derive from the animal feed (Brunetto et al., 2012). An increase in soil exchangeable Ca and Mg was reported by Brunetto et al. (2012) following eight years of pig manure applications (as pig slurry and pig deep litter) while Qian et al. (2005) reported a decreasing trend with manure rate in amounts of exchangeable Ca in soils amended with pig manure.

The cropping system adopted on a farm can affect soil quality (Rachman et al., 2003; Limon-Ortega et al., 2009). Perennial crops can be harvested multiple times during their life time and have deeper roots than annual crops (Cransberg and McFarlane, 1994). The establishment of perennial vegetation is known to sequester C in soil organic matter and vegetation (Wienhold and Tanaka, 2001). Tiemann and Grandy, (2015) suggested that large root biomass of perennial crops and reduced tillage frequency of soils under perennial cropping could be the reasons for increased soil C accrual. Soil C sequestration is important in building soil fertility, protecting soil from compaction, and nurturing soil biodiversity (Franzluebbers et al., 2014). Subsurface nitrate leaching from soils under annual cropping is higher than losses in soils cultivated to perennial crops (Randall and Mulla, 2001; Tomer and Liebman, 2014). In a similar study by Stewart et al., (2015), comparing nitrogen effects on soil properties of soils under switch grass and no till corn, it was recorded that the decrease in available P concentration in soils under switch grass was lower (-5.38 Kg P ha^{-1}) compared to no till corn soils (-24.04 Kg Pha^{-1}) suggesting a greater use of available P or greater loss of P by surface runoff on annual plots. Perennial forages can replenish soil organic matter (Franzluebbers et al., 2014). Pugesgaard et al. (2014) also reported smaller nitrate leaching under perennial grass clover compared with winter wheat (annual crop). They also reported less compaction in perennial plots. Culman et al. (2010) reported a significant increase in total N, water stable aggregate and soil organic C concentrations in perennial grasslands compared to soils under annual crops.

This review shows that while several studies exist on the effect of liquid pig manure on soil chemical properties, very few studies have been carried out on the effect of solid pig manure and cropping system on soil chemical properties. We are also not aware of any direct comparison between solid and liquid pig manure for their effect on chemical properties of prairie soils. The objectives of this study were, therefore,

- to determine the effect of five years of liquid and solid pig manure application on selected soil chemical properties and
- to determine the influence of annual and perennial cropping system on soil chemical properties.

3.3 Materials and Methods

3.3.1 Site Information and Experiment Overview

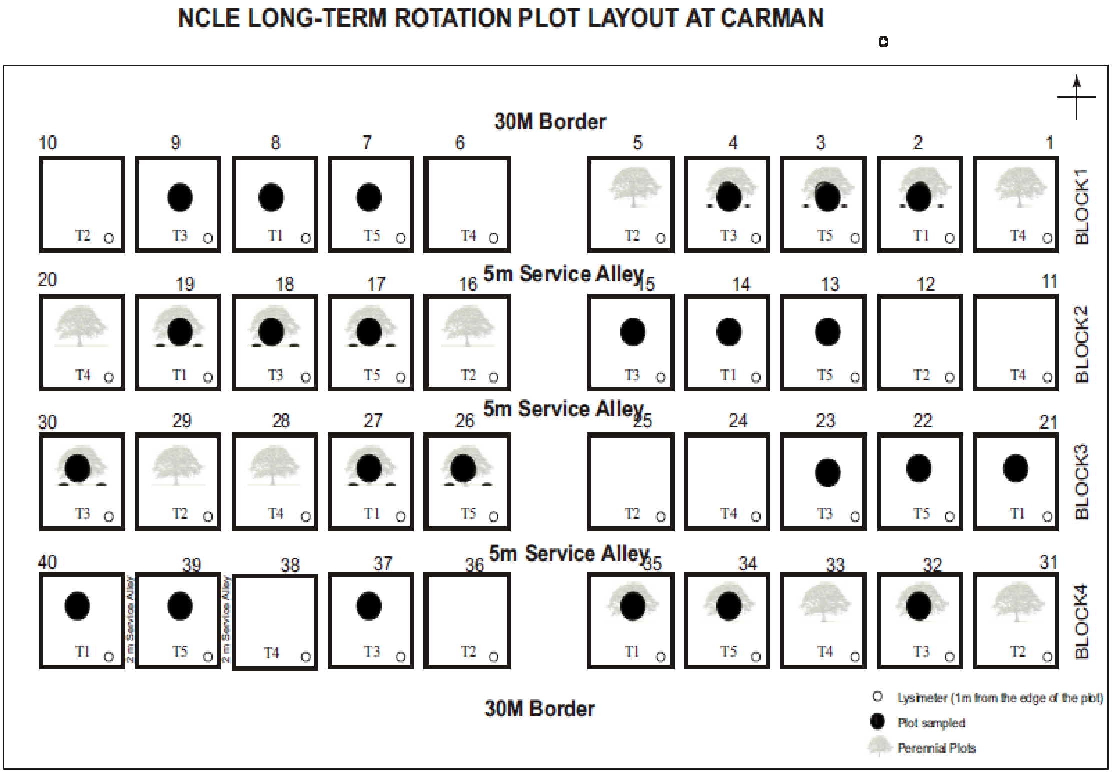
The study was established in 2009 at the University of Manitoba's Ian Morrison Research Station in Carman, Manitoba (49° 29' 63"N, 98° 02' 150" W, 239 m a.s.l). The soil at the site was a Hibsin Orthic Black Chernozem with a sandy loam texture. The site consisted of forty 10 m long x 10 m wide plots, each of which was maintained under either annual or perennial cropping from the start of the experiment in 2009.

The experimental design was a split plot (Fig 3.1), with cropping system (annual and perennial) as the main plot and manure treatment as the sub-plot, replicated four times. The manure treatments were: (1) N-based liquid pig manure (N-LPM) (liquid pig manure was applied in 2009-2013 at rates targeted to meet the crop N requirement); (2) N-based solid pig manure (N-SPM) - solid pig manure was applied in 2009-2013 at rates targeted to meet the N needs of the crops; and (3) Control (CON) - no manure or synthetic fertilizer was applied.

In the annual cropping system, a canola-barley crop rotation was maintained until fall of 2013. In the perennial cropping system, a mixture of timothy (*Phleum pretense*) and orchard (*Dactylis glomerata*) grass was maintained till fall of 2012, then ploughed under and seeded with canola in 2013.

Liquid pig manure was applied as a slurry while solid manure was applied by surface broadcast in all five years of the study. Incorporation of manure was done on annual plots alone while manure was not incorporated into the soil on perennial plots (except in 2013 when the plots were seeded to canola).

The quantity of manure applied, total N and P, and available N applied are presented in Table 3.1 and Table 3.2.



Treatments

T1 = Treatment 1 - Liquid hog manure N based
T2 = Treatment 2 - Liquid hog manure P based
T3 = Treatment 3 - Solid hog manure N based
T4 = Treatment 4 - Solid hog manure P based
T5 = Treatment 5 - Control

Rotation	Annual	Perennial
Year 1	Canola	Timothy/Orchard grass
Year 2	Barley	Timothy/Orchard grass
Year 3	Canola	Timothy/Orchard grass
Year 4	Barley	Timothy/Orchard grass
Year 5	Canola	Canola

Figure 3.5 Plot layout at Carman

Table 3.3 Total P, total N, available N and quantity of manure applied to annual plots in all five years of the study

	LPM				SPM			
Year	Total P	Total N	Avail N	Manure applied	Total P	Total N	Avail N	Manure applied
	--------------kg ha^{-1}---------------			L ha^{-1}	------------------kg ha^{-1}--------			Mg ha^{-1}
2009	26	109	58	28758	81	69	36	22.4
2010	175	397	222	79309	n/a	321	127	60.5
2011	22	85	54	31488	232	397	110	61
2012	57	200	107	36400	83	325	104	43
2013	24	103	56	19720	48	153	41	21
Cumulative	304	894	497	195675		1265	418	207.9

Table 3.4 Total P, total N, available N and quantity of manure applied to perennial plots in all five years of the study

	LPM				SPM			
Year	Total P	Total N	Avail N	Manure applied	Total P	Total N	Avail N	Manure applied
	-------------- kg ha^{-1}--------------			L ha^{-1}	------------------kg ha^{-1}--------			Mg ha^{-1}
2009	29	123	59	32352	88.6	76	35	24.6
2010	181	412	202	82342	n/a	216	76	40.7
2011	44	315	95	62998	281	481	134	74
2012	85	299	134	54410	103	400	135	53
2013	63	272	148	52460	168	533	143	73
Cumulative	402	1421	638	284562		1706	523	265.3

3.3.2 Sample Collection

Soil samples were collected from each plot (0- 15 and 15-30 cm depth intervals) using a Giddings soil sampler, #15-TS Model GSRTS (Giddings Machine Co., Windsor, CO) just before treatment application in the spring of 2014. A composite sample was collected per plot from all the plots at two depths (0-15 and 15-30 cm). The samples were then air-dried and ground to pass through a 2-mm sieve in preparation for chemical analysis. Samples for organic C determination were finely ground soil (<1 mm) using a mortar and pestle.

3.3.1. Laboratory Analysis

Soil NO_3-N and NH_4-N concentrations were measured in 2 M KCl extracts (5:1 extractant to soil ratio) using cadmium reduction and phenate methods, respectively (Maynard et al., 2006). Soil available P concentration was determined using the Olsen method (Olsen et al., 1954; Olsen and Sommers 1982). Total P and total N concentrations were determined using the wet oxidation method (Akinremi et al. 2003). Total P concentration was measured in the digest using colorimetric method (Murphy and Riley, 1962) while total N concentration was measured using a Technicon auto-analyzer II (Pulse Instrumentation Ltd, Saskatoon, SK). Organic carbon was determined using the Walkley-Black acid digestion method (Walkley and Black, 1934). Cation exchange capacity (CEC) and exchangeable cation were measured with the ammonium acetate method (McKeague, 1981). Soil pH was measured in a 1:2 soil:water suspension while EC was measured in extracts from 1:1 soil:water suspensions (Janzen 1993; Rhoades 1996).

3.3.2. Statistical Analysis

Data were analysed using PROC GLIMMIX in SAS 9.4 (SAS Institute, 2014). Analysis of variance was performed separately for each depth interval (0-15 cm, 15-30 cm) for all soil property measured as depth was not of primary interest in the study. PROC UNIVARIATE was used to test for normality and a Gaussian distribution was assumed for the response variables in the model for analysis. The statistical model included block as a random factor and manure and cropping system as fixed factors. Means were compared using the Tukey-Kramer multiple comparison test at a probability level of 0.05.

3.4 Results

3.4.1 Soil Available Phosphorus

Manure treatment and cropping system effects were significant for soil available P concentration in the 0-15 cm layer (Table 3.3) but not in the 15-30 cm layer (Table 3.4). In the 0-15 cm layer, available P concentration increased with treatment in the order CON < LPM < SPM, with both manure types (that is, SPM and LPM) significantly increasing soil available P concentration by 258- 471%, while SPM produced significantly higher available P concentration than LPM (Fig 3.2). In the same depth interval, plots under perennial grasses had 31% greater soil available P concentration than soils under annual crops (Table 3.3).

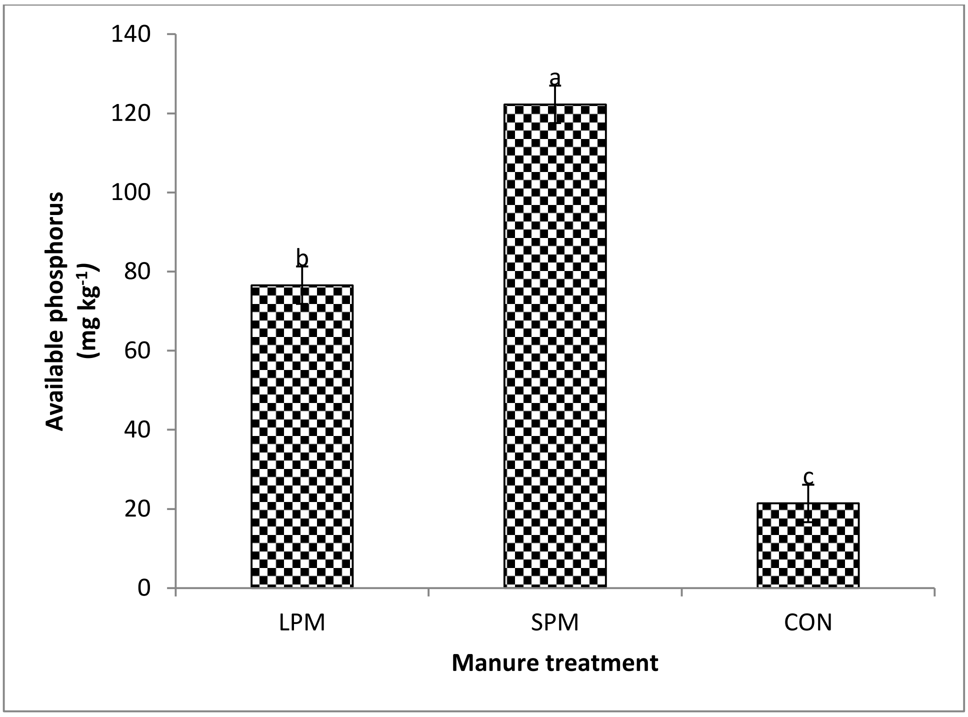


Figure 3.2 Manure treatment effect on soil available P in the 0-15 cm depth. Error bars represent standard error of the means Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test

Table 3.3. Effect of manure and cropping system on soil chemical properties at the 0-15 cm depths

	Available P	**Available N**	**Total P**	**Total N**	**Soil pH**	**Soil EC**	**Organic Carbon**	**Exch Ca**	**Exch K**	**Exch Mg**	**CEC**
	(mg kg^{-1})	**(mg kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**		**(μs cm^{-1})**	**(mg kg^{-})**	(cmol$_c$ kg^{-1}**)**	(cmol$_c$ kg^{-1}**)**	(cmol$_c$ kg^{-1}**)**	(cmol$_c$ kg^{-1}**)**
Cropping system											
Annual	63.6**b**	43.5**b**	577**b**	1618	6.65	356	16248	5.42	0.90	2.31	10.0
Perennial	83.2**a**	54.6**a**	666**a**	1707	6.44	468	17892	4.69	1.02	2.26	9.64
Model effect							**P value [a]**				
Cropping system	**<0.001**	**0.03**	**0.02**	0.41	0.14	0.004	0.32	0.56	0.18	0.89	0.70
Manure	**<0.0001**	**0.002**	**<0.0001**	<0.0001	0.29	0.0001	**0.001**	**0.01**	**<0.0001**	0.39	0.04
Cropping system × Manure	0.09	0.08	0.41	**0.02**	0.65	**0.02**	0.11	0.72	0.06	0.49	0.42

[a] Probability value is significant at 0.05 and highlighted in bold

Table 3.4. Effect of manure and cropping system on soil chemical properties at the 15-30 depth interval

	Available P	**Available N**	**Total P**	**Total N**	**Soil pH**	**Soil EC**	**Organic Carbon**	**Exch Ca**	**Exch K**	**Exch Mg**	**CEC**
	(mg kg^{-1})	**(mg kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**		**(µs cm^{-1})**	**(mg kg^{-1})**	cmol$_c$ kg^{-1}**)**	cmol$_c$ kg^{-1}**)**	(cmol$_c$ kg^{-1}**)**	(cmol$_c$ kg^{-1}**)**
Cropping system											
Annual	9.61	21.7**b**	406	1188	7.91	297	11412	11.4	0.26	3.60	10.5
Perennial	12.9	32.4**a**	432	1053	7.76	411	10972	9.88	0.34	2.42	9.8
Model effect						**P value [a]**					
Cropping system	0.41	**0.007**	0.43	0.56	0.57	0.10	0.80	0.61	0.39	0.14	0.62
Manure	0.06	**0.03**	0.33	0.29	0.49	**0.03**	0.69	0.34	**0.002**	0.06	0.96
Cropping system × Manure	0.80	0.08	0.39	**0.04**	0.45	0.10	0.08	0.86	0.09	0.07	0.17

[a] Probability value is significant at 0.05 and highlighted in bold

3.4.2 Soil Available Nitrogen

Repeated application of solid pig manure to the soil increased soil available N concentration in both depth intervals (Table 3.3 and 3.4). In the 0-15 cm depth interval, SPM produced a significantly greater soil available N concentration than the control and LPM (Fig 3.3a). In the 15-30 cm soil depth interval, available N concentration in SPM-amended soil was also significantly greater than that in the control, but did not differ significantly from that in LPM-amended soil (Fig 3.3b). Averaged across manure treatments, perennial plots had significantly greater (26-49%) soil available N concentration than annual plots regardless of soil depth interval (Table 3.3 and 3.4).

(A) **(B)**

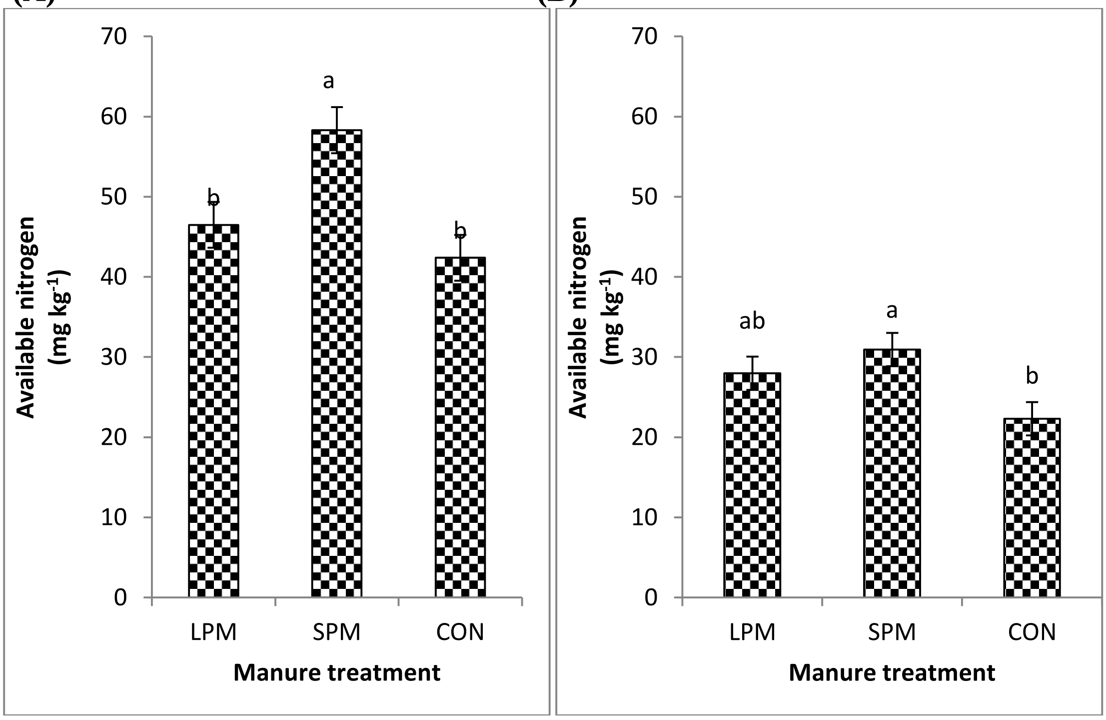


Figure 3.3 Manure treatment effect on soil available N in the (A) 0-15 cm depth (B) 15 -30 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different (P >0.05) according to the Tukey-Kramer multiple comparison test

3.4.3 Total Nitrogen

The cropping system by manure treatment interaction was significant for total N concentration in both soil layers (Table 3.3). In the 0-15 cm layer, pig manure application increased soil total N concentration by 13-31% in perennial plots, with the greater concentration observed in SPM-amended plots. In annual plots, however, only SPM amended soils had a greater total N concentration in this layer while no significant difference was detected between LPM and control plots (Fig. 3.4). Also, a significant difference between the two manure treatments was detected only in the perennial plots in which SPM produced greater total N concentration than LPM application in the 15-30 cm depth interval (Fig 3.5).

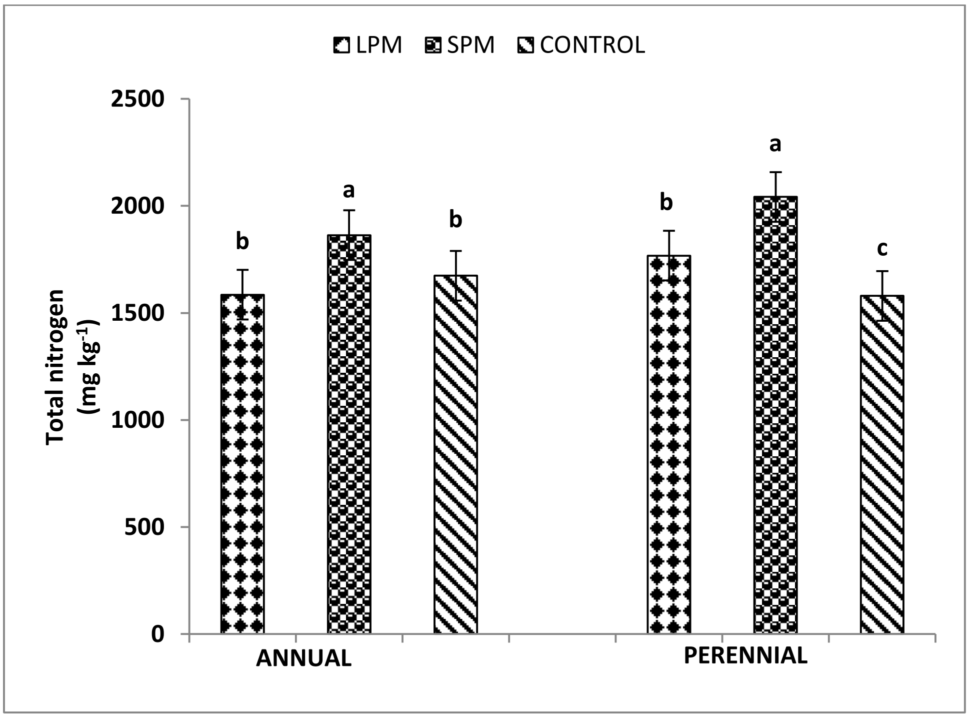


Figure 3.4 Cropping by manure treatment interaction effect on soil total N in the 0-15 cm depth. Error bars represent standard error of the means.Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test. Note: Multiple comparison test was done within each cropping system

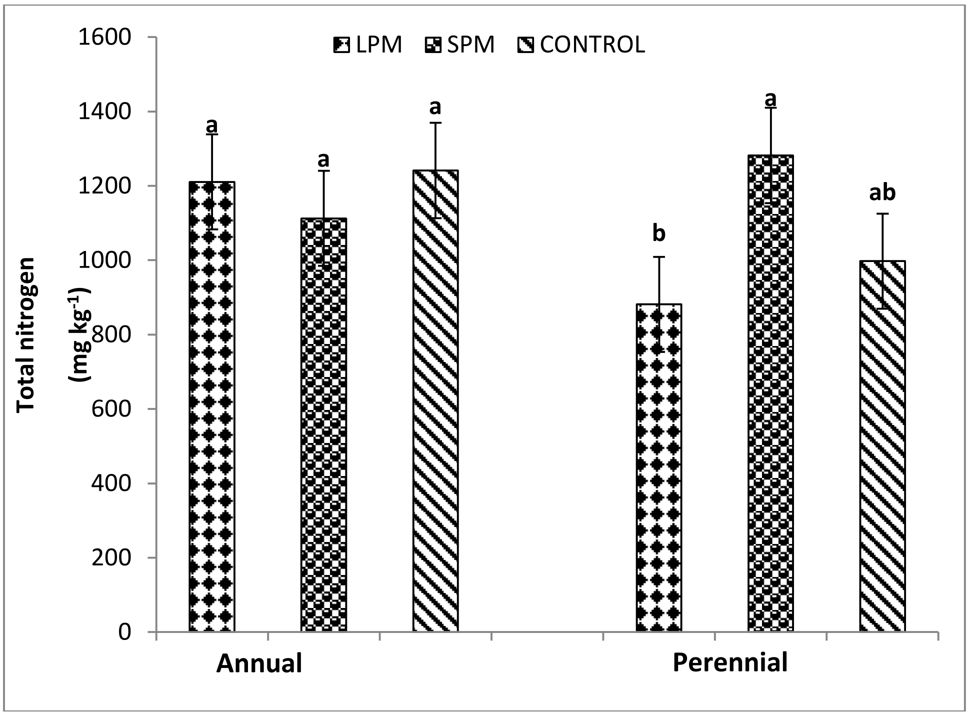


Figure 3.5 Cropping by manure treatment interaction effect on soil total N in the 15-30 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different (P >0.05) according to the Tukey-Kramer multiple comparison test. Note: Multiple comparison test was done within each cropping system

3.4.4 Total Phosphorus

Manure treatment and cropping system effects were significant for soil total P concentration only in the 0-15 cm depth interval. In this layer, all manure treatment means were significantly different from each other, with total P concentrations decreasing in the order SPM > LPM > control (Fig 3.6). Averaged across manure treatments, soils under perennial grasses in this layer had 15% greater total P concentration than soils under annual cropping (Table 3.3).

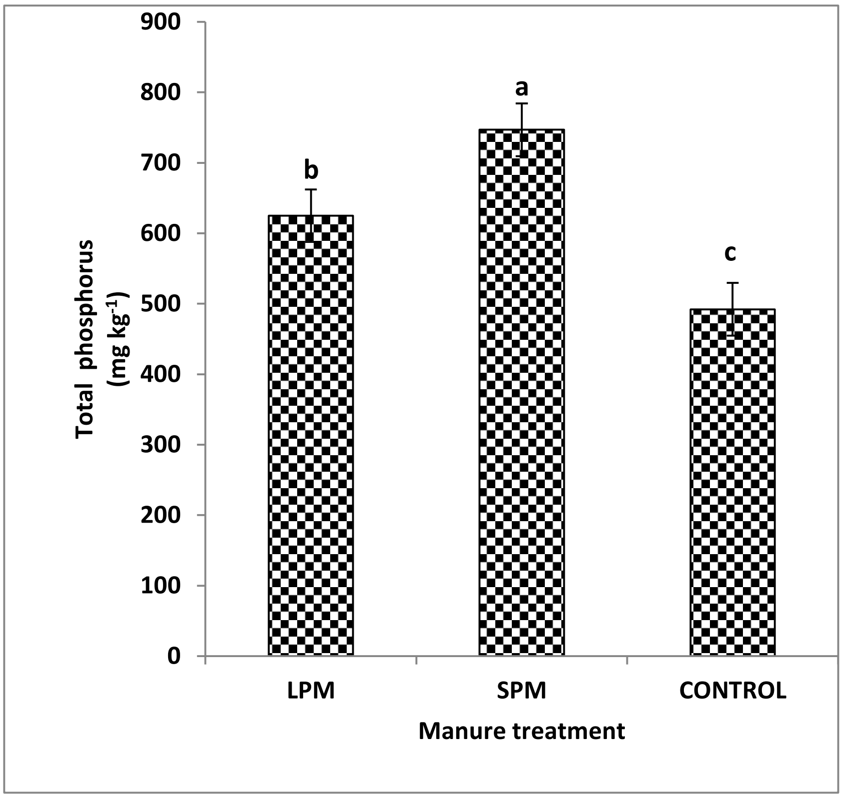


Figure 3.6 Manure treatment effect on soil total P in the 0-15 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey -Kramer multiple comparison test.

3.4.5 Organic Carbon

Manure treatment effect was significant for soil organic C concentration in the 0-15 cm depth interval (Table 3.3). Soils amended with SPM had the greatest soil organic C concentration while LPM amended soil were not significantly different from the control (Fig 3.7). In the 15-30 cm depth interval, manure treatment had no significant effect on organic C concentration (Table 3.3). There was no significant effect of cropping system on soil organic C regardless of soil depth interval (Table 3.3 and 3.4).

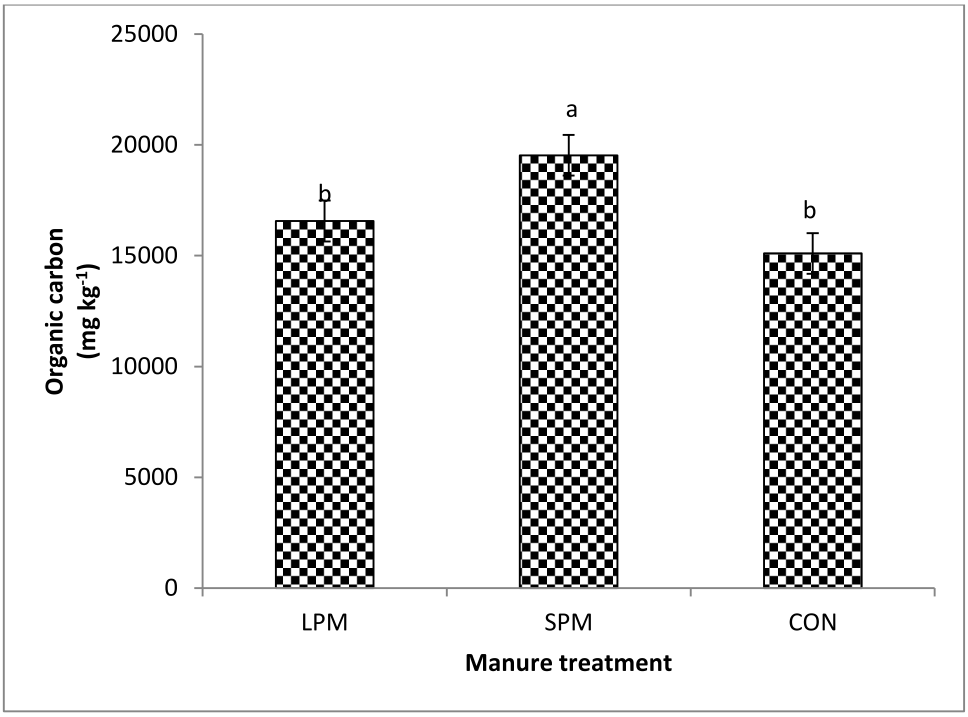


Figure 3.7 Manure treatment effect on soil organic carbon in the 0-15 cm depth. Error bars represent standard error of the means .Bars with the same letter are not significantly different (P > 0.05) according to the Tukey-Kramer multiple comparison test

3.4.6 Soil pH

Manure treatment had no significant effect on soil pH at both 0-15 cm and 15-30 cm. There was no significant effect of cropping system on soil pH regardless of soil depth interval (Table 3.3 and 3.4).

3.4.7 Electrical Conductivity

The cropping system by manure treatment interaction was significant for EC in the 0-15 cm depth interval (Table 3.3). While manure treatments did not differ significantly in the annual plots, SPM produced the greatest EC in the perennial plots (Fig 3.8).

In the 15-30 cm depth layer, EC was significantly greater in SPM-amended plots than in the control, but there was no significant difference between SPM and the control and between SPM and LPM (Fig 3.9).

Cropping system had no significant effect on soil electrical conductivity in the 15-30 cm depth interval (Table 3.4).

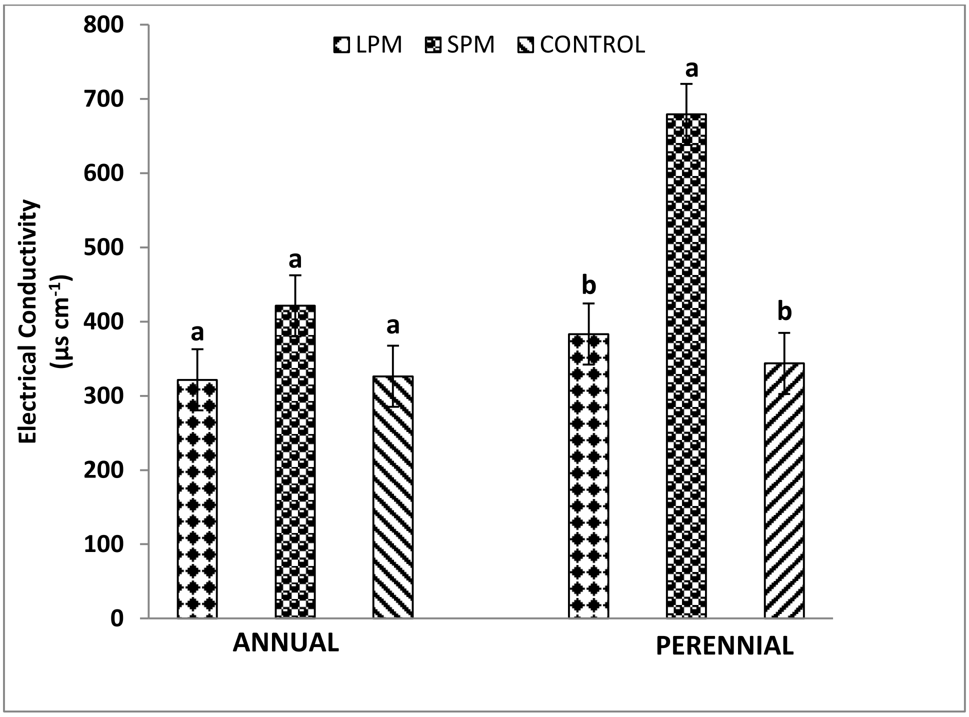


Figure 3.8 Cropping system by manure treatment effect on soil in 0-15 cm depth. Error bars represent standard error of the means Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test.
Note: Multiple comparison test was done within each cropping system

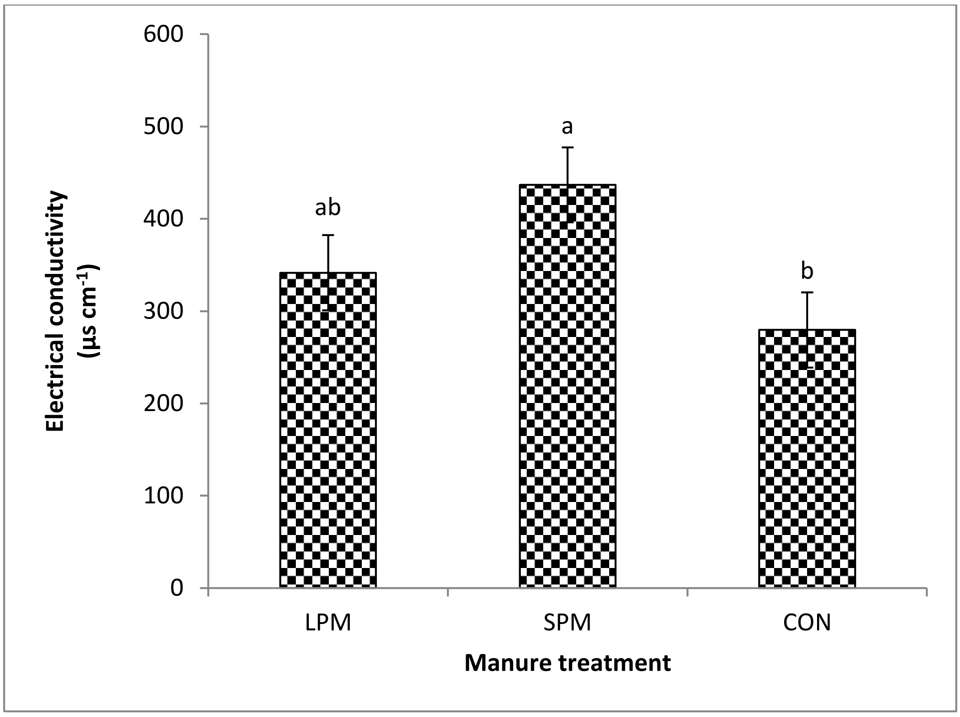


Figure 3.9 Manure treatment effect on soil electrical conductivity in the 15-30 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different (P >0.05) according to the Tukey-Kramer multiple comparison test

3.4.8 Cation Exchange Capacity

In the 0-15 cm depth interval, the CEC of SPM amended soils was the highest with a value of 9.8 $cmol_c\ kg^{-1}$. The CEC of SPM-amended soils was significantly greater than that of LPM-amended soils but was not significantly different from that of control soils (Fig 3.10). Manure treatment had no significant effect on CEC in the 15-30 cm layer, while the cropping system effect was not significant in either soil depth (Table 3.3 and 3.4).

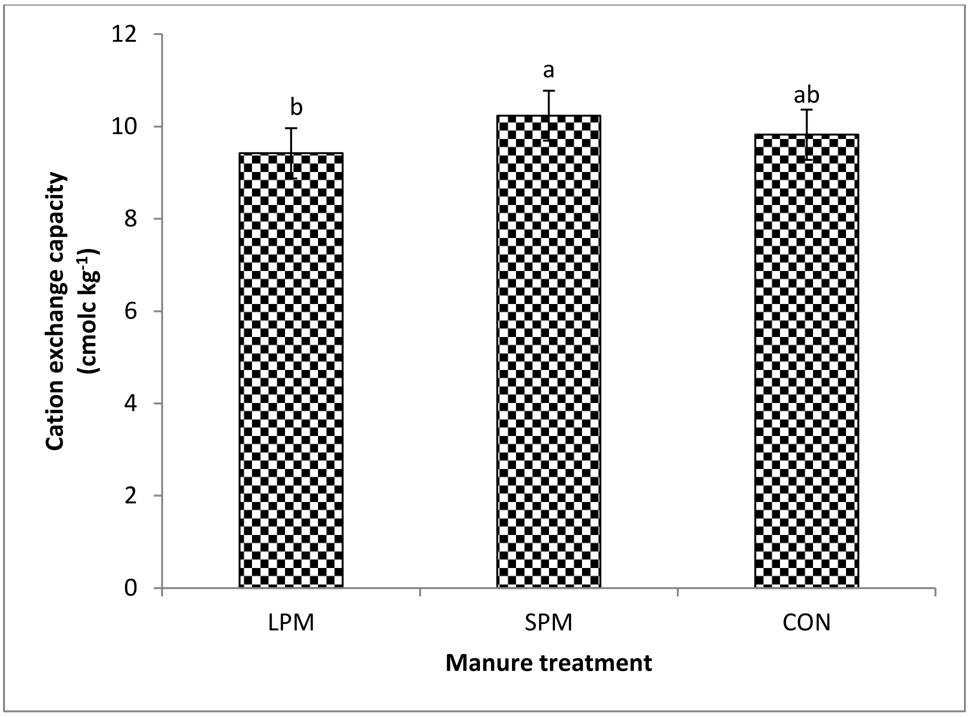


Figure 3.10 Manure treatment effect on cation exchange capacity in the 0-15 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test.

3.4.9 Exchangeable Cations

3.4.9.1 Exchangeable Calcium

In the 0-15 cm depth interval, exchangeable Ca^{2+} concentration was significantly lower in LPM-amended soils than in the control but did not differ significantly between the two manure types and between SPM-amended plots and the control (Fig 3.11). Manure treatments did not differ significantly with respect to exchangeable Ca^{2+} concentration in the 15-30 cm depth interval (Table 3.3). In both soil layers, cropping system had no significant effect on exchangeable Ca^{2+} concentration (Table 3.3 and 3.4).

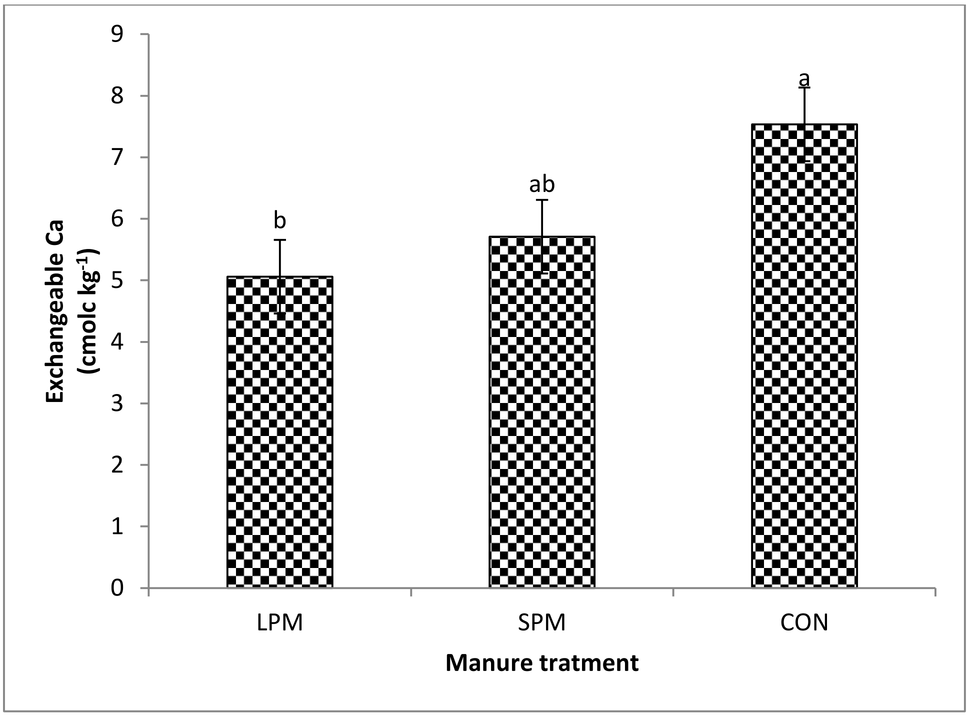


Figure 3.11 Manure treatment effect on exchangeable calcium in the 0-15 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test.

3.4.9.2 Exchangeable Potassium

In the 0-15 cm depth interval, exchangeable K^+ concentration was greater in SPM-amended soils than LPM-amended soils (Fig 3.12). Liquid pig manure also produced significantly greater exchangeable K^+ concentration than the control. The lowest exchangeable K^+ was in control soils. In the 15-30 cm depth interval, SPM-amended soils had a higher exchangeable K^+ concentration than LPM-amended and control soils. There was no significant difference in exchangeable K^+ concentration between soils that received LPM and the control (Table 3.3). The effect of cropping system was not significant for exchangeable K^+ concentration in both soil layers (Table 3.3 and 3.4).

(A) (B)

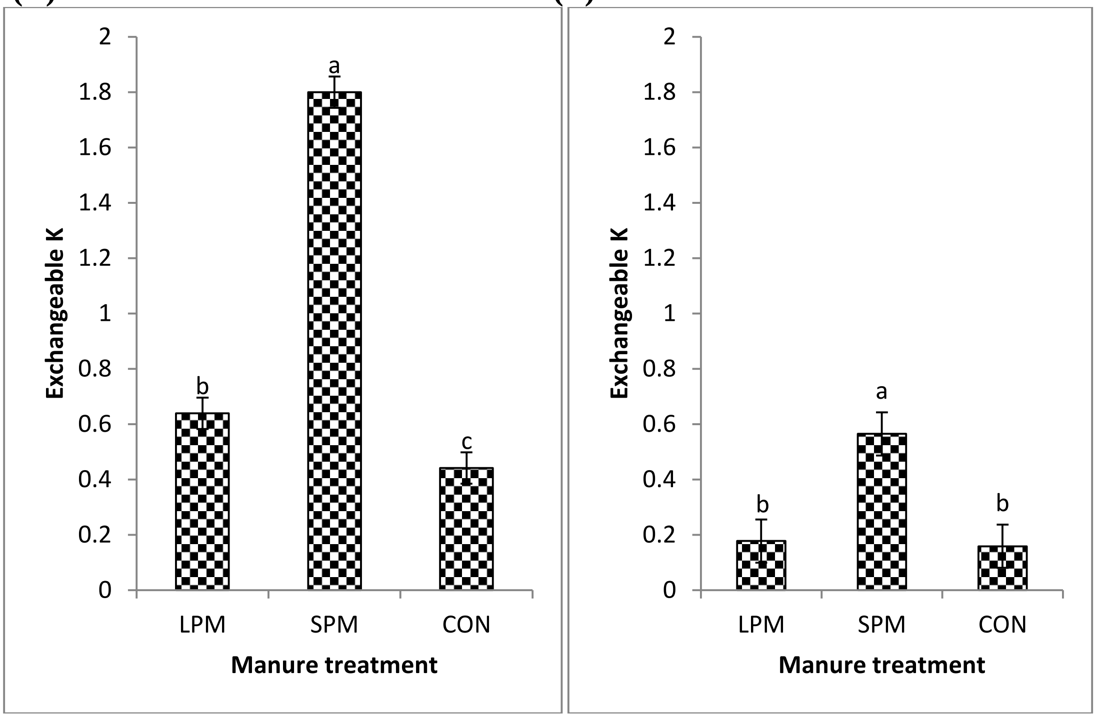


Figure 3.12 Manure treatment effect on exchangeable potassium in the (A) 0-15 cm depth (B) 15-30 cm depth. Error bars represent standard error of the means. Bars with the same letter are not significantly different ($P > 0.05$) according to the Tukey-Kramer multiple comparison test

3.5.9.3 Exchangeable Magnesium

There was no significant effect of manure treatment or cropping system for exchangeable magnesium in both the 0-15 cm depth and 15- 30 cm depth (Table 3.3 and 3.4).

3.6 Discussion

3.6.1 Soil Available Phosphorus

The increased soil available P in pig manure amended soils relative to the control could be due to the addition of a P rich organic amendment (pig manure) to the soil (Von Wandruszka 2006). Our results is consistent with those reported by Lourenzi et al. (2013) , Lourenzi et al. (2014a), Balota et al. (2014), Broetto et al. (2014) and Penha et al. (2015), in which pig manure (slurry or deep litter) addition to soil, increased soil available P. The observed increase in available P of pig manure amended soils in our study is consistent with the suggestion of constant replenishment of available P through the dissolution of stable inorganic P pools and organic P mineralization (Tiessen and Moir 1993; Hountin et al. 2000; Broetto et al. 2014).

The greater soil available P concentration in SPM-amended compared with LPM-amended soils in our study corroborates results from other studies, which showed that soils amended with pig deep litter had greater available P concentration than pig slurry-amended soil (Guardini et al. 2012a; Couto et al. 2013; Lourenzi et al. 2014a). The greater available P concentration in SPM-amended soil could be attributed to the greater total P concentration in SPM compared to LPM (The Agricultural Guidelines Development Committee 2007; Guardini et al. 2012a; Lourenzi et al. 2014a). We attributed the increase in soil available P concentration observed only in the 0- 15 cm layer to this depth interval being the region of manure application (Guardini et al. 2012a. This is also an indication of the limited downward movement of P in this soil (Wang et al. 2008).

The increase in soil available P concentration in perennial plots relative to annual plots is consistent with results from a study by Stewart et al. (2015), which showed that the decrease in available P concentration in soils under switch grass was lower (-5.38 kg P ha^{-1}) than the decrease observed in soils under no-till corn (-24.04 Kg P ha^{-1}). This suggest a greater use of available P by annual crops and increased residual P concentration in soils in perennial plots (Stewart et al. 2015). The greater soil available P concentration in perennial plots could also be due to the high root biomass of perennial crops that reduces erosion and P losses in surface soil (Broetto et al. 2014).

3.6.2 Soil Available Nitrogen

The observed effect of LPM on soil available N concentration in the 0-15 cm depth interval is consistent with results from a study by Lourenzi et al. (2013), which showed that 19 applications of pig slurry did not significantly increase soil mineral N concentration relative to unamended soil. They attributed this lack of response to the leaching of mineral N below the 60-cm depth and to losses by runoff (Lourenzi et al., 2013). Angers et al. (2010) and Mooleki et al. (2002), however, observed an increase in available N concentration in soil fertilized with LPM. The lack of response to LPM application in our study could be partly due to the rapid accumulation of inorganic N during the first few days following pig slurry application (Rochette et al. 2000b; Chantigny et al. 2001; Yanardağ et al. 2015), followed by a decrease with time as a result of crop uptake and losses from the soil through nitrate leaching (Daudén et al. 2004; Nikiema et al. 2013).

The 38-39% increase in available N concentration in SPM-amended soil could be attributed to the higher organic N content and organic C of SPM compared with LPM (The Agricultural Guidelines Development Committee 2007). Also, since SPM contains straw bedding, which has a high C:N ratio, degradation is slower and takes longer. However, while the lower C:N ratio of LPM causes it to degrade faster, the nutrients contained in LPM thus become rapidly available in the periods after application (Rochette et al. 2000a; Couto et al. 2013).

The increased available N concentration in perennial plots compared to annual plots is similar to reports by Masto et al. (2008) and Liebig et al. (2012), who found that perennial plots had higher available N concentration. These results may be an artefact of the experiment. The seeding of the perennial plot to canola in 2013 necessitated the application of large amounts of manure N with no credit given to the grasses that were ploughed under. This might have caused an unusually high available N concentration in the soil in these plots in 2014.

3.6.3 Soil Total Phosphorus

The increased soil total P concentration in the 0-15 cm depth interval of pig manure amended soils is due to the addition of P-rich pig manure (Von Wandruszka 2006). The results from our study are in contrast to results obtained by Qian et al (2004) in a study comparing P distribution in swine and cattle manure amended soils. In the study, pig slurry application had no effect on soil total P concentration while cattle manure increased total P concentration relative to the control. Qian et al (2004) attributed this result to the high N:P ratio of the pig manure compared with cattle manure, and to the fact that the P added by LPM matched crop removal. Broetto et al. (2014), however, reported an increase in soil total P concentration after 20 years of pig slurry application in soils that received high rates of pig slurry. They attributed this increase to the higher amount of P added by the manure relative to P uptake by plants and also to the favourable conditions for P accumulation, such as the no- tillage management employed during their study and low soil erosion susceptibility. Results from Broetto et al. (2014) are similar to results from our study. Couto et al. (2013) also reported an increase in soil P following pig slurry and pig deep litter application over a period of 8 years. Angers et al. (2010), in their study on the retention of P in soils following long-term application of pig manure, observed an increase in soil total P concentration with the addition of pig manure.

The Agricultural Guidelines Development Committee (2007) estimates that fresh solid pig manure contains about 2.8 kg Mg^{-1} total P while liquid manure contains about 0.7 kg Mg^{-1} of total P. The greater increase in total P in SPM-amended soil could therefore be due to SPM having a higher total P concentration than LPM (The Agricultural Guidelines Development Committee 2007; Guardini et al. 2012a). Results from our study are consistent with Guardini et al. (2012b), who observed a greater increase in total P concentration in soils amended with pig deep litter (SPM) compared to pig slurry-amended soils.

The lack of a significant effect of pig manure on soil total P concentration in the 15-30 cm depth interval may due to top layer being the region of manure application.

The soil profile under perennial plots contained consistently lower residual N concentrations than that under annual cropping in soil tests conducted in the fall. As such, a greater amount of manure was added to the perennial plots during the five-year period compared to the annual plots. These differences could account for the differences in the total P in the topsoil of these two cropping systems. In addition, the high root biomass of perennial crops decreased susceptibility to erosion and runoff losses of P compared to annual crops (Broetto et al. 2014).

3.6.4 Soil Total Nitrogen

Perennial plots have been known to prevent nitrate leaching (Nikiema et al. 2013) and can accumulate soil total N (Culman et al. 2010; Blanco-Canqui et al. 2014). Solid manures, due to their higher C:N ratio relative to pig slurries, have lower N mineralization rates (Qian and Schoenau 2002). Thus, the repeated application of solid manures could lead to the accumulation of total N with time. The increase in soil total N concentration in perennial plots amended with SPM could be due to the synergistic effect of perennial cropping and SPM on total N. The increase in total N concentration in LPM-amended soils in the perennial plots compared to the control could also be due to the N-rich LPM contributing more to the soil N pool when added to soil.

The increase in total N concentration in SPM-amended soil in annual plots could be attributed to the lower rate of N mineralization of the solid manure (Qian and Schoenau 2002) compared with LPM, which has a lower C:N ratio (Rochette et al. 2000a; Couto et al. 2013). This could have led to N accumulation in SPM-amended soil over time.

The greater total N concentration in the 15-30 cm depth interval in SPM-amended soils under perennial cropping was surprising, as the solid manure was not incorporated in this plot until 2013 when the perennial plot was seeded to canola. The incorporation that was carried out in 2013 could have added some of the preserved SPM from the surface soil into the lower depth, leading to an increase in soil N concentration. In the annual plots, the lack of total N response to pig manure application was possibly due to a more rapid mineralization from manure incorporation in the annual plots and losses of N due to leaching.

3.6.5 Soil pH

Ahmed et al. (2013) reported no significant differences between soil pH in control plots and liquid pig manure-amended plots. Similar results were reported by Richards et al. (2011), and Couto et al. (2013). Lourenzi et al. (2013) also observed no response of pH to pig slurry and pig litter soils. However, in the study, soils that received twice the recommended dose of deep litter had increased soil pH (Lourenzi et al., 2013). Various studies have reported increases in soil pH following pig manure application (Wienhold, 2005; Brunetto et al., 2012; Lourenzi et al., 2011) while a decrease in soil pH following repeated applications of pig manure was reported by others (Lipoth and Schoenau, 2007; Adeli et al., 2008). The Hibsin soil that was used in our study had a near neutral pH (6.5) and may not be amenable to pH increases following manure addition.

The cropping effect on soil pH reported in our study is consistent with reports from Gilley et al. (2013) who reported no change in soil pH in a narrow grass hedge system.

3.6.6 Soil Electrical Conductivity

Studies have shown that pig manure can increase soil EC (Plaza et al. 2002; Adeli et al. 2008) while others indicated no significant effect of pig effluent application (Turner et al. 2010). In our study, the perennial plots amended with SPM had the highest EC. While some studies have shown that pig manure has a number of dissolved salts (Adeli et al. 2008), few studies have reported the effect of perennial cropping on soil EC. Results from our study could also be due to the greater amount of SPM added to perennial plots to meet crop N requirements, which in turn increased soil EC.

The increase in EC in the 15-30 cm depth interval in solid pig manure-amended soil could be due to the presence of dissolved salts in the solid pig manure (Adeli et al. 2008). Although, this EC increase in SPM-amended soil was significant, the soil was still classified as non-saline as the electrical conductivity of 437 µs cm^{-1} is less than 4000 µs cm^{-1} (Ashraf et al., 2008).

3.6.7 Soil Organic Carbon

The increase in soil organic C concentration with addition of SPM could be due to the large C:N ratio and high dry matter content of solid pig manure (Brunetto et al. 2012; Couto et al. 2013; Comin et al. 2013). Brunetto et al. (2012) reported similar results, with pig deep litter amended soils having a higher organic C concentration than the control soils and pig slurry-amended soils. Result from our study are consistent with those from other previous studies (Assefa et al. 2004; Comin et al. 2013; Balota et al. 2014). The lack of a significant manure effect on soil organic C in the 15-30 cm depth interval could be due to the addition of pig manure to the surface soil without deep incorporation (Comin et al. 2013). The lack of response of soil organic C concentration to LPM application in our study could be a result of the rapid decomposition of organic matter in liquid manure due the narrower C:N ratio of LPM (Rochette et al. 2000a). Angers et al. (2010) similarly found no significant difference in organic C concentration between soils fertilized with LPM and unamended soils.

Results from our study on the effect of cropping system on soil organic C in the 0-15 cm soil layer is in contrast to studies by Culman et al. (2010), which showed an increase in soil organic C in soils under perennial vegetation relative to annual croplands. They attributed the increase to the ability of perennial grasses to sequester carbon, and to the high root biomass of perennial grasses compared to annual crops (Culman et al. 2010). Results from our study could be due to the short timeframe of our study. Other studies (Ernst and Siri-Prieto 2009; Tiemann and Grady 2015) have reported similar results to our study in which organic C in soils under perennial grasses were not significantly different from the control or annual plots. Tiemann and Grandy (2015) concluded that the lack of increase in soil organic C under perennial grasses is due to the unstable soil organic C accrued and slow build-up of potentially mineralizable C.

3.6.8 Cation Exchange Capacity

The lack of a significant difference in CEC between LPM-amended soil and the control is in contrast to the study by Ndayegamiye and Cote (1989), in which liquid pig manure at igh rates increased soil CEC relative to unamended soil. Results from their study, however, showed a greater increase in soil CEC with solid cattle manure application. The slightly lower, but not significantly different CEC of LPM amended soil compared with the control is similar to the results reported by Brunetto et al. (2012). The higher CEC of SPM-amended soils than the LPM-amended soils could be due to the greater organic matter content of these SPM amended soils (Brunetto et al. 2012).

The non-significant effect observed for CEC in the 15-30 cm depth interval could be due to a lack of response of organic matter to pig manure as an increase in humic matter can increase CEC.

The lack of significant differences in soil organic C between cropping systems in this study could be the reason for the non-significant cropping effect on CEC as the addition of humic matter can increase soil CEC (Penha et al. 2015).

3.6.9 Exchangeable Cations

3.6.9.1 Exchangeable Ca

The lower exchangeable Ca^{2+} concentration observed in our study is consistent with observations by Smanhotto et al. (2013). A similar result was observed 59 d after sowing soybean in pig slurry-amended soil in a study on the nutrient behaviour of pig slurry (Smanhotto et al. 2013). Results from our study are also similar to those obtained by Qian et al. (2005), who reported a significant decrease in exchangeable Ca concentration in liquid pig manure-amended soils after 5 years of repeated manure application. The lack of significant difference in exchangeable Ca^{2+} between SPM amended soils and control soils in our study may be due to the low concentration of Ca^{2+} in pig manure, the reaction of Ca^{2+} with phosphates to form insoluble mineral compounds or the higher adsorption of Ca to organic matter (Lourenzi et al. 2011). Other studies have reported increases in exchangeable Ca^{2+} concentration with pig manure addition (Sharpley et al. 2004; Franke et al. 2008; Lourenzi et al. 2011; Lourenzi et al. 2013).

It was surprising that the exchangeable Ca concentration in manure treated soils was smaller than in the control in spite of the possibility of Ca addition by the manure. It is possible that other cations in the manure, such as K^+, NH_4^+ and Na^+, replaced the native soil Ca^{2+} which then formed a precipitate with manure and soil P. Ige et al. (2006) examined the relationship between soil test P and soil properties and found only the exchangeable K^+ to be related to soil test P. They postulated that this relationship may be an indication of a similar source of K^+ and P, and the possibility of K^+ replacing exchangeable Ca^{2+}, which then precipitated with P to increase the soil residual P. A similar process may be in operation in our manure-amended soil as the reduced exchangeable Ca was accompanied by an increase in exchangeable K^+.

3.6.9.2 Exchangeable K

Results from our study are consistent with those of Adeli et al. (2008), who reported an increase in exchangeable K^+ concentration with the addition of liquid pig manure to soil. Bernal et al. (1993) also reported an increase in exchangeable K^+ concentration of two calcareous soils with the addition of pig slurry. McAndrews et al. (2006) observed that soils amended with fresh solid pig manure had greater exchangeable K^+ than control soils. Franke et al. (2008) reported an increase in exchangeable K^+ following application of solid beef cattle manure. The increase in exchangeable K^+ and a decrease in exchangeable Ca^{2+} following manure addition is an indication that there were exchange reactions between K^+ in the manure and Ca^{2+} on the soil exchange complex (Akinremi and Cho 1993). Qian et al. (2005) also observed this trend of an increase in exchangeable K^+ and a concomitant decrease in Ca^{2+} concentration after 5 years of repeated pig manure application. Hence, the increase in exchangeable K^+ concentration observed in SPM- and LPM-amended soils in our study could be due to exchange reactions between exchangeable K^+ and Ca^{2+} (Akinremi and Cho 1993).

The lack of significant differences between LPM-amended soil and the control in the 15-30 cm depth interval could be due to the retardation of K^+ movement by its exchange reactions with Ca^{2+} within the surface 0-15 cm layer. Cho (1985) demonstrated that exchange reactions between cations in soil could reduce their movement in soils.

3.6.9.2 Exchangeable Mg

Results from our study is consistent with that of Couto et al. (2013), who reported no significant effect of pig slurry and pig deep litter on the exchangeable Mg. In their study, only soils amended with twice the recommended dose of pig litter had increased exchangeable Mg. Other studies have reported increases in exchangeable Mg with pig manure addition (Franke et al., 2008; Lourenzi et al., 2011; Lourenzi et al., 2013) after years of study. The short-term nature of our study (5 years) could be the reason for lack response of exchangeable Mg to pig manure addition in both soil depth interval (0-15 cm, 15-30 cm).

The non-significant cropping effect for exchangeable Mg was probably due to the lack of a significant effect of cropping system on CEC and organic carbon.

3.7 Conclusion

Land application of pig manure influenced the chemical properties of an Orthic Black Chernozem. Liquid pig manure addition increased available P, total P and exchangeable K^+ concentrations and reduced exchangeable Ca^{2+} concentration in the 0-15 cm soil layer regardless of cropping system. Solid pig manure increased soil available N and exchangeable K^+ in both soil layers and, total P, available P, organic C concentrations in the 0-15 cm depth interval.

The significantly lower exchangeable Ca^{2+} concentration in LPM-amended soil suggests reduced P availability in this soil due to the increased potential of precipitation reactions of P with the displaced Ca^{2+}. Further studies are recommended to monitor the effect of reduced exchangeable Ca^{2+} concentration on soil structure over time.

In the 15-30 cm soil layer, SPM-amended soil had significantly greater exchangeable K^{+} and available N concentrations than the control and LPM-amended soils. Soils under perennial cropping had significantly greater available P and total P concentrations when compared with annual plots.

Although LPM improved some soil chemical properties following pig manure application, greater improvement in soil chemical properties was recorded in SPM-amended soils. Our results suggest that SPM has a potential to improve soil chemical properties of prairie soils.

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4. GENERAL SYNTHESIS

The high rate of pig production in Manitoba invariably leads to large tonnes of manure generated annually (Sri Ranjan et al., 2005). Land application of this manure is the most common form of manure use (Bailey and Buckley, 1998). Pig manure is rich in all essential plant nutrients and can improve soil physical and chemical properties. Due to the ease of handling, liquid pig manure handling system is more common in Canada (Beaulieu, 2004). However, in recent years, a few producers in Manitoba have experimented with the solid manure handling system. The choice of cropping system employed by a farmer could affect soil quality (Limon-Ortega et al., 2009), as the ability of perennial plants to sequester organic carbon and improve soil properties through increases in soil organic carbon, is an advantage over annual crops.

A comparison of the effect of liquid and solid pig manures on the physical and chemical properties of soil cropped to annual and perennial grasses has not been undertaken on prairie soils. A knowledge of the impact that a shift from LPM to SPM management system will have on soils that receive these manures will be beneficial in future manure management practices. This study was conducted in order to determine the influence of solid and liquid pig manure and cropping system on selected soil physical and chemical properties. Thus, following five years of annual application of liquid and solid pig manure to an Orthic Black Chernozem, soil sampling was done to measure saturated hydraulic conductivity, bulk density, aggregate stability, water retention (0.2 bar and 15 bar), available water and some chemical properties such as available N and P, total N and P, pH and electrical conductivity, cation exchange capacity, exchangeable cations and organic carbon. Soil samples for chemical properties were taken at the 0-15 cm depth and 15-30 cm depth while samples for physical properties were taken at the 0-10 cm depth and 10-20 cm depth. The reason for the difference in sampling depth for the two category of properties measured, was due to the fact that the impact of organic amendment or cropping on physical properties are time dependent and also observed relatively close to the soil surface.

The application of solid pig manure (SPM) to an Orthic Black Chernozem resulted in greater soil organic carbon content, smaller bulk density, greater saturated hydraulic conductivity, available and total phosphorus, available nitrogen, cation exchange capacity and exchangeable potassium at the first soil depth compared to liquid pig manure amended soils. We found that the effect of manure on water retention properties varied with the cropping system which suggests that the form of cropping system used on a farm could affect water retention properties.

Solid pig manure amended soils were observed to have greater available soil nutrients over time (notably phosphorus), which suggests constant replenishment of inorganic nutrients, by the mineralization of organic nutrients to their inorganic form over time. Our results thereby suggest that the continuous application of solid pig manure could lead to over application of phosphorus, as more phosphorus is added to the soil when applying manure based on nitrogen requirement of crops (especially on perennial plots). The significantly greater electrical conductivity at the 15-30 cm depth also suggests the potential for an increase in salinity of these soils over time.

Although the liquid pig manure amended soils had lower bulk density, increased aggregate stability, available phosphorus, total phosphorus, exchangeable potassium, these increases were observed only at the top 15 cm and the effect of LPM was not as great as we expected on soil physical and chemical properties. The LPM did not also increase cation exchange capacity and organic carbon. These properties (organic carbon and cation exchange capacity) have a great influence on soil physical and chemical properties and could be the reason why LPM did not significantly affect some soil properties and its effect was not as we expected.

The increase in aggregate stability of soil was due to increase in the organic carbon of SPM amended soils. Since soil bulk density and aggregate stability are dependent on soil organic carbon, the greater increase in aggregate stability of SPM amended soils is due to the increase in organic carbon.

We found that application of pig manure reduced the exchangeable calcium in pig manure amended soils, with the significant decrease being in liquid pig manure amended soils. This suggest decreased P availability in liquid pig manure amended soils as a result of the increased potential of precipitation reactions of P with the displaced Ca^{2+}, as was observed in the study. Exchangeable Ca^{2+} also influences the structural stability of a soil (Bennett et al., 2014) as it increases aggregation. However, since increases in aggregate stability of pig manure amended soils were observed despite decrease in exchangeable Ca^{2+}, our study suggests that the increase in aggregate stability is more associated with increases in soil organic carbon than exchangeable Ca^{2+}.

Our results also suggest that perennial crops, through their extensive root system are able to decrease soil bulk density and increase saturated hydraulic conductivity. The soils on perennial plots also had greater available N and P because of a greater quantity of manure added to this plots to meet the N requirement of the grasses. This suggests that N-based manure application on perennial plots may also lead to over application of P over time.

The variation in manure incorporation for the different cropping could have had an effect on some of the properties and could be the reason for manure by cropping system interaction observed for some properties such as available water, water retention properties and total nitrogen. The conversion of perennial plots to annual plots in 2013 could also have resulted in this interaction as the conversion might have resulted in some soil carbon been lost due to the conversion to annual plots (Fraser and Amiro, 2013).

4.1 Conclusions and recommendations

This study provides some information on the effect of SPM on soil physical and chemical properties and suggests that SPM is a better organic amendment when compared to LPM in improving surface soil physical and chemical properties of prairie soils. We recommend that care should be taken in the application of solid pig manure to soils annually as it could lead to the over application of P and increase in soil salinity over time. Also, this study suggests the use of perennial cropping system to increase soil available and total phosphorus, soil available nitrogen, increase saturated hydraulic conductivity and reduce bulk density. With time, an increase in aggregate stability and some other soil physical and chemical properties is also speculated. Since the application of SPM on perennial grasses could lead to over application, we recommend careful planning for manure application over time or supplementing the nitrogen requirement of the plant through inorganic fertilizers. Further studies should also be done to observe the effect of LPM and perennial cropping system on soil physical and chemical properties over time. Also, monitoring the effect of LPM and SPM on exchangeable Ca is also recommended.

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