IMPACT OF LONG-TERM MANURE APPLICATION ON SOIL MACRONUTRIENT LEVELS IN SOUTHERN ALBERTA

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For my Mom and Dad
Thanks for everything

Abstract

The role of manure applications on soil nutrient dynamics in years after manure applications cease has not been extensively studied. An investigation of two long-term manure trials in the Battersea Drain watershed in southern Alberta was undertaken in 2004 to determine changes in soil nutrient status three years after the initial study was completed. The investigation of the nutrient status of an intensive livestock operation was another component of the study. There was a significant decrease in levels of soil nitrogen, phosphorus and potassium in the plots that received manure application rates over 60 Mg ha^{-1}. The nutrient status of the farm showed a net export of nitrogen and an accumulation of phosphorus and potassium in the soil. Recommendations for alternate methods for handling manure were presented.

I have no special talent. I am only passionately curious.

Albert Einstein

Table of Contents

Table of Figures

Table of Tables

Chapter 1 - Introduction

1.0 Canadian Soil Quality and Manure Handling Practices

One consistent theme for all agriculturally based human civilizations has been the degradation of the soil resource and a modification of the natural environment. For example, parts of Greece, Lebanon and Syria that were once agriculturally productive are now barren due to poor management of the soil resource over hundreds of years (Brady and Weil 2008; Gardiner and Miller 2004). North America is no exception, as the prairie soils in Western Canada and the American Midwest have been drastically altered since European settlement began (Aswathanarayana 1999; Gardiner and Miller 2004). The settlers farmed using the same techniques as they had in Europe, which were not suited to the drier climate of these regions. During the drought periods of the early 20th century, erosion of ploughed soils produced violent dust storms and resulted in the loss of approximately half of the original topsoil in the American midwest (Gardiner and Miller 2004).

Although farming practices have improved since the 1930s, the demand for food production to feed the world's population has contributed to other forms of soil and environmental degradation since the 1960s (Brady and Weil 2008; Gardiner and Miller 2004; Schjønning *et al.* 2004). Increased demands for food and stagnant commodity prices have forced producers to specialize and increase the size of their operations to achieve economies of scale. The small mixed farming operations that characterized early settlement in North America have given way to larger operations dedicated to intensive livestock and crop production operations.

The 2001 Canadian census counted 11% fewer farms in Canada than in 1996, the most rapid decline in numbers of farms between censuses since 1971(Beaulieu 2003). Although the number of farms has decreased over the past 30 years, the number of cattle per farm rose nearly 20% between 1991 and 2001 from an average of 89 head in 1991 to 127 head in 2001 (Beulieu 2003). This increase was mostly due to beef expansion during that time period, a change of production system to take a less valuable commodity and turn it into the higher value product. In Alberta, cattle numbers increased by 51% between 1986 and 1996, from 3.75 million to 5.67 million (Larney *et al.* 2000). This increase in cattle production was not evenly distributed across the province, but rather represented an intensification of the cattle production system. The increase in cattle numbers resulted from a change from small herds, cow-calf operations to feeder cattle in a more industrial cattle production system (Beaulieu 2003).

The result of the decline in farm numbers and intensification of cattle production has been a concentration of these larger livestock operations in certain regions, which in turn has created a problem of much greater manure production in smaller geographic areas (Beaulieu 2001). The increasing number of confined feeding operations in North America has resulted in increased animal manure production on a relatively small land base (Hart *et al.* 1997; Taylor and Rickerl 1998). Confined livestock operations have increased in Alberta for the past 20 years, with an average of 4800 cattle per feedlot, with a total capacity of approximately 1.2 million animals province-wide (Whalen and Chang 2001). In the past, small operations had sufficient land base on which to spread this waste without much potential for a buildup of macronutrients in excess of plant use (Chang *et al.* 1994; Larney *et al.* 2000).

These macronutrients include nitrogen, phosphorus and potassium, and when the concentration of nitrogen and phosphorus become excessive in the soil, there is a risk of contamination of ground and surface water (Chang *et al.* 1994; Rodvang *et al.* 2002). Excessive levels of potassium can contribute to soil salinity, and when found in high levels of feed, can cause metabolic problems in cattle (Hao and Chang 2003).

Long-term application of manure has been the focus of many studies not only in Alberta, but in many parts of the world. Although the role of manure application in soil nutrient dynamics has been investigated, few studies have investigated the impact of long-term manure application on macronutrient pools. There is a gap in information available on the changes that occur in these pools once application of manure stops. The assumption is that soil nutrient levels decrease, but there is little information available regarding the rate of decrease. Bridging this gap in knowledge is becoming increasingly important with intensification of livestock production in the world.

1.1 Background

Most industrialized countries of the world have been struggling with management of animal waste products for a number of years. The countries of northern Europe were among the first of industrialized nations to study the environmental impacts of waste management, and to enact laws to protect the environment (Wossink and Benson 1999). The Netherlands had one of the highest animal densities in Europe that, combined with sandy soils, lead to pollution impacts seen as early as the 1960s but were not addressed until 1984 (Wossink and Benson 1999). Belgium, Denmark, parts of France, Germany and Italy also experienced a rapid growth of animal densities beginning in the 1960s and began implementing operating rules surrounding these operations in the 1990s (Wossink and Benson 1999; Mulier *et al.* 2003; Provolo 2005).

The European Union and the 15 member nations implemented nitrate policies in the 1970s, laws restricting pig and poultry farms in the 1980s, reduction of nutrient application rates in the 1990s and balancing production and utilization of P and N by 2000 (Wossink and Benson 1999). Countries such as Italy enacted a regional act in the Lombardy region to enforce the nitrate directive in 1993 (Provolo 2004) and Belgium enacted more stringent regulations regarding manure handling in 1996 (Mulier *et al.* 2003).

Intensive livestock operations in concentrated areas have become more common in Japan as well. Intensive agriculture in the area surrounding the Bay of Funka in Japan has contributed to high N levels in the Bay and has resulted in eutrophication in estuaries along the coast (Woli *et al.* 2004). Intensive animal production has been cited as a non-point source water pollutant in Pennsylvania, the Chesapeake Bay watershed and in the Mid- Atlantic region of the U.S. (Lanyon *et al.* 2006). The states of Arkansas, Maryland and Oklahoma have implemented P indices, and Delaware, Florida and Pennsylvania have proposals to do the same

(Kleinman *et al.* 2002). Environmental regulation in Europe has provided a great deal of information for regulators in both the United States and Canada, which have lagged behind in implementing such strategies (Wossink and Benson 1999).

The dynamics of livestock production in Canada has undergone significant changes since the 1970s. The numbers of farms reporting cattle in western provinces have generally dropped since 1976 (Statistics Canada 1998) but the number of cattle per farm has increased (Statistics Canada 2006). There has also been a concentration of these larger livestock operations in certain geographic regions, resulting in higher manure production in localized areas. Larger livestock operations produce large amounts of manure that must be handled, stored and applied to soil (Beaulieu *et al.* 2001). In the past, smaller farms with livestock had sufficient land base on which to spread manure without much potential for buildup of nutrients in excess of plant use (Chang *et al.* 1994; Larney *et al.* 2000). Although the number of livestock per operation has increased, the land base per operation has not increased proportionately. In areas where livestock concentrations are high, transport of manure may be necessary to avoid over application on land near the source (Beaulieu *et al.* 2001). Changing markets and export sales can also impact manure production.

Cattle exports in Canada were approximately $3.9 billion in 2002 prior to the discovery of bovine spongiform encephalopathy (BSE) in a Canadian cow on May 20, 2003 (Statistics Canada 2006). Exports amounted to only $1.9 billion in 2004 and the border to the United States remained closed to Canadian cattle imports until July 18, 2005 when live cattle under the age of 30 months were allowed in. The BSE crisis resulted in Canadian cattlemen feeding record high levels of animals for 26 months and the ban on cattle over the age of 30 months for export to the United States has left producers with large numbers of cull cows with limited market and low prices (Statistics Canada 2006) and as a result, much more manure to contend with. Larger operations with limited land base impacted by the BSE crisis have had to find other ways to manage manure. More manure produced also means increased levels of manure nutrients with the potential to have a negative impact the environment.

In Alberta, the highest concentration of intensive livestock operations is in the County of Lethbridge, in the Picture Butte area, north of Lethbridge. The county covers an area of approximately 3080 km^2 and contains approximately 700,000 feedlot cattle (Olson *et al.* 2003). The manure produced by these animals is applied to surrounding farmland, much of which is irrigated (Olson *et al.* 2003). The volume of manure produced and the limited land base on which it is spread is a concern in this area, as well as in other areas with intensive operations.

1.1.1 Nitrogen Cycle

Soil nitrogen is part of a complex system of gains, losses, transformations and reactions (Gardiner and Miller 2004; Christensen 2004) and is unique among elements essential to plant growth due to the relatively large amount required by most agricultural crops (Stevenson 1982; Brady and Weil 2008). The “N cycle” does not exist in nature because the soil has an N_2 cycle of its own (also known as the internal N_3 cycle) and the N atom moves from one form to another in a completely random way (Stevenson 1982; Tan 2000). The cycle illustrated in Figure 1.1 illustrates the overall sequence of biochemical reactions of N as it passes from one system to another. Microorganisms are responsible for many soil N transformations, and the forms of N in the soil (Stevenson and Cole 1999; Christensen 2004). Biological N transformations are composed of oxidation and reduction reactions. Oxidized compounds include N_2O, NO_2^- and NO_3^-, while reduced compounds include NH_3 and most organic-N compounds (Stevenson and Cole 1999).

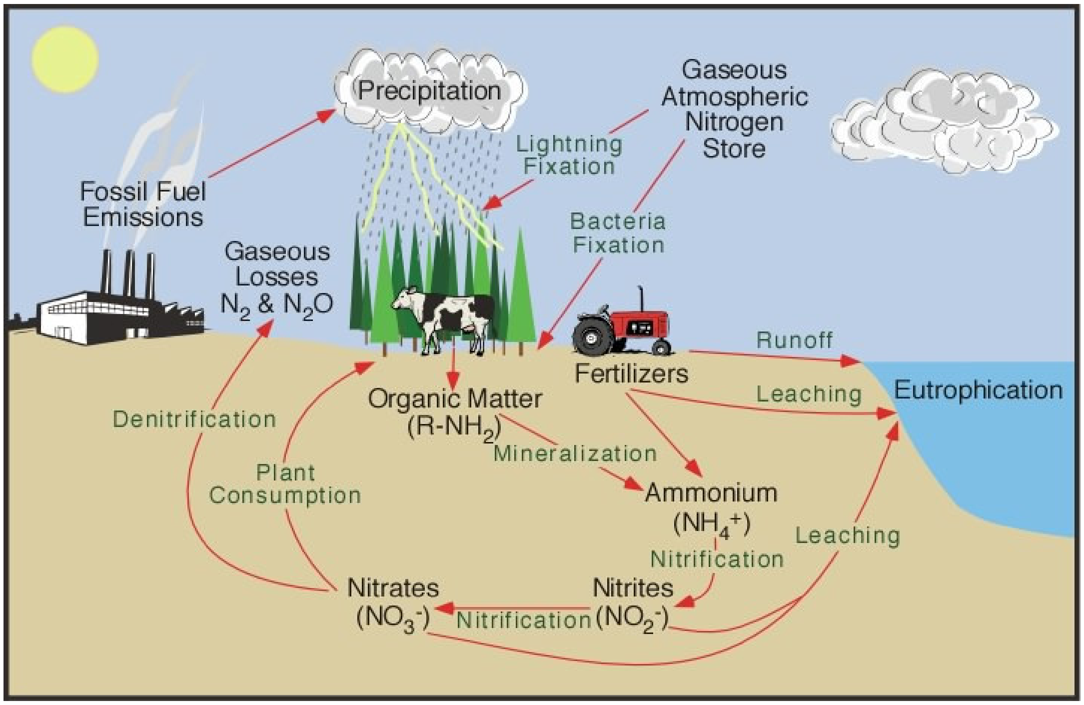

Figure 1.1 Nitrogen cycle (Pidwirny, 2006)

Nitrogen fixation by microorganisms is key to plants obtaining N from the atmosphere by either symbiotic or non-symbiotic methods (Tan 2000). Certain bacteria, actinomycetes and cyanobacteria are capable of converting dinitrogen (N_2)

gas in the atmosphere to forms that are available to all forms of life through the N cycle (Brady and Weil 2008).

Mineralization, the process by which ammonium is released when soil microbes consume humic compounds in the soil to release ammonium ions (Brady and Weil 2008; Christensen 2004) and through nitrification produces nitrates that are available to plants. Mineralization occurs at the same time as immobilization. Immobilization is the conversion by soil microorganisms of inorganic nitrogen ions such as NO_3^- and NH_4^+ to organic forms so that the nutrient is no longer available to plants or other organisms and becomes part of the "internal N_2 cycle" (Brady and Weil 2008; Tan 2000). The N taken up by microorganism is not returned to the soil solution until they die and decay as part of the N cycle (Brady and Weil 2008).

Ammonium and nitrate ions are both soluble in water, but ammonium ions are held to cation exchange sites by adsoption, while nitrates moves downward with percolating waters (Brady and Weil 2008; Gardiner and Miller 2004; Christensen 2004). Losses of nitrogen also occur by volatilization, which is the loss of N in from urea as NH_3, a gaseous N form that occurs under conditions of moist soils and warm temperatures (Brady and Weil 2008). Conditions for volatilization to take place include a soil temperature of above 5ºC, air temperature above 10ºC and high pH soils since it is a chemical not a biological process (Gardiner and Miller 2004).

Denitrification is the biological process by which NO_3 is converted to nitrite (NO_2), which converts to nitrous oxide (N_2O) and nitrogen gas (N_2), which then enters the atmosphere (Brady and Weil 2008; Gardiner and Miller 2004). Facultatative anaerobic bacteria or heterotrophs are often present in high numbers in the soil, and obtain their energy from the oxidation of organic compounds (Brady and Weil 2008). Under saturated soil conditions, these heterotrophs strip the oxygen from the nitrate ions and nitrogen is lost to the atmosphere in gaseous form (Brady and Weil 2008; Gardiner and Miller 2004).

It is estimated that up to 50% of nitrogen in manure is lost through these various processes prior to removal from feedlots, and up to 50% of the remaining nitrogen is lost during removal, transportation and spreading (Eghball and Power 1994; Eghball and Gilley 1999). A study in Saskatchewan indicated that levels of NH_4-N and NO_3-N were higher in soils that were amended with manure than those that were not, but that the available N supply was lower than urea amended soils (Qian and Schoenau 2000).

1.1.2 Phosphorus Cycle

The cycle can be divided into three general parts; slow inorganic P, rapid cycling inorganic P (Pi) and organic P (Po) and slow organic (Figure 1.2). The slow inorganic portion includes both primary and secondary Pi minerals, which break down slowly and move to the rapid cycling Pi and Po portion of the cycle. Schoenau *et al.* (1989) found that labile Pi and Po comprised only a small amount of the total P. Immobilization and mineralization reactions maximize the occurrence of inorganic P in the labile secondary forms and are therefore most effective in the surface soil horizons where roots are most concentrated and the most biological activity takes place (Schoenau *et al.*1989).

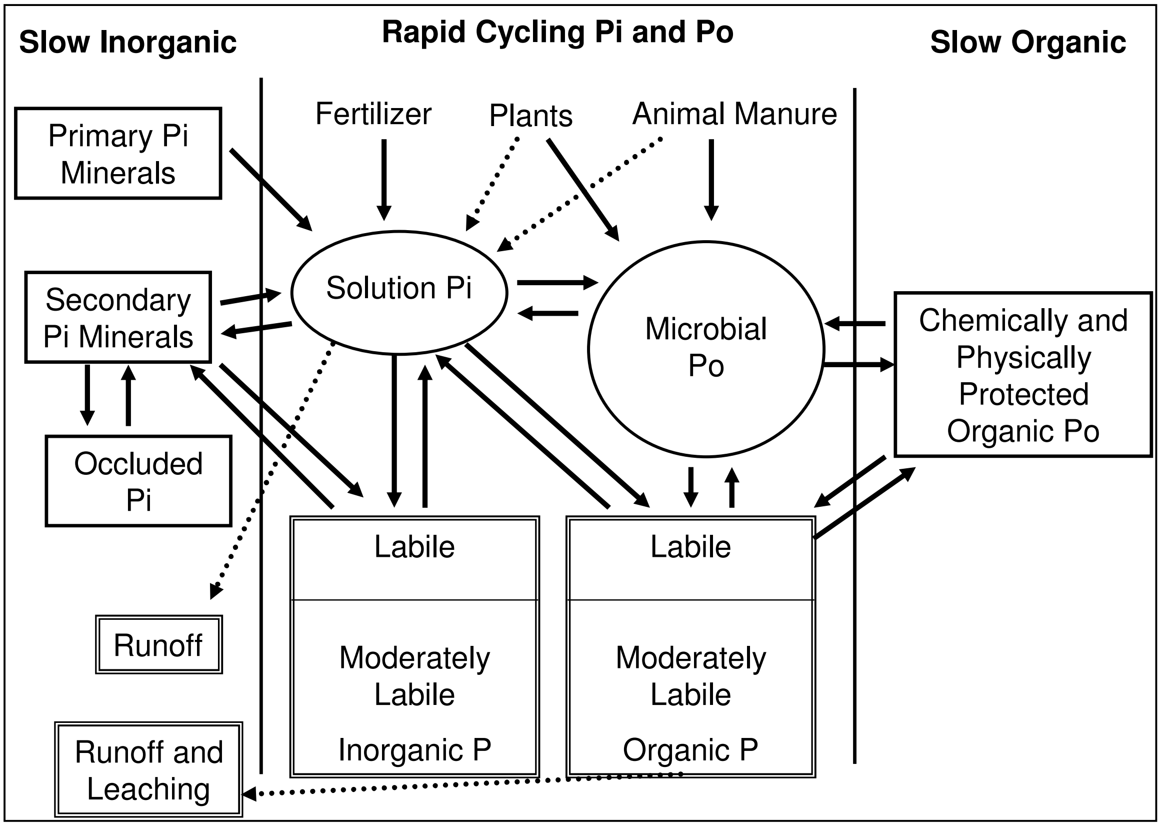

Figure 1.2 Soil phosphorus cycle (Adapted from Stewart and Tiessen, 1987)

The microorganisms in the soil that decompose plant and manure residues tie up some of the P in their bodies, some becomes associated with organic matter in the soil and is available at a much slower rate and some becomes slowly available to the plants (Po). The majority of P in the soil (98 to 99%) is in the stable forms, primary or secondary minerals and soil organic matter. Only 1 to 2% is in microbial tissue (labile or moderately labile Pi and Po) with only about 0.01% as soluble P (Brady and Weil 2008; Tan 2000).

Phosphorus is taken up by plants in the Pi form, the form that rarely exceeds 10 μM in soil solutions (Schachtman *et al.* 1998). The plant roots are able to uptake

Pi close to the roots and create a gradient so that Pi moves via diffusion towards the root. The forms of Pi in the soil depend on the pH of the soil, and the highest uptake for most plants occurs between pH 5.0 and 6.0 (Schachtman *et al.* 1998; Tan 2000).

Phosphorus applied in manure quickly converts to less available forms and only becomes plant available in later years (Brady and Weil 2008). Phosphorus accumulation that occurs from repeated applications of cattle feedlot manure can lead to an increased risk of soil P loss via erosion, leaching and runoff into water bodies (Whalen and Chang 2001). Phosphorus is not generally lost from the soil through leaching, since in the soluble inorganic form it is strongly adsorbed to the mineral surfaces in the soil (Brady and Weil 2008). Dormaar and Chang (1995) found that the amount of manure applied in their study and by feedlot operators can change the soil P pool to the point that 1995 laboratory methods were not be able to accurately estimate soil P pools. There have been developments in methods to estimate P since 1995. Myers *et al.* (2005) used ion-sink methods to adsorb P ions from the in situ labile P pool in the soil to more accurately estimate plant available P.

1.1.3 Potassium Cycle

Potassium is the cation required in the largest amount by plants (Askegaard *et al.* 2004) but it does not actually become part of the organic compound but acts as an activator for cellular enzymes (Brady and Weil 2008; Askegaard *et al.* 2004). Potassium is essential in controlling osmotic water potentials, for photosynthesis, protein synthesis, nitrogen fixation in legumes, starch formation and transport of sugars (Brady and Weil 2008; Gardiner and Miller 2004; Askegaard *et al.* 2004). It can be taken up in amounts beyond what is necessary for plant growth and function, known as luxurious consumption, and may reduce magnesium (Mg) adsorption in the plant (Gardiner and Miller 2004).

The main source of K in soils is primary minerals such as micas and feldspars, which weather, allowing K to be more plant available (Askegaard *et al.* 2004). The movement from primary minerals to clay minerals (exchangeable K) and to non-exchangeable or fixed K is illustrated in Figure 1.3.

Potassium in soils exists in four forms that differ in their availability to crops. Potassium in soil solution that is immediately available for plants; exchangeable K that is held on exchange sites on clay and organic matter and exchanges readily with other cations and is readily available to plants; slowly exchangeable K held in 2:1 clay minerals, is not readily accessible for exchange and is not readily available to plants (also known as fixed K); and lattice K that is in unweathered mica or K feldpar and is not available during a typical growing season (Askegaard *et al.* 2004). Potassium moves back and forth from the non-exchangeable to exchangeable forms and some K moves to the soil solution, becoming plant available but also subject to leaching (Brady and Weil 2008; Gardiner and Miller 2004; Askegaard *et al.* 2004).

The majority of K in the soil is not available to plants and K in manure applied to the soil enters the soil solution K and much of it is quickly adsorbed. The K can reenter the soil solution K by desorption or it may become part of the less available K pool. Potassium excreted in manure and applied to the soil is acted upon by soil organisms and becomes part of the soil solution K, from there is adsorbed to the soil as exchangeable K and some becomes part of the non-exchangeable or fixed portion.

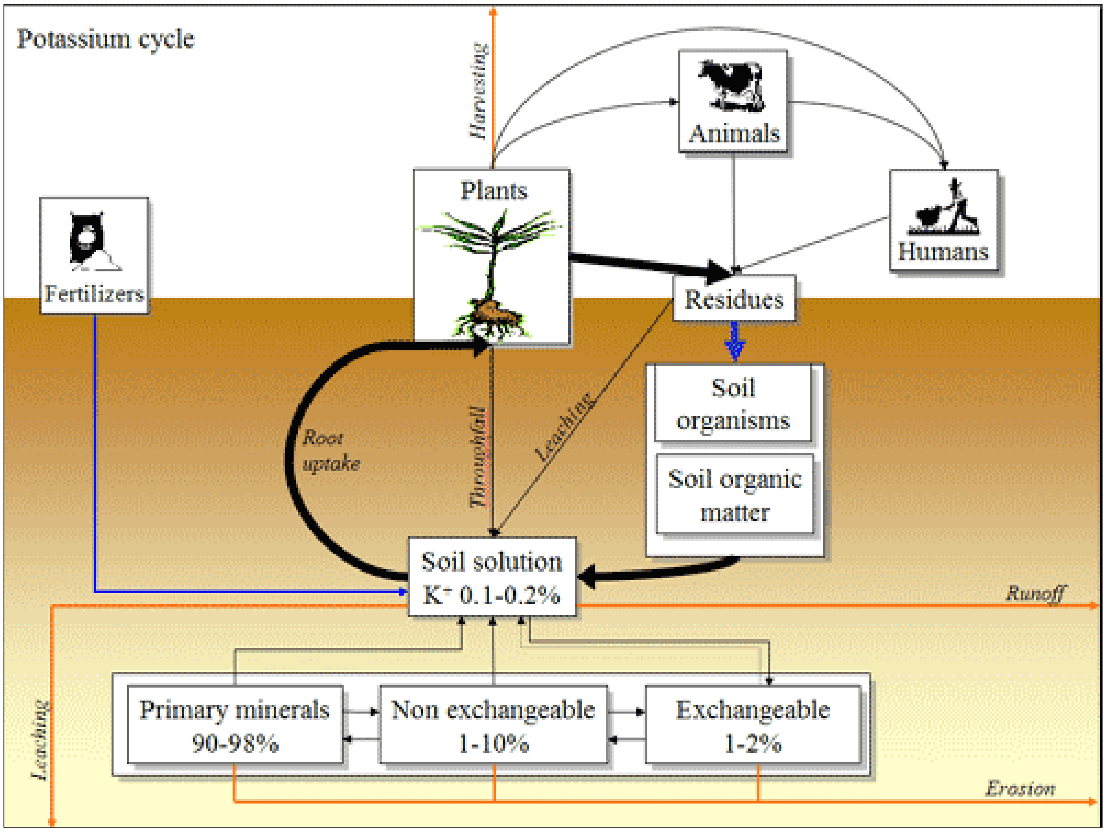

Figure 1.3 Potassium cycle (UBC SoilWeb, 2010) where the blue lines are inputs and orange lines are losses.

The cycle is very dynamic and K is released from the fixed portion to the exchangeable K pool and is desorbed as plants utilize soil solution K (Brady and Weil 2008; Tisdale *et al.* 1985).

Potassium in western Canadian soils is generally high in native soils, due to geologic parent material, as compared to more acidic tropical or eastern soils (Tisdale *et al.* 1985). Potassium in groundwater can be an indicator or seepage of manure, since it is found at levels below 15 mg L^{-1} in native ground waters (Maulé and Fonstad 2000) and were found at concentrations of 6 to 38 mg L^{-1} within 3 to 8 meters under a feedlot. In livestock manure, K is found at rates higher than N or P (Lupwayi *et al.* 2000; Ontario Cattleman's Association 2005) and mostly excreted in urine (Shepherd *et al.* 2002).

Soil salinity may increase as a result of high levels of manure application, causing high levels of K in the soil that may interfere with crop uptake of other nutrients (Hao and Chang 2003). Potassium and sodium also can affect hydraulic conductivity and permeability of soil (Hao and Chang 2003). Potassium is less mobile in soil, tends to remain in the surface soil, and is only effectively tied up by the cation exchange of clay minerals (Hao and Chang 2003).

1.2 Summary

Agriculture has changed and new challenges have been created. Intensive livestock production and the associated environmental impacts of large amounts of manure in a small area mean the risk for damage to the environment has increased. The experiences in Europe have shown that a proactive approach to manage livestock manure is essential to preventing damage from occurring.

1.3 Study Objectives

The Battersea Watershed located in the Lethbridge Northern Irrigation District (LNID) was identified by the Battersea Drain Working Group as an area of concern for manure nutrient management issues. This area has one of the highest concentrations of intensive livestock operations in Alberta. The amount of manure produced by these operations has lead to environmental issues related to land application of manure on a limited land base.

The first component of this research was a study of two long-term manure trials within the Battersea watershed (Olson *et al.* 2003). The two trials were operated from 1993 to 2001 and were decommissioned in 2001. This component was conducted to determine changes in soil nutrient levels three years after the initial long-term study terminated.

The second component of this research involved the investigation of an intensive livestock operation, including both dairy and confined cattle feeding components, within the Battersea Drain Watershed. The purpose was to determine the status of soil nutrients after repeated manure applications and to recommend future manure management options.

Chapter 2 - Literature Review

2.0 Introduction

Animal manure has been recognized and used as a plant nutrient source in Japan, China and Korea for 4000 years (Dormaar *et al.* 1988). It is a natural source of N and P and other nutrients and the organic material in manure is beneficial to both soils and plants (Dormaar *et al.* 1988; Gilley and Eghball 1998; Whalen and Chang 2002). The mechanization of agriculture and the introduction of cheaper petrochemical-based commercial fertilizers after World War II resulted in the transformation of manure from a resource into a waste product (Huang and Uri 1999; Keeny and Nelson 1982; Miner *et al.* 2000; Paoletti *et al.* 1993).

Another major change since the end of World War II has been an increase in demand for affordable protein-rich foods such as meat, dairy and eggs, which has driven the change from small family farms to confined operations (Miner *et al.* 2000). In order to meet demand, the supplies of these products had to increase. According to the FAO, global meat production almost doubled between 1980 and 2004, mostly in developing countries at an annual rate of more than 5 percent (FAO 2005). Confined livestock operations have increased in number in Alberta for the past 20 years, to an average of 4800 cattle per feedlot, with a total capacity of approximately 1.2 million animals province-wide (Whalen and Chang 2001).

Changes in cattle distribution as well as intensification of livestock operations are key issues that are logically linked to manure management. Confined feeding operations exist in most developed nations (Miner *et al.* 2000; Provolo 2004; Woli *et al.* 2004; Wossink and Benson 1999) and tend to be geographically separated from feed production (Lanyon *et al.* 2006). Manure production and handling are a major component of confined livestock operations, and the tendency for these operations to spatially congregate has resulted in a concentration of manure in these areas (Olson and Paterson 2005). High concentrations of manure on a limited land base can result in environmental degradation of surface and ground water (Kleinman *et al.* 2002; Woli *et al.* 2004). These changes require reconsidering manure as an important part of livestock operations, and utilizing it as a resource rather than a waste product.

The environmental impacts of soil nutrient loading from excessive manure application have been studied extensively in Europe, the United States and Japan (Wossink and Benson 1999; Kleinman *et al.* 2002; Provolo 2004; Woli *et al.* 2004). The studies concluded that intensive livestock operations were contributing significantly to environmental pollution and degradation problems in these countries. The significance of these studies has been the implementation of best management practices by the livestock industry.

2.1 Manure Research

Studies conducted on manure may focus on nutrient content and plant availability (Hart *et al*. 1997), but have been increasingly focused on potential hazards when applied in large quantities (Taylor and Rickerl 1998; Woli *et al.* 2004; Provolo 2004; Kleinman *et al*. 2002). High levels of nitrates in ground water and phosphorus loading of surface water are the two most common areas of research, and have lead to the implementation of limits in some industrialized countries (Strebel *et al.* 1989).

Western Europe was one of the first places in the world to create limits for manure application on agricultural land (Wossink and Benson 1999; Wossink and Gardebroek 2006). Policies controlling nitrates in groundwater were introduced in the 1970s by the European Union (EU). Establishment of water monitoring programs, creation of a code of good agricultural practices and a national action plan were required by all member states starting in the 1990s (Wossink and Benson 1999).

In response to local problems with nitrate loading, Italy implemented their own nitrate directive prior to the EU directive (Provolo 2004) while the Netherlands postponed implementation due to lobby pressure by farmers' groups in the 1980s (Wossink and Benson 1999). A three phase plan was proposed in the Netherlands to address some of the concerns expressed by the lobby (Wossink and Benson 1999). The first phase attached a manure production right or quota to each farm according to its livestock population and acreage and did not allow farms with insufficient acreage to increase livestock numbers. Increasing livestock densities on lands in the Eastern part of The Netherlands and in north-western Germany resulted in N production by livestock of more than 250 kg N ha year (Strebel *et al.* 1989). Farms on sandy soils were prohibited from applying manure between September 1 and February 1, when crops were not being grown, to prevent nitrates from moving down the soil profile into groundwater. A National Manure Bank was created with the intent to redistributed manure from high livestock density areas to arable farmland (Wossink and Benson 1999).

The second phase was designed to gradually reduce nutrient application rates, prepare farmers for the third phase and address ammonia emissions. The aim of the third phase was to balance production and utilization of P an N by 2000 (Wossink and Benson 1999). The aim of this three phase plan was to gradually reduce manure application rates to alleviate pollution concerns.

While the EU was dealing with nitrate problems, Japan, with a more limited land base, was already facing agriculture intensification problems related to manure application in the 1990s. In a recent study, Woli *et al* (2004) discovered a decrease in water quality in rivers that flowed near livestock and dairy operations in Japan. This study showed that agricultural production practices in Japan had created high N surpluses due to the increased use of chemical fertilizer and application of manure to farmland.

In North America, the advent of the industrial livestock operation in the 1970s has also lead to problems, but the identification of these manure related issues was more slow to reach stages that require legislation because of a lack of political will and an abundance of land in North America. Despite having access to land, the costs associated with transporting manure lead to similar problems of manure concentrations near the operations. By the late 1990s, problems were beginning to arise and phosphorus indices were implemented in Arkansas, Maryland and Oklahoma and are proposed in Delaware, Florida and Pennsylvania (Kleinman *et al.* 2002). Areas of Pennsylvania, the Chesapeake Bay area and the

Mid-Atlantic region of the United States are affected by agricultural non-point source water pollution (Lanyon *et al.* 2006). Reduction of P surpluses on cropland that contribute to this form of pollution has been the focus of study in this region. One study concluded that potential P inputs have exceeded crop P removal each year from 1939 to 2002 (Lanyon *et al.* 2006).

The intensification of livestock production in Canada is a relatively recent development, with the first feedlot operations of significant size and densities showing up in the 1980s. The issues surrounding this agricultural production mechanism have begun to show up in areas of Canada that have adopted this method of beef production just like they have elsewhere in the world. To date, there has been some research done in southern Alberta on the impacts of livestock manure on agricultural land. Howard (2003) reviewed over 200 references from literature pertaining to soil P in Alberta as a part of a study to identify limits for soil P limits of agricultural land in Alberta. Olson and Paterson (2005) presented the implications of moving to a P-based system for manure application in Alberta, concluding that a larger land base would be necessary if manure applications were based on P rather than N. Rodvang *et al.* (2002) examined livestock manure applications as they related to groundwater quality, and concluded that fine- and coarse-textured soils were vulnerable to agricultural contamination in the Lethbridge Northern Irrigation District in Alberta.

There have been a number of studies conducted in conjunction with Agriculture and Agri-Food Canada that focused on application of excess feedlot manure on soil quality over a number of years. Chang *et al.* (1990) investigated the effects of four different rates of annual manure applications on pH, electrical conductivity (EC) and accumulation of mineral ions to 150 cm in Chernozemic Dark Brown soil with a clay texture. The study was initiated in 1973 and concluded that the change in soil parameters being measured varied with manure application rates, but remained constant within the irrigation regime regardless of levels of manure applied.

Chang and Entz (1996) examined the same plots used for the study by Chang *et al.* (1990) but investigated the accumulation, distribution, movement and potential for pollution of soil and water of mineral N in the soil. Chang and Entz (1996) concluded that NO_3-N moved down in the soil profile with time. Some NO_3-N moved below 150 cm in high precipitation years and could be a potential groundwater pollution problem in years with high precipitation.

Whalen and Chang (2001) investigated P balance on irrigated and non-irrigated soils after 16 annual manure applications. They found that P accumulations in cropped soils have occurred where manure was applied based on N requirements of crops. Manure application rates of 30 Mg ha^{-1} and 60 Mg ha^{-1} led to five to six times more P than recommended for barley, and manure rates over 60 Mg ha^{-1} led to a risk of ground water contamination from P in irrigated plots (Whalen and Chang, 2001).

Olson *et al.* (2003) conducted a comprehensive 8 year study on the effects of manure application rates on soil quality, shallow groundwater quality and crop production on two soil types under irrigated conditions and sought to make recommendations for managing manure application rates based on the results found. The study began in 1993 and focused on the impacts of manure and fertilizer applications on nitrate leaching to shallow groundwater under irrigated conditions (Olson *et al.* 2003). Soils were analyzed for NO_3-N, orthophosphate-P, total N, total P, sodium (Na), K, magnesium (Mg), chloride (Cl), bicarbonate (HCO_2), sodium adsorption ratio (SAR), and electrical conductivity (EC). The results showed manure applications significantly increased all but the calcium, sulphate-S and pH levels in the soil, which were not affected by manure application. The Olson *et al.* (2003) research sites were the basis for the current study examining the impacts of three years without manure application on N, P, K, pH and EC values in the coarse and medium textured sites.

2.2 Cattle Diet and Nutrient Loss in Feces

The nutrients in manure are the result of excess amounts consumed by livestock animals and excreted through urine and feces (Powers and Van Horn 2001). Animal nutritional intake varies, and accounts for variation in excreted nutrient levels of manure (Powers and Van Horn 2001).

Cattle require a variety of inorganic minerals for growth and reproduction (National Research Council 2001). These include both macronutrients, which are important for bone structure, tissues and body fluids, and micronutrients, which serve as components of enzymes in the body (National Research Council 2001). Macronutrients, required in grams, include calcium (Ca), phosphorus (P), sodium (Na), chlorine (Cl), potassium(K), magnesium (Mg) and sulfur (S). Micronutrients include cobalt (Co), copper (Cu), iodine (I), manganese (Mn), molybdenum (Mo), selenium (Se) and zinc (Zn).

Nitrogen, as part of protein, is required by dairy animals for maintenance, pregnancy, growth and lactation (Klopfenstien *et al.* 2002). Microorganisms within the digestive system of cattle also require N for microbial growth during ruminal fermentation of feed (Klopfenstien *et al.* 2002). Excess N from protein is primarily excreted as urea in urine, and a portion of this N is volatilized due to urease activity in feces (Klopfenstien *et al.* 2002). Manure N is composed of urea ($CO(NH_2)_2$), which is organic N, and is easily broken down to ammonium-nitrogen (NH_4-N) and more resistant fractions that are mineralized much more slowly (Beauchamp 1986). A study in Nebraska found that N excretion in manure was similar to N intake because the N requirements of the animal were not changed by diet and approximately 90% of the N fed was excreted (Erickson and Klopfenstein 2001).

Of all the macronutrients required by cattle, P is the one with the greatest potential risk to the environment (National Research Council 2001). Phosphorus has the most known biological functions of any other mineral element and is mainly used in development of bones and teeth, and is located in every cell in the body (National Research Council 2001; Klopfenstien *et al.* 2002). Ruminal microorganisms use phosphorus in order to digest cellulose (National Research Council 2001).

Cereal grains and oilseed meal contain P in the form of phytic acid (Klopfenstien *et al.* 2002). Swine and poultry have insufficient intestinal phytase, and much of the P present in feed is excreted in feces. The amount of P excreted is proportional to what was fed. The addition of phytase to diets can increase phytate P availability to the animal, and thus decrease the amount of inorganic P required in feed (Klopfenstien *et al.* 2002).

In mature lactating cows, P intake is divided between milk, urine and feces, with the majority (60-70%) of excess P ending up in feces (Dou *et al.* 2002).). Phosphorus requirements are highest during the last trimester of pregnancy (National Research Council 2001). The percent of total phosphorus in feces is 95 to 98 percent of what was fed to the animal, and as intake increases in cattle diet, efficiency of absorption decreases (National Research Council 2001).

Typical dairy diets contain 0.4 to 0.5 % P on a dry matter basis, which exceeds the suggested requirements set out by the NRC by 20 –25%, and may contribute to P loading of soils where manure is applied (Klopfenstien *et al.* 2002). This practice of overfeeding P is mainly due to the belief that adding P to dairy diets can improve reproductive performance (Klopfenstien *et al.* 2002). However, phosphorus fed to dairy animals in excess of requirements (0.31%) was excreted in feces (Klopfenstien *et al.* 2002).

Potassium requirements for cattle are the highest of all mineral cations required for growth and maintenance (National Research Council 2001). Potassium is excreted mainly in urine and application of manure with high levels of potassium can lead to high potassium content in forages and can cause a variety of metabolic problems in cattle (National Research Council 2001).

2.3 Manure production

Cattle will produce different amounts of manure per day based on age and type of animal. A typical beef cow aged 15 to 24 months produces on average 21 litres per day (21 kg per day) while dairy cows produce on average 45 litres per day (45 kg per day) (Ontario Cattlemen's Association 2005). Table 2.1 illustrates the levels of N, P and ammonium-N (NH_4-N) in cattle manure based on type of animal as compared to other common confined livestock animals.

Table 2.1 Average nutrient content and moisture content of livestock manure (AAFRD, 2000)

Type of livestock	Nitrogen kg/tonne	Phosphorus kg/tonne	Ammonium-N - NH_4-N	Moisture
Beef	10.0	2.4	2.6	50%
Dairy	4.0	0.9	1.8	92%
Hog	3.5	1.1	1.6	96%
Chicken	16.0	12.2	12.3	60%

Nutrients found in livestock manures may not be immediately available to plants. For example, in most cattle feedlot manures, approximately 25% of organic N, 100% of NH_4-N (minus gaseous losses) and 50% of total P are available for crop uptake during the first year after application (AAFRD 2000). The residual nutrients become plant available slowly over the following three or four years (AAFRD 2000).

Table 2.2 shows the percentages of manure, N and P produced by various types of livestock. Beef cattle account for half of the manure produced from all livestock in Canada (Statistics Canada 2003).

Table 2.2 Livestock type compared to manure production, nitrogen and phosphorus content of manure (Statistics Canada 2003)

Livestock Type	*Manure Produced (% of Total)*	*Nitrogen Content (% of Total)*	*Phosphorus Content (% of Total)*
Beef cattle	52	51	51
Dairy cows	19	16	13
Hogs	16	16	21
Poultry	7	7	8
Calves	3	5	5
Horses	3	3	2
Sheep	<1	<1	<1
TOTAL PRODUCTION (millions of kg per year)	131 765	783	214

2.4 Manure Impacts from Confined Operations

The increasing number of confined feeding operations in North America has resulted in increased animal manure production on a relatively small land base (Hart *et al.* 1997; Taylor and Rickerl 1998). Manure produced in confined feeding operations is generally applied on land close to the feedlot operation (Whalen and Chang 2001), which is also considered the most economical and therefore the best way for feedlots to dispose of manure and return nutrients to the plant cycle (Dormaar and Chang 1995).

The long-term trend in the Canadian livestock industry is a decrease in the number of livestock farms and an increase in average farm size. The manure from feedlots represents a large nutrient resource (Eghball and Power 1994; Chang *et al.* 1994; Eghball and Gilley 1999; Maulé and Fonstad 2000). Cattle manure has traditionally been applied to the land based on N content and is used as a crop nutrient (Dormaar and Chang 1995). Over application of nutrients can lead to pollution of water and soil and can also affect crop production (Chang *et al.* 1994).

Studies conducted in Alberta by Freeze and Sommerfeldt (1985) determined that manure could be economically substituted for commercial fertilizer at hauling distances of up to approximately 15 km from the production site due to weight and high transportation costs. This was based on nitrogen and phosphate costs, 1983 price data, labour costs and farm size. Larger farm-feedlot operations would consider some different costs, such as machinery and labour costs, than smaller operations and could economically haul manure up to 13 km (Freeze and Sommerfeldt 1985). There is little doubt that the economical distance may be even less in 2010 due to the relatively higher cost of fuel and other costs associated with hauling manure.

Manure is often applied to meet crop requirements for N and over many years of continuous over-application of manure, beyond agronomic thresholds, can result in plant available soil P, nitrate-N (NO_3-N), and soil K exceeding crop needs (Hart *et al.* 1997). The agronomic threshold is an agronomic threshold of soil P is defined as "*the soil nutrient level, as determined by soil test analysis, beyond which there is no practical economic or crop yield response to added nutrient from either commercial (inorganic) fertilizer or organic fertilizer sources*" (AAFRD 2003). When nutrients such as P reach levels in excess of the soils storage capacity, erosion of the element rise to high levels, export from the soil can occur with potentially serious environmental problems such as eutrophication, algal blooms and oxygen depletion in surface waters (Taylor and Rickerl 1998). Leaching of NO_3-N, for example, can cause groundwater contamination, while excess salts in manure can also contribute to salinization of cropland (Taylor and Rickerl 1998). Excess macronutrients can also adversely affect crop production, for example, an over abundance of plant available N can cause plants to luxuriously consume (use in excess of plant requirements) N, which often leads to excessive vegetative growth, delayed maturity and lodging of crops (Brady and Weil 2008).

Problems with manure nutrient management tend not to be proactively dealt with but rather tend to be solved after the impact has occurred (Slaton *et al.* 2004). The concept that manure is a natural product and therefore is less harmful than chemical fertilizers may be to blame for this trend. However, forcing producers to make changes by strict enforcement of regulations may not be the answer. Initiatives that focus on information (I), education (E), technical assistance (T), and economic subsidies (S) (IETS programs) have worked better and are preferred by land owner-operators rather than compliance with regulations (Napier and Bridges 2002). The efficacy of this approach is debatable, as one study in Ohio showed that the IETS program did not accomplish their objectives (Napier and Bridges 2002).

When nutrients from manure leaches into the soil or runs off the surface from confined feedlots during rainfall or snowmelt it is considered point-source pollution, as there is a definite source of the pollution. Once it is spread on surrounding fields in excess of crop requirements, it is considered to be non-point source pollutant and therefore relatively difficult to trace and monitor (Taylor and Rickerl 1998). Given the relatively small area around a feedlot where it is economically feasible to transport manure, it is most likely that the soils around these areas are at the greatest risk for potential loss to runoff or leaching of manure-base macronutrients (Hart *et al.* 1997).

As most manure spread on land becomes a non-point source of pollution, it becomes more difficult in some jurisdictions to determine which fields are causing problems, and the focus must be on management practices to reduce pollution potential (Carpenter *et al.* 1998). Composting can reduce the weight and volume of manure, and nitrogen losses can be somewhat controlled during this process (Eghball and Power 1994).

Manure contains significant quantities of monovalent cations such as sodium (Na^+) and K and may contribute to the breakdown of soil aggregates and displace divalent cations such as Ca and magnesium Mg on the soil exchange complex (Whalen and Chang 2002). Whalen and Chang (2002) suggest that this displacement may break down soil aggregates in the 0 to 5 cm depth of soil.

2.4.1 Nitrogen

Nitrogen in the form of nitrate in water poses a risk to human and animal health, causing methemoglobinemia (blue baby syndrome) in human infants and animals (Carpenter *et al.* 1998). Excessive fertilizer use and urban sources are major sources of nitrogen pollution of water (Carpenter *et al.* 1998) and manure. Manure removal from feedlots, and the associated handling of the manure results in an estimated 50% loss of N, primarily by runoff, ammonia volatilization and denitrification (Eghball and Power 1994). From a crop standpoint, an oversupply of N can cause excessive vegetative growth, delayed maturity and lodging of crops (Brady and Weil 2008).

2.4.2. Phosphorus

A variety of factors including soil type, hydrology, topography and farming practices can influence the risk of P transport (Sharpley and Tunney 2000; Whalen and Chang 2001). The risk of P pollution in water is greater in conventionally farmed situations and in coarser textured soils (Kleinman *et al.* 2003; Whalen and Chang 2001) versus minimum tillage and fine textured soils. Weather can also play a major role, as an intense rainfall shortly after manure application can produce runoff of P regardless of soil P levels (Sharpley and Tunney 2000; Whalen and Chang 2001).

When nutrients such as P rise to high levels, export from fields can occur, causing serious environmental problems such as eutrophication, algal blooms and oxygen depletion in surface waters (Taylor and Rickerl 1998). Loss of P may also occur through artificial drainage, which connects macropores below the surface of the soil to surface water (Kleinman *et al.* 2003). Leaching of P in sandy loam soil was linked to elevated P concentrations in subsurface soil that received P applications in the form of manure or mineral fertilizers (Kleinman *et al.* 2003). Inorganic phosphorus (Pi) from manure can be leached even where high calcium carbonate levels exist in the soil profile, and could possibly reach groundwater in areas with shallow ground water (Whalen and Chang 2001).

Inorganic phosphorus (Pi) from manure can be leached even where high calcium carbonate levels exist in the soil profile, and could possibly reach groundwater in areas with shallow ground water (Whalen and Chang 2001). Loss of P may also occur through artificial drainage, which connects macropores below the surface of the soil to surface water (Kleinman *et al.* 2003). Leaching of P in sandy loam soil was linked to elevated P concentrations in subsurface soil that recieved P applications in the form of manure or mineral fertilizers (Kleinman *et al.* 2003).

In Ireland, the Environmental Protection Agency has restricted application of manure to lands that have greater than 15 mg kg^{-1} Morgan's P, which is approximately 60 mg kg^{-1} Olsen P, and requires farmers to develop nutrient-management plans that include all land they spread manure on, regardless of ownership (Sharpley and Tunney 2000). In the United States, certain states have begun looking at changing recommendations for P application rates, and may soon be basing rates more on potential for runoff (Sharpley and Tunney 2000). However, as most manure spread on land becomes a non-point source of pollution, it becomes more difficult in some jurisdictions to determine which fields are causing problems, and the focus must be on management practices to reduce pollution potential (Carpenter *et al.* 1998). The application of a P index that can account for transport may be one answer to determining how manure may be applied in a given area (Sharpley and Tunney 2000).

Manure application guidelines in Alberta are currently based on crop requirements for nitrogen. The ratio of crop available nitrogen to crop available phosphorus in cattle feedlot manure is 4:1 or 5:1, resulting in phosphorus levels in excess of crop requirements (Whalen and Chang 2001). Changing the application guidelines to phosphorus content would likely result in extreme changes in manure handling by producers who may not be able to apply manure for years.

2.4.3 Potassium

Despite such high rates of K returned to the soil from manure, K is seldom regarded as a potential contaminant and there are few studies that investigate the impact of K in manure on the soil or environment (Eigenberg *et al.* 1998). Although excessive K poses little threat to surface or ground waters, it may pose a risk to dairy cattle. Luxurious uptake of K by perennial grasses results in excessive K in dairy cows, and for dry cows this can lead to milk fever, hypocalcemia, downer cow syndrome or possibly death (Hart *et al.* 1997).

In one study of repeated manure applications, electrical conductivity (EC) was shown to increase over time, potentially leading to soil salinization (Chang *et al.* 1990; Taylor and Rickerl 1998). The same study concluded that leaching rates on irrigated land were higher than non-irrigated land, which did not have enough water infiltrating the soil to leach soluble salts out of the soil. Salinity in long-term manured fields is most likely to be caused by K than Na due to its slow movement in soil and high levels in manure (Hao and Chang 2003).

2.5 Plant Uptake of Nutrients

Over-application of nutrients can lead to pollution of water and soil and can also affect crop production (Chang *et al.* 1994). The ratio of crop available N to crop available P in cattle feedlot manure is 4:1 or 5:1, resulting in accumulation of P in excess of crop requirements (Whalen and Chang 2001). Variation exists not only in farming operations, but also the type of soil and the quantity and quality of manure applied.

Years of continuous over-application of manure, beyond agronomic thresholds, can result in NO_3-N, plant available soil P, and soil K exceeding crop needs (Hart *et al.* 1997). One solution is to match crop nutrient requirements to the nutrients present in manure, also known as application at an agronomic rate (Hart *et al.* 1997). This is applying manure at levels equal to crop removal, or applying manure at specific rates in specific areas of the field or farm (Hart *et al.* 1997). Soil testing prior to application is an important step in determination of appropriate application rates, whether manure or commercial fertilizer is used (Hart *et al.* 1997).

2.6 On farm Nutrient Budgets

Various programs have been developed in parts of North America in an attempt to create nutrient budgets, but most are specific to the region in which they are developed (Janzen *et al*, 2002; Hilborn and McKague 2003). A complete nutrient budget includes all inputs and all outputs of a farming system. This can be challenging when considering the size and scope of intensive livestock operations. Operators must increasingly become more accountable for management of their operation and must develop nutrient management plans or budgets to account for manure nutrient production and crop utilization (Powers and Van Horn 2001).

The challenge of creating a workable budget is to determine how much manure will be produced and the level of nutrients that can be utilized or stored in the soil. Matching crop nutrient requirements to the nutrients present in manure, also known as application at an agronomic rate (Hart *et al.* 1997) is a method to achieve such a balance. To develop a nutrient budget, one must know the nutrients excreted in manure, how it is handled and stored, how it is applied and ultimate utilization by crops (Eigenberg *et al.* 1998). This is applying manure at levels equal to crop removal, or applying manure at specific rates in specific areas of the field or farm (Hart *et al.* 1997). Soil testing prior to application is an important step in determination of appropriate application rates, whether manure or commercial fertilizer is used (Hart *et al.* 1997)

Calculating nutrients in manure using the mass-balance approach examines animal diet and performance (Powers and Van Horn 2001). The nutrients in manure are on average equal to the levels of nutrients consumed by livestock animals, minus fractions from hair and tissue lost in feedlots, which become part of the manure (Powers and Van Horn 2001). Animal nutritional intake varies, and accounts for variation in excreted nutrient levels (Powers and Van Horn 2001). A useful nutrient budget must consider all inputs and outputs of the farming operation, which can then be used to determine where losses are occurring and what measures can be taken to achieve a balance of nutrients.

2.7 Economic Impacts

The nutrients found in manure are comparable to those found in commercial fertilizer. The monetary value of the nutrients is considerable. Nitrogen in manure produced in the Great Plains region of the US could provide 100 kg of N for 8.4% of corn production if it could be totally conserved and made available to the crop (Eghball and Power 1994). The monetary value of nutrient in livestock manure in

1994 would have been over $400 Million (US) if purchased as inorganic fertilizer (Eghball and Power 1994) and would definitely be higher based on 2010 fertilizer prices.

Table 2.3 illustrates the value of N and P in several types of livestock manure. This is calculated assuming a price of $0.45 per kilogram for available N, $0.35 per kilogram for P_2O_5 and $0.25 per kilogram for K_2O based on 2006 values. The total value of nutrients in dairy manure would be $2.62 per kg, for beef cattle it would be $6.89 per kg, for hogs $2.47 per kg and chicken $13.52 per kg.

Table 2.3 Value of nutrients in average livestock manure (adapted from Tisdale *et al.* 1985)

Livestock Type	Total N kg tonne^{-1}	P kg tonne^{-1}	K kg tonne^{-1}	Total Value* $ kg
Beef	10	2.4	6.2	6.89
Dairy	4	0.9	2.0	2.62
Swine	3.5	1.1	10.8	2.47
Chicken	16	12.2	8.2	13.52

*Monetary value per kg is: 45 cents for available N, 35 cents for P and 25 cents for K in 2006 values.

2.8 Summary

Intensive livestock operations are becoming larger and more concentrated in certain geographic areas of the country. Herd sizes over 700 head have become more common in Alberta, although cattle densities are still higher in Ontario and Quebec. Alberta produces more than half of the steer and heifer production in the country. This has lead to an increased concentration of manure that must be applied on a limited area near the operation to be economically feasible.

Repeated application of manure has increased levels of nitrogen and phosphorus in the soil and has increased the potential for contamination of surface and ground waters. Manure also contributes salts to the soil, which can lead to salinity problems after repeated application. Excessive levels of nutrients can impact soils, plants, surface and ground waters and potentially can impact health of both human and animal populations.

Manure also has benefits for both the soil and plants, and is a source of organic matter and nutrients. Nutrients essential to plant growth and development can be supplied by applying manure at agronomic rates.

Beef and dairy diets play an important role in determining the nutrients excreted in manure. Management of feedlot operations is vital to preventing potential nutrient loading of the soil and to keep the operation viable. Testing soil prior to manure application and calculating crop nutrient requirements are key components to efficient management. Managing manure resources to achieve a balance of nutrients are important in achieving a sustainable intensive livestock operation.

Chapter 3 - Methods

3.0 Location of Study Areas

The highest concentration of intensive livestock operations in Alberta is located in the County of Lethbridge, near the town of Picture Butte, approximately 30 km north of the City of Lethbridge. Picture Butte is located at an elevation of 890 meters above sea level, at located at latitude 49° 5', longitude 112° 47'. The location of the study sites within the province and relative to Lethbridge are shown in Figures 3.1.

The County of Lethbridge covers an area of approximately 3080 km^2, contains approximately 700,000 feedlot cattle and is mostly irrigated (Olson *et al*. 2003). The three primary study sites are located east of Picture Butte, and are described in Section 3.1.

3.1 Background and Description of Sample Sites

The volume of manure produced by 700 000 feedlot cattle, coupled with a limited land base on which to spread manure, is an increasing concern within the County of Lethbridge. Most of the land east of Picture Butte ranges from Class 2 to 5 (see Figure 3.2), and has limitations related to topography, soil type and climate (Government of Canada, 1970). Irrigation is a common feature in the area, which is in the Lethbridge Northern Irrigation District. Pivot irrigation is the dominant irrigation method, although wheel-move irrigation is still used in fields unsuitable for installing pivots. Runoff from irrigation and rainfall are channeled into the

Battersea Drain, which then drains into the Oldman River east of Nolan Bridge, located on Highway 845 north of Coaldale.

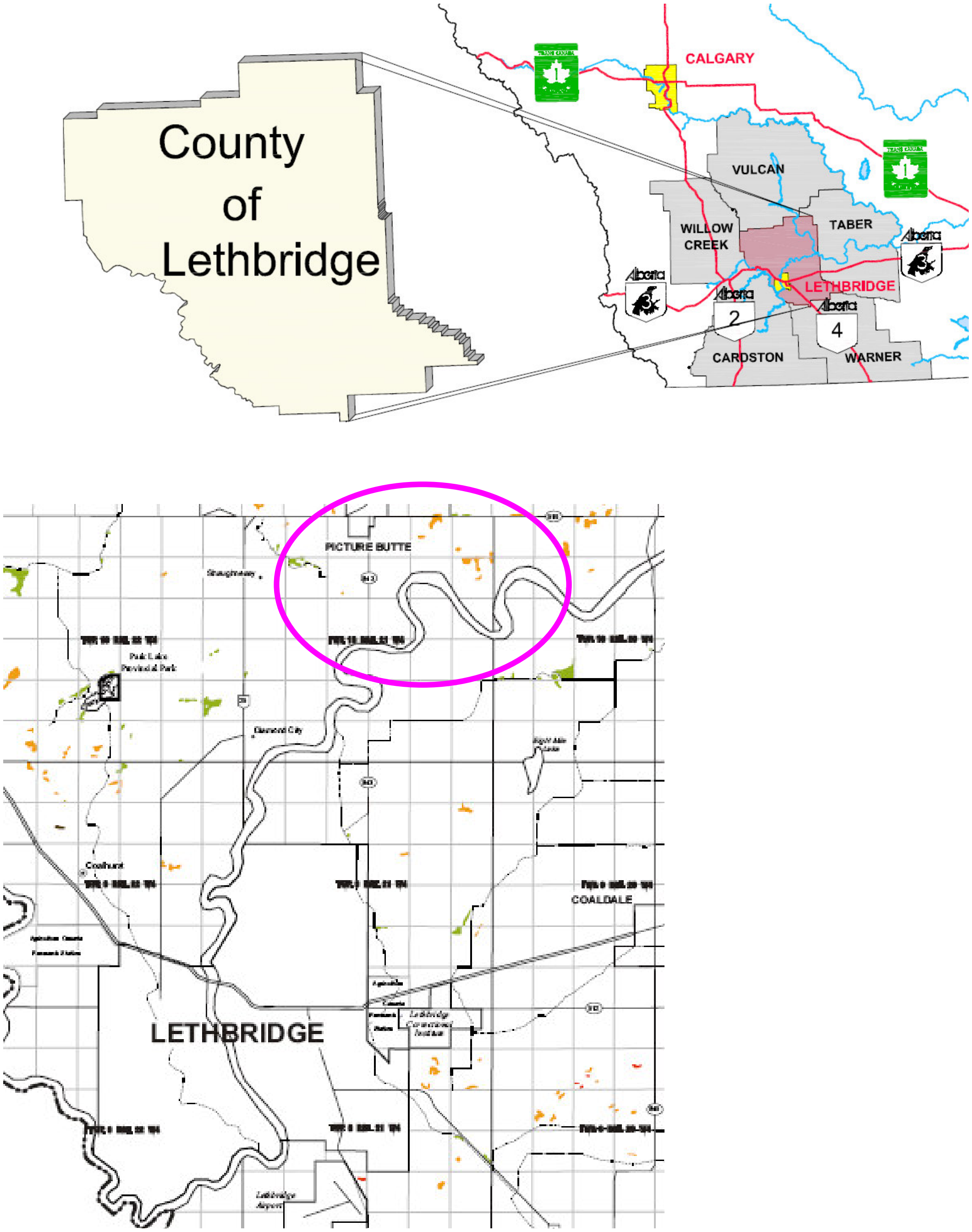

Figure 3.1 Map of Southern Alberta including County names and major cities. The County of Lethbridge contained the study areas (County of Lethbridge 2005). Location of study area relative to the city of Lethbridge – general area of the study quarters are outlined in pink (Adapted from AAFRD 1995).

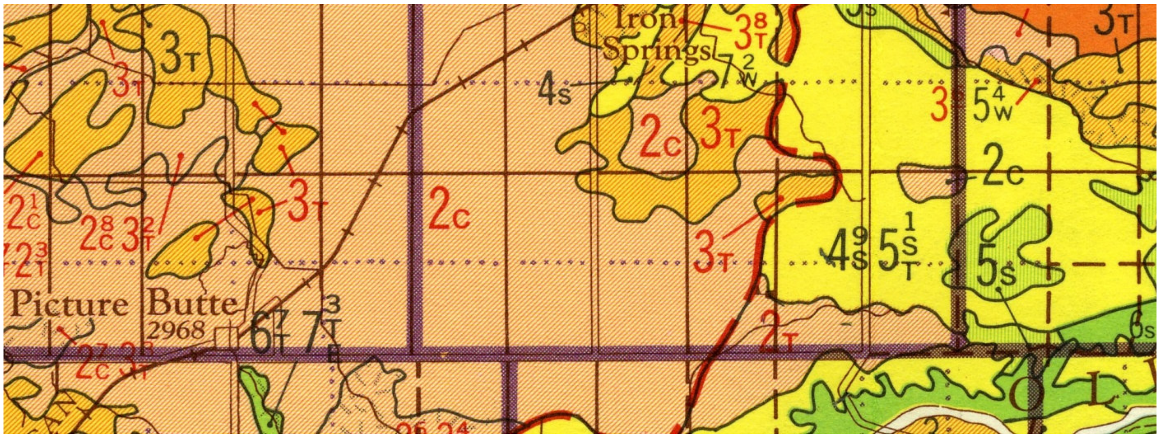

Figure 3.2 Land Classes found in the region of the study, obtained from the Canada Land Inventory Map for Soil Capability for Agriculture, Lethbridge 82H Sheet. (Government of Canada, 1970)

A long-term manure management field study on irrigated land was undertaken in this area by Alberta Agriculture beginning in 1993 and is discussed in Section 2.2 of Chapter 2. Soils were selected for the long-term study based on soil type. They will be referred to as coarse textured and medium textured soils for the purposes of this research. The sites were chosen as the focus of this study because of their long-term nature and management by landowners between 2001 and 2004. This study focused on the impact of repeated manure applications on soil nutrient levels. The coarse textured site is located approximately 11 km east of Picture Butte (Figure 3.3), on the southeast pivot corner of NE 2-11-20 W4. The medium textured soil is located approximately 5 km east-northeast of Picture Butte, along the east side of NE 7-11-20 W4 (Figure 3.3). Corner pins had been installed in both plots by Alberta Agriculture during the long-term study, so that the plots could be located in the future. The original plots were no longer visible and had to be relocated and re-staked prior to sampling.

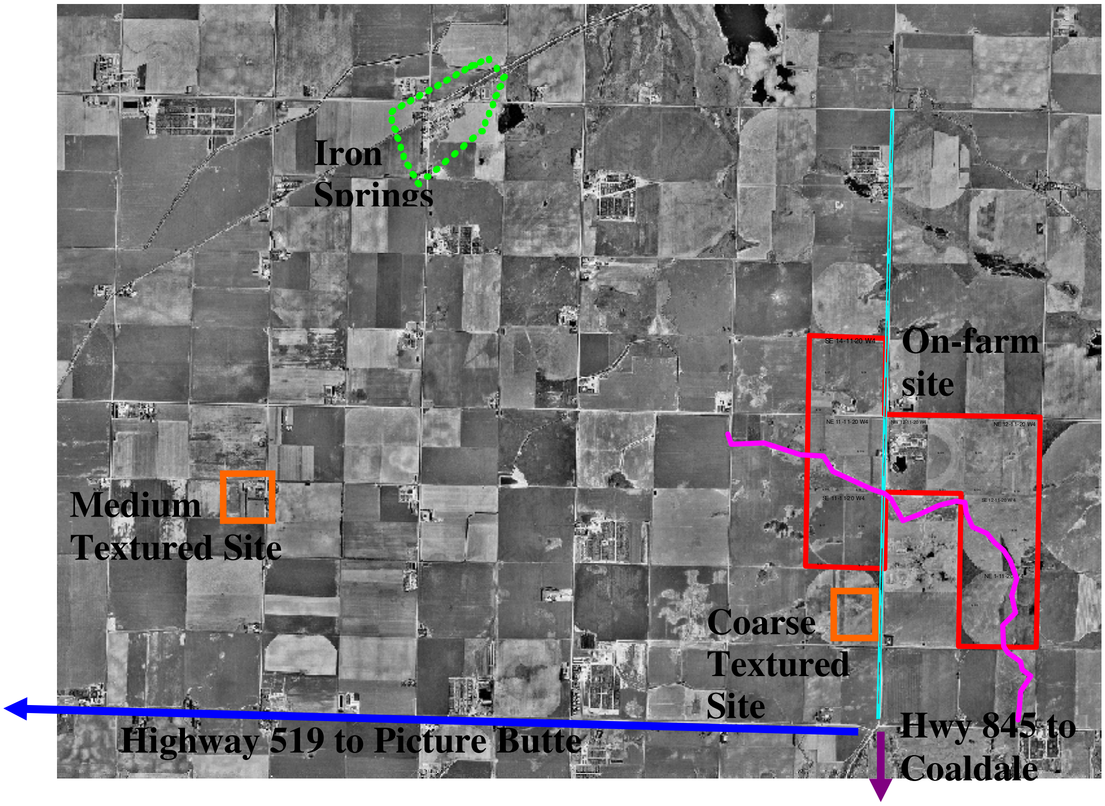

Figure 3.3 Location of sites indicated on an aerial photo of the sites. Orange squares indicate long-term study sites, red shape indicates on farm site. The pink line indicates a portion of the Battersea Drain that runs through the on farm study location.

The on farm portion of the study was undertaken to develop a nutrient budget for a specific farming operation within the Battersea Drain Basin, to determine if current management practices within the watershed were viable in the long-term. The farm under study has been managed by the same family for three generations, and has included livestock and cropping operations for much of the past century. Due to the dissection of the farming operation by the Battersea Drain and potential for runoff polluting the water, proper manure and synthetic fertilizer use is a critical part of modern operations.

The on farm portion of this study involved investigation of Schuld Farms located north of the coarse textured plot (Figure 3.3). This operation has been composed of a combination of dairy and feeder livestock for more than 80 years and has had a large confined feeding operation for over 27 years. There has been no intensive study of the operation prior to 2004. Historical soil sampling records exist, but were not utilized for this study due to lack of information on the exact location of soil sampling and methodology.

3.2 Climate

Total precipitation of 412.7 mm on average falls on the Picture Butte area, and there are on average 116 frost free days (AlbertaFirst, 2010). Most of the precipitation falls as rain during the growing season. The average seasonal temperatures are listed in Table 3.1. Chinook winds are a major influence in this area of Alberta, and can cause crop stress during the summer in areas without irrigation. The snowpack in the winter is often melted by these winds, and may be sublimated and lost to the overall moisture budget for the region. The lack of snow cover combined with drying winds may also impact the survival of perennial crops, so varietal choice is important to consider.

Table 3.1 Seasonal temperature averages in area around Picture Butte AB

Month	January	April	July	October
Average Temperature (° C)	- 10.6	4.8	18.0	7.1

Source: AlbertaFirst, 2010

3.3 Soils and Geology

The historic research plots were located on Orthic Dark Brown Chernozemic soil. According to the Agricultural Region of Alberta Soil Inventory Database

(AGRASID) the coarse textured soils are formed on moderately coarse sediment parent material deposited by wind or water, but more likely fluvial in origin. The coarse textured site was mapped as dominantly Kessler soil series with the Lethbridge soil a significant series (AGRASID 1998), and has hummocky topography, a landscape with rolling hills with low relief.

The medium textured soil was identified as Lethbridge soil series with undifferentiated fine soils (AGRASID 1998). In this case, the Lethbridge series is dominant with undifferentiated fine soil as a significant series and was most likely deposited by fluvial-lacustrine action (Olson *et al*. 2003).

The soils at the on farm site were also Lethbridge and Kessler soil series. The Lethbridge series indicated that these soils met the criteria of the Lethbridge series, with undulating high relief, that were less than 10% saline, and between 10 and 30% have regolithic profiles and were calcareous or eroded (AGRASID 1998). The Kessler series have between 10 and 30% of soil with a finer texture than the dominant soil, with hummocky, low relief.

3.4 Land Use

3.4.1 Long-term Sites

The long-term sites had both been under long-term crop production for many years prior to plot establishment in 1992. The coarse textured site was located on the dry pivot corner of the quarter section and relied mostly on rainfall for moisture. Commercial fertilizer had been applied every two to three years, depending on soil moisture conditions, and manure was applied every five or six years. The site was seeded to continuous barley (*Hordeum vulgare* L.) since 1980. Prior to the study, manure was last applied in 1991, 2 years prior to the start of the long-term trials. At some point during the years between 1990 and 1992, manure was stockpiled along the east side of the plot area for approximately a week, under dry climatic conditions (Olson *et al*. 2003).

The medium textured site was flood irrigated from 1935 until 1972, and irrigated by side-roll sprinkler irrigation after 1972. The crop rotation before 1972 was four years of alfalfa (*Medicago sativa* L.), one year of grain, one year of summerfallow, one year of sugarbeet (*Beta vulgaris* L.) and one year of grain. After 1972, the alfalfa phase was removed from the rotation. After 1983, the crop rotation was one year sugarbeet, two years soft white spring wheat (*Triticum aestivum* L.) and one year barley. Manure was applied to the summerfallow phase prior to 1983, at unknown rates and frequencies. Commercial fertilizer use was based on soil testing after 1983, and use prior to 1983 was not known (Olson *et al*. 2003).

3.4.2 On Farm Site

Schuld's livestock operation consists on average of 150 dairy cows, 100 dairy heifers and calves, 1800 head finishing cattle and 190 cow/calf pairs. The dairy produces 1.2 million litres of milk each year. The finishing cattle produce roughly 650 pounds of gain per animal per year. Approximately 500 tonnes per year of alfalfa are produced for export to a market in British Columbia. Purchases of grains and supplements total 5.5 tonnes per year.

Land management involves a 6 year rotation outlined in Table 3.2. The crop rotations that are employed allow for the application of manure from the feedlot and dairy onto the silage fields in the spring or fall. The alfalfa removes large amount of nutrients, and is able to remove nitrates from deeper in the soil (up to 2 meters).

3.5 Data Collection

3.5.1 Long-term Sites Experimental Design

The experimental design included six main treatments: a control (receiving no nitrogen inputs), 60 kg ha^{-1} of inorganic nitrogen (N) fertilizer, and 20, 40, 60 and 120 Mg ha^{-1} of wet cattle manure. Main plot size was 16 by 16 m, separated by 1m borders to form two subplots of 8 by 16 m. On half of the control and the 60 kg ha^{-1} inorganic N, main plots received an additional 120 kg ha^{-1} inorganic nitrogen fertilizer to give a total of four fertilizer-N rates (0, 60, 120 and 180 kg ha $^{-1}$). On the manured plots, half of each main plot was given no further additions beyond the manure applications and the other half (subplot 8 by 16 m) was designated as Best Management Practice (BMP) subtreatment in terms of crop N requirements. The BMP plots were to receive commercial fertilizer nitrogen if the amount of available nitrogen was determined to be less than 180 kg ha^{-1}, but only the 20 Mg ha^{-1} BMP required additional nitrogen on both sites in the first year, and both BMP-manure and non-BMP-manure were treated the same until October 1999. Manure application to the BMP plots was discontinued and became residual-manure subtreatments after that time (Olson *et al*. 2003).

Table 3.2 Typical crop rotation for Schuld farms over a six year period, including field location, acres and hectares under cultivation, and crop type grown each year.

Field Identifiers				Crop Rotation					
Field	Location	Cultivated acres	Cultivated Hectares	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
NW 12-11-20 W4	West half	80	32.34	alfalfa	corn	corn	barley/rye grass	alfalfa	alfalfa
NE 12-11-20 W4	West half	80	32.34	corn	barley/alfalfa (silage)	alfalfa	alfalfa	alfalfa	corn
NE 12-11-20 W4	East half	80	32.34	alfalfa	alfalfa	alfalfa	corn	corn	barley silage
NE 11-11-20 W4	North half	80	32.34	barley/alfalfa (silage)	alfalfa	alfalfa	alfalfa	alfalfa	barley silage
SE 11-11-20 W4	West half	80	32.34	alfalfa	barley silage	barley silage	barley/alfalfa (silage)	alfalfa	alfalfa
SE 11-11-20 W4	East half	80	32.34	alfalfa	wheat	barley silage	barley silage	barley/alfalfa (silage)	alfalfa
SE 14-11-20 W4	Full	110	44.52	rye grass	barley	barley	barley/rye grass	rye grass	rye grass
SE 12-11-20 W4	Full	125	50.86	alfalfa	barley silage	barley/alfalfa (silage)	alfalfa	alfalfa	alfalfa
NE 1-11-20 W4	Full	90	36.42	alfalfa	alfalfa	barley silage	corn	corn	alfalfa

The plot locations were determined by locating corner pins using a pin finder (metal detector), measuring out the length and width of the plots and placing stakes at the locations to be sampled. Figures 3.4 and 3.5 illustrate the layout of the coarse textured and medium textured sites respectively, with the sample locations indicated in red. The plots that had cattle manure applied and the control were sampled but the fertilizer plots were not included in this study.

3.5.1.1 Soil Sampling

The sites that were sampled in 2004 were those manured plots not included in the BMP sub-treatment, and the control. These plots were selected to determine the effects of residual manure on nutrient levels in the soils. In order to account for application of commercial fertilizer phosphorus, samples were taken from both the 0 to 5 cm and 0 to 15 cm depths.

A truck-mounted, hydraulically-powered coring drill was used to collect a 1.5 m core at each sampling point. Two trucks drove side by side down the plots and within 2 m of the center of each plot, and each truck took one core. The cores were divided into increments (0 to 0.15, 0.15 to 0.30, 0.30 to 0.60, 0.60 to 0.90, 0.90 to 1.20, 1.20 to1.50 m). Samples from each core were bulked together in a pail, mixed and a representative sub-sample taken. Each representative sample was bagged, labeled and placed on the truck. Soils were air dried immediately upon delivery to the lab. After drying, the soils were ground and passed through a 2 mm mesh. They were analyzed at the Irrigation Branch, Alberta Agriculture, Food and Rural Development lab.

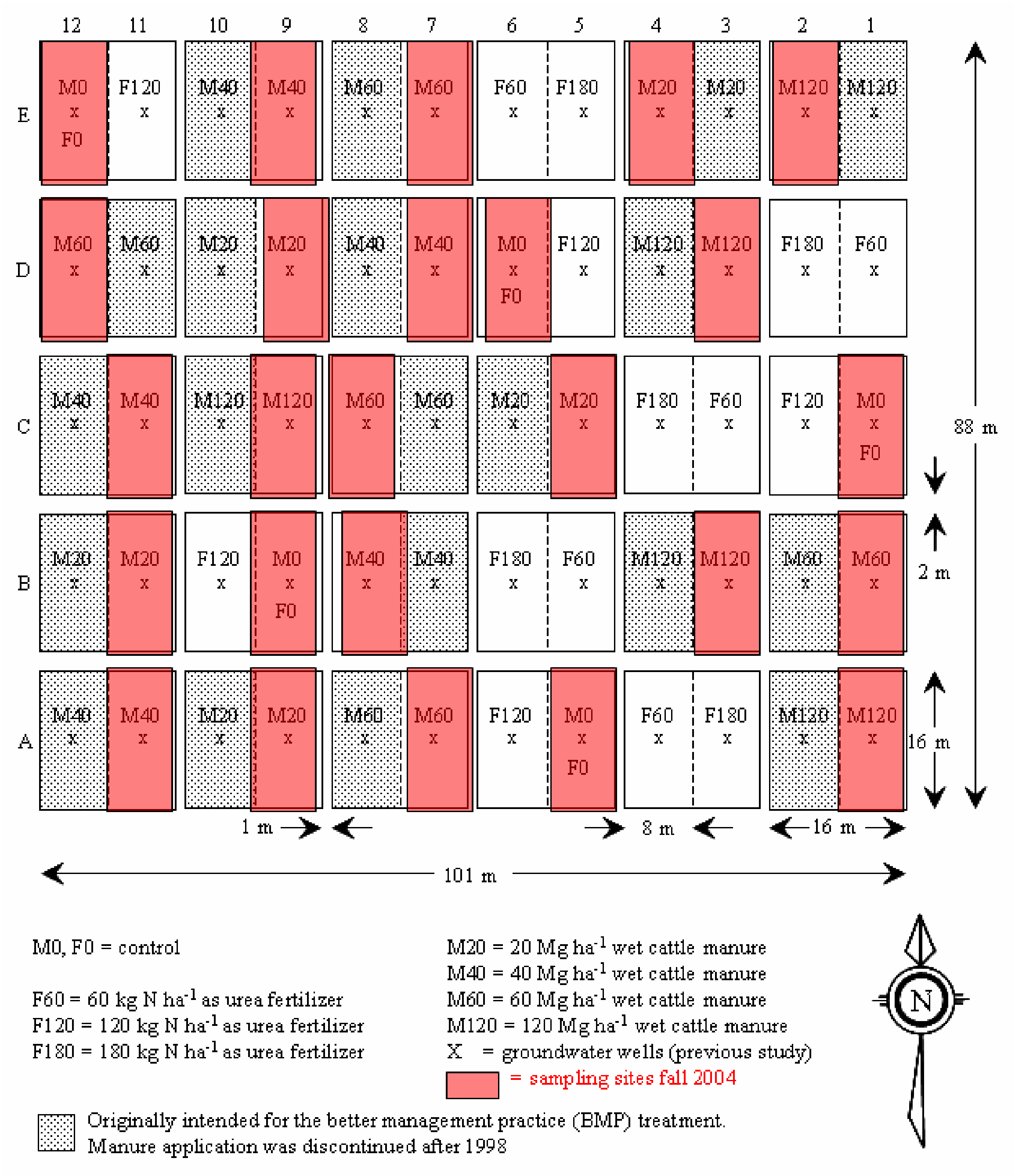

Figure 3.4 Layout of plots and sample collection sites for coarse textured site (NE 2-11-20 W4). Adapted from Olsen *et al.* (2003)

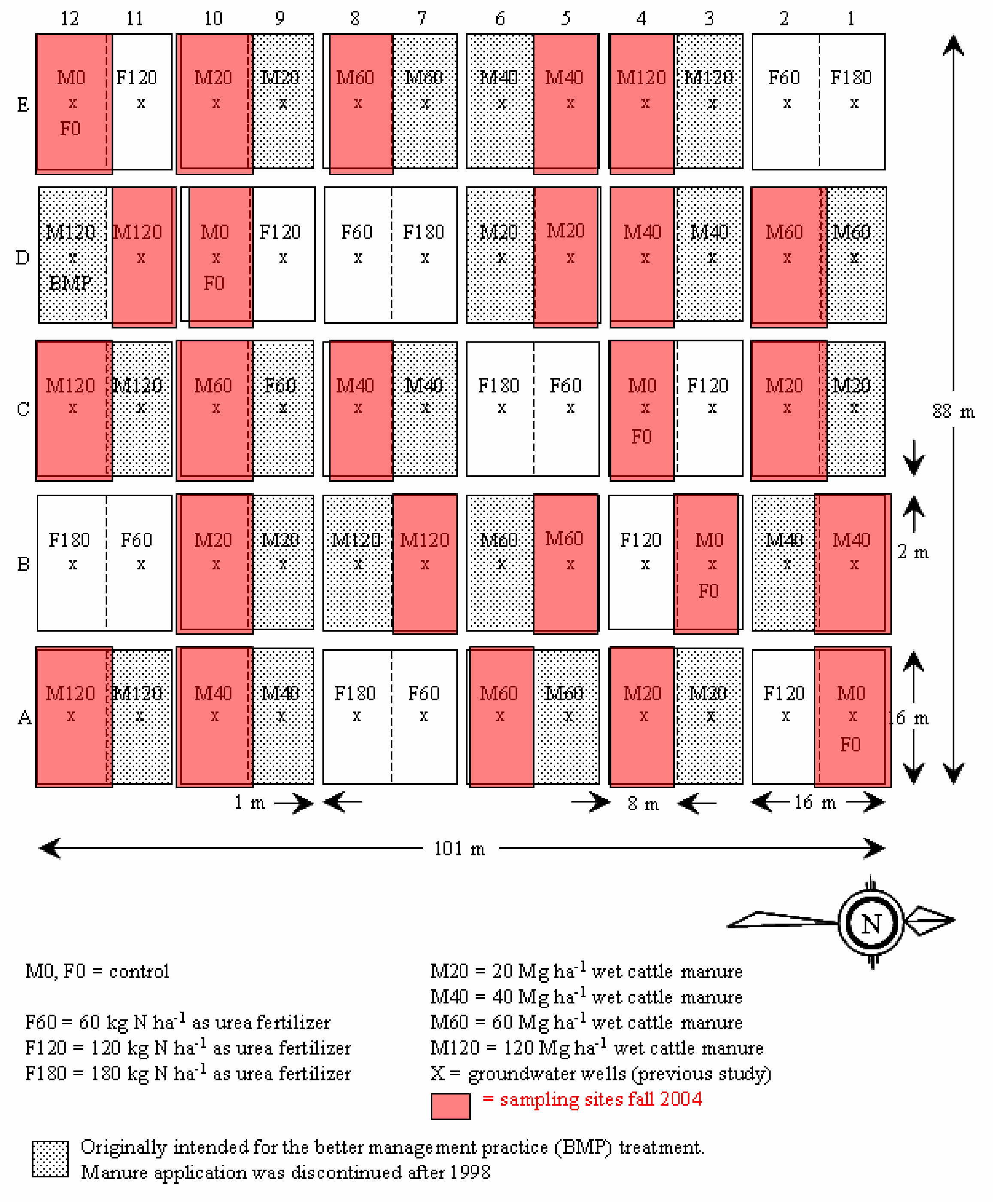

Figure 3.5 Layout of plots and sample collection sites for medium textured site (NE 7-11-20 W4). Adapted from Olsen *et al.* (2003)

3.5.2 On farm Site Experimental Design

The seven quarters selected for the study were divided based on legal subdivisions (LSD), which is a 40-acre unit, and a representative site was chosen within each LSD. Sites were chosen by examining air photos and topographic maps and augmented with field visits to ensure accuracy of these resources. Depressional areas, saline areas and extreme high spots were avoided.

The estimation of the nutrient status for the farm involved collecting information from crops, feed, manure, livestock production and soils. The main nutrients studied were nitrogen, phosphorus and potassium. The pH and electrical conductivity in the soil were also measured as important indicators of overall nutrient levels.

Figure 3.6 shows the study site from an aerial photo, with the study boundaries outlined in red. Crops grown in 2004 are also shown on Figure 3.6. Benchmarks were set at each representative location and identified by global positioning system (GPS) reference. This was to ensure that future samples were taken from the same area around the benchmark site to preserve continuity. The latitude and longitude of the benchmarks are listed in Appendix I and shown in Figure 3.6 as blue circles.

3.5.2.1 Soil Sampling

To determine soil nutrient levels, four benchmark locations were selected. After crop harvest in October 2004, soil cores were taken from the benchmark location as well as 20 meters to the north and south of each benchmark location.

Figure 3.6 Aerial view of on farm study area, photo from 2003 courtesy of the County of Lethbridge. Legal location and crops grown in 2004 are included, and benchmarks are indicated by blue dots.

Cores were taken to a depth of 1.5 meters. Once the core was removed from the ground, it was divided using a soil knife into increments (0 to 0.15, 0.15 to 0.30, 0.30 to 0.60, 0.60 to 0.90, 0.90 to 1.20, 1.20 to1.50 m). The three samples taken at each site were bulked together and a sub sample taken after thorough mixing of the bulked sample. Samples were tagged for identification and air-dried immediately upon delivery to the lab.

3.5.2.2 Plant Sampling

To assist with crop yield determination and nutrient levels in the crop, crop samples were taken beginning on June 16 and 17, 2004, just prior to the first cut of alfalfa. There were 16 sites that were in alfalfa production in 2004. main sampling sites were located using GPS and at each site, 5 samples were taken using a 0.25 m^2 sampling grid cutting as close to the ground as possible with a hand sickle. The 5 samples were taken at the benchmark and approximately five and ten meters to the north and south of the benchmark, placed in paper bags and labeled. Upon arrival at the lab, each sample was weighed then oven dried and the dry weight of each sample was taken to determine percent moisture and yield. Dry matter yield for the crop was estimated and cross-referenced to yields provided by the producer. Alfalfa samples were taken, in the manner described above, at each harvest interval.

The barley fields were sampled by the same method as for the alfalfa, and were taken prior to silage harvest in July. Oats were taken in late fall prior to harvest; the crop was swathed prior to sample collection, so a sample was taken as close to the benchmark locations as possible. Yield could not be estimated because of this method and the harvested oats were being used as animal feed. The corn was silaged before a sample could be obtained.

Samples were placed in cotton bags, labeled and taken to the lab and oven-dried. Samples were ground and a sub-sample taken from each of the five field samples to obtain a representative sample for lab analysis. Each composite sample was tested for Total N and Total P.

3.5.2.3 Feed Sampling

Feed sampling was conducted to determine the nutrient levels in the feed materials as well as the mixture fed to the cattle. Feed samples were collected monthly from animal feed bunkers, within 2 hours of the feed being dropped. Samples were split to obtain the required amount of final sample, weighed, dried at approximately 60 degrees Celsius for at least 48 hours and then weighed again. Samples from feed components such as grain, supplement and silage were also collected and dried in the same manner.

3.5.2.4 Manure Sampling

Manure samples were collected to determine the nutrient content and to estimate the rates of manure applied. Solid feed manure samples were taken during spreading of manure onto fields. Tarps were laid out to collect manure as it was spread. Each tarp was 1.2 by 1.8 meters (4 by 6 feet) and was anchored to the ground in the path of manure spreading (Figure 3.7). The manure spreading trucks drove over the tarps at regular speed and the tarp estimated what volume of manure was applied. Nine samples were collected from 2 of the fields receiving manure in the fall of 2004. Volume of manure applied was estimated based on tarp size and weight of manure.

Figure 3.7 Manure collection using tarp (author's photo).

Liquid dairy manure from the catchment pit south of the dairy barn was sampled in July. It had been agitated for a few hours prior to sampling, in preparation to being spread on a grass pasture. The liquid manure tank was sampled in 4 locations, using a long handled sampling pole and 1-litre container. Samples were stored in a cooler and submitted to the lab upon return to the Research Station.

3.6 Laboratory Analysis

3.6.1 Analysis of Plant, Feed and Manure Samples

Plant and feed samples were ground using a Wiley mill and passed through a 2 mm mesh to remove stones. A sub-sample was taken from the bulk sample and ground in a feed mill. A sample was placed into an aluminum vessel and then analyzed for total N by combustion using a Carlo Erba CHN analyzer Model 1104. The plant samples were also analyzed for P and K using the Inductively Coupled Plasma Spectroscopic Method (AOAC 2003).

Manure samples were also tested using this method, and were tested for Na, P and K. Liquid manure samples were frozen upon arrival at the lab, and were thawed at a later time for analysis. Analysis was done at Norwest Labs in Lethbridge using the Inductively Coupled Plasma Spectroscopic method (AOAC, 2003).

3.6.2 Soil Analysis

The bulk samples of soils collected in the field (by methods outlined in section 3.5.2.1) were ground and sieved by methods as outlined in section 3.3.2.1. Soils were analyzed at the in the AAFRD Irrigation Branch lab at Lethbridge and were analyzed for nitrate-N, phosphate, potassium, pH and E.C.

3.6.2.1 Soil Test Nitrogen

The soil was ground and passed through a 2.0 mm sieve prior to weighing 10 grams of soil and placing it into a 7-dram vial for transport to the lab. Nitrate-nitrogen was extracted from a soil solution by using 2.0 M potassium chloride (KCl) solution. In the lab, the soil was transferred into a 125-ml Erlenmeyer flask, and 100 ml of extracting solution was added, giving a 10:1 extract. The flask was then placed on an electric shaker for 1 hour. In preparation for filtering the samples, #42 filter papers were washed with double distilled water (D.D. H_2O) and then rinsed with 2M KCl prior to filtering. The solution was filtered after shaking, and two blanks and a standard were also included in each run. The filtrate collected was analyzed Technicon GTPC AutoAnalyzer System for NO_3-N and NH_4-N in mg L^{-1} (Carter 1993).

3.6.2.2 Soil Test Phosphorus and Potassium

The Modified Kelowna Method (Carter, 1993) was used to determine the levels of phosphorus and potassium in the soil samples. Ten grams of ground and sieved soil was placed into a 7-dram vial and transported to the lab. The soil was then transferred to a 125 ml Erlenmeyer flask and 100 ml of solution was added (10:1 extract). This solution was shaken for one half hour, and filtered through unwashed #42 filter paper into 6 dram vials. Two blanks and one standard were included per run. The filtrate was analyzed using the Technicon Gtpc AutoAnalyzer System for PO_4-P (mg/L) and the on farm K ($mMole_c$/L or Meq/L) (Carter 1993). The K was analyzed using the filtrate collected for measuring EC and pH, using the JY70 Plus Inductively Coupled Plasma spectrometer.

3.6.2.3 Electrical Conductivity and pH

One hundred grams of soil was placed in a 500 ml plastic container, distilled water was incrementally added to this soil sample and stirred with a spatula until saturation was achieved. This point was determined visually when the soil the soil was smooth, glistened and flowed easily. The amount of distilled water used to achieve saturation was recorded. Samples were left overnight and stirred again. A pH probe was then inserted into each sample to determine pH (Carter, 1993).

The extract of the saturated paste was obtained using Buchner filters with low-ash, highly retentive filter paper, set into an Erlenmeyer flask and with vacuum suction applied. The resulting extract was then used to determine the electrical conductivity (EC) by EC meter (Carter, 1993).

3.7 Analytical Analysis

Soil test data collected for the long-term sites were analyzed using ProcMixed (SAS Institute 2005) using treatment and year as fixed effects and replicate as the random effect. Mean comparisons were performed using Tukey's studentized range test at P<0,05 (SAS Institute 2005). The Bonferroni adjustment was used as overcorrection for the number of comparisons made and for a more stringent test.

3.8 Summary

The on farm and long term studies were undertaken for slightly different reasons, but were both intended to investigate long term manure application on soils. The methods of collecting soil samples and analyzing them were consistent as were the laboratory analysis of samples. The results of these will be presented in Chapter 4.

Chapter 4 - Results

4.0 Introduction

This study was undertaken to investigate long term manure management on a farm, both by studying the farm and long term manure plots located nearby. The on farm portion (coarse textured and medium textured sites) was undertaken to develop a nutrient budget for a specific farming operation within the Battersea Drain Basin, to determine if current management practices within the watershed were viable in the long-term, while the long term plots were selected to determine the effects of residual manure on nutrient levels in the soils. Results of soil collection, analysis of the coarse- and medium-textured sites and the on farm site, results of the soil analysis and statistics derived laboratory results will all be presented in this section. The long-term sites are grouped by soil texture and the values for the on farm site are sorted by nutrient.

The laboratory results are grouped by treatment, depth and replicate for pH, EC, NO_3-N, PO_4-P and K. The results for EC were recorded in dSm^{-1}, N and P in mg L^{-1}, and K and S as mmolc L^{-1}. Values were converted to kg ha^{-1} for NO_3-N, PO_4-P and K. One sample from the coarse textured plots was missing from the analysis, as the sample was lost between the field and the laboratory and was excluded from the statistical portion of the analysis.

4.1 Long-term Sites – Coarse Textured Soil

4.1.1 Nitrate-Nitrogen

Nitrate-nitrogen is a plant available form of nitrogen that is very water soluble, and thus is prone to leaching losses under saturated conditions but may also be lost to the atmosphere via denitrification. Some treatments in the coarse textured site exhibited a significant difference in NO_3-N levels between 2001 and 2004, and may have been due plant uptake, leaching or denitrification. The trend of NO_3-N levels followed the same pattern in 2004 as in 2001, where the lowest levels of NO_3-N were the treatments with the lowest rates of manure application (Table 4.1), and is discussed below.

At most depths, the control treatment (0 Mg ha^{-1}) increased in NO_3-N between 2001 and 2004 but at rates that were not statistically significant. In 2001, the control had lower NO_3-N levels in the 0-15 cm (GLM = 2.05, DF = 8, p = 0.1052) and 15-30 cm (GLM = 2.19, DF = 8, p = 0.0867) depths compared to the next two soil depths of 30-60 cm (GLM = 2.58, DF = 8, p = 0.0506) and 60-90 cm (GLM = 1.33, DF = 8, p = 0.2964) By 2004, the highest levels of NO_3-N were found in the top 15 cm, and decreased levels were found lower in the soil profile. Despite these changes, none of these results were significantly different between the two years.

The 20 Mg ha^{-1} manure treatment also did not have a statistically significant change over the three years, although the general trend was a decrease in NO_3-N rates during that time period. The changes in both the 20 Mg ha^{-1} and 40 Mg ha^{-1} manure treatments were not statistically significant when comparing the results from 2001 and 2004. However, there were some differences in the measured rates which exhibited some decreases over this time period, especially at the lower depths of the soil profile from 120-150 cm (GLM = 4.29, DF = 8, p=0.0064). The standard error values were quite high in the lower depths of these treatments as well.

Plots that received the higher rates of manure (60 Mg ha^{-1} and 120 Mg ha^{-1}) had higher levels of NO_3-N in 2001 as compared to the control and other two manure treatments, and remained higher at all soil depths in 2004. Nitrate-nitrogen levels in the 60 Mg ha^{-1} and 120 Mg ha^{-1} manure treatments exhibited statistically significant decreases in the 0-15 cm soil depths between 2001 and 2004 (GLM = 2.05, DF = 8, p = 0.1052). In the 60 Mg ha^{-1} treatment, statistically significant decreases in soil NO_3-N also occurred at all soil depths except 30-60 cm (GLM = 2.58, DF = 8, p = 0.0506) and 90-120 cm (GLM = 1.73, DF = 8, p=0.1704). The 120 Mg ha^{-1} manure treatment showed a similar trend to the 60 Mg ha^{-1} manure treatment, showing a statistically significant decrease in NO_3-N rates at all depths below 30 cm.

The highest standard errors were also associated with soil depths in which NO_3-N decreased most between 2001 and 2004. Overall, the trend towards higher soil NO_3-N levels at lower depths apparent in 2001 was still visible in 2004.

Table 4.1 Nitrate-nitrogen levels in coarse textured site†

		Manure Treatment (Mg ha^{-1})																	
		0			20			40			60			120			ALL		
Depth (cm)	Year	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N
0-15	2001	1.7a	0.7	5	13.4a	3.0	5	24.1a	5.7	5	44.2a	9.0	5	68.4a	7.5	5	30.4	5.4	25
	2004	8.7a	2.2	5	12.1a	2.0	5	18.2a	1.5	5	19.9b	4.1	4	34.6b	1.6	4	18.0	2.1	23
15-30	2001	1.1a	0.3	5	4.9a	1.0	5	6.6a	1.8	5	20.1a	6.6	5	21.2a	3.0	5	10.8	2.2	25
	2004	4.8a	1.2	5	4.3a	1.5	5	5.2a	0.7	5	5.3b	1.4	4	11.0a	1.7	4	5.9	0.7	23
30-60	2001	2.4a	0.6	5	11.2a	3.7	5	14.8a	2.0	5	34.7a	14.8	4	61.5a	13.6	5	24.5	5.7	24
	2004	3.6a	1.0	5	2.4a	0.8	5	5.3a	0.9	5	11.9a	5.0	5	27.9b	9.4	5	10.2	2.8	25
60-90	2001	2.5a	0.5	5	18.0a	6.2	5	20.5a	6.3	5	107.6a	37.4	5	92.2a	20.4	5	48.1	11.8	25
	2004	2.4a	0.7	5	2.0a	0.5	5	3.0a	0.6	5	16.0b	10.3	5	19.3b	9.7	4	8.1	2.9	24
90-120	2001	2.2a	0.7	5	23.6a	9.3	5	44.4a	25.8	5	140.6a	43.3	5	108.3a	21.4	5	63.8	14.7	25
	2004	1.5a	0.4	5	1.3a	0.3	4	2.0a	0.4	5	22.6b	10.8	5	18.7b	9.2	4	9.1	3.3	23
120-150	2001	1.6a	0.4	5	16.9a	7.2	5	106.4a	52.2	5	91.5a	27.7	5	160.1a	45.2	5	75.3	18.2	25
	2004	2.3a	0.6	5	2.9a	0.3	5	5.0a	1.0	5	19.3a	6.6	4	20.2b	4.1	4	9.1	2.1	23

† Mean values in each column followed by the same letter are not significantly different ($P<0.05$).

4.1.2 Plant Available Phosphorus

The overall trend for plant available P in the coarse textured soil was a decrease in levels between 2001 and 2004 within the top 15 cm of soil, with the exception of the control (Table 4.2). At soil levels below 15 cm, P levels generally dropped with a few exceptions. There was only one treatment and depth that showed a statistically significant decrease in plant available P.

The control (0 Mg ha^{-1}) exhibited a slight increase at two depths 0-15 cm (GLM = 23.29, DF = 8, $p = <0.001$) and 120-150 cm (GLM = 3.21, DF = 8, $p = 0.0225$) between 2001 and 2004, while the other four soil depths all decreased over this same time period. Although the P level increased in the top 15 cm of the control from 68.1 kg ha^{-1} in 2001 to 103.4 kg ha^{-1} in 2004, it was not a statistically significant increase (GLM = 23.29, DF = 8, $p = <0.0001$).

The 20 Mg ha^{-1} and 40 Mg ha^{-1} manure treatments showed decreased levels of P in all soil depths except within the 30-60 cm depth of each treatment (GLM = 2.57, DF = 8, $p=0.0513$). Plant available P increase modestly but was not statistically significant in either manure treatment.

The 60 Mg ha^{-1} manure treatment exhibited decreased soil available P at each soil depth above 120 cm. The lowest sampling depth of 120-50 cm showed a moderate increase between 2001 and 2004 (GLM = 3.21, DF = 8, $p = 0.0225$). Again, none of the changes within this treatment were found to be statistically significant.

The 120 Mg ha^{-1} manure treatment contained the only statistically significant change in plant available P in the coarse textured site. In the 0-15 cm depth, P levels dropped from 1104.0 kg ha^{-1} in 2001 to 879.8 kg ha^{-1} in 2004 (GLM = 23.29, DF = 8,

$p = <0.001$). This statistically significant decrease was followed by modest increases in the next two soil depths, 15-30 cm (GLM = 18.05, DF = 8, $p = <0.0001$) and 30-60 cm (GLM = 2.57, DF = 8, $p = 0.0513$), although neither was statistically significant. Further down in this profile, the P levels decreased between 2001 and 2004, with the exception of a modest but not statistically significant increase in the 120-150 cm soil depth (GLM = 3.21, DF = 8, $p = 0.0225$).

The highest standard errors were associated with soil depths that had the greatest decrease in plant available P between 2001 and 2004. As well, the highest levels of plant available P were correlated with the highest rates of manure application both in 2001 and 2004.

4.1.3 Water Soluble Potassium

Water soluble potassium levels decreased between 2001 and 2004 in all treatments except for the control (Table 4.3). The highest K values were found in the highest manure treatments, 60 Mg ha^{-1} (and 120 Mg ha^{-1} and the lowest K in the control both in 2001 and 2004. The control (0 Mg ha^{-1}) treatment, the 20 Mg ha^{-1} and 40 Mg ha^{-1} manure treatments did not exhibit any statistically significant changes between 2001 and 2004 at any soil depth.

Potassium levels in the control did show a trend, increasing modestly at all soil depths except 15-30 cm (GLM = 22.37, DF = 8, $p = <0.0001$) between 2001 and 2004. While none of the K increases were statistically significant, it is worth noting this increase once the area was returned to normal farming practices in the 2002

Table 4.2 Plant available phosphorus levels in coarse textured site[†]

		Manure Treatment (Mg ha-1)																	
		0			20			40			60			120			ALL		
Depth (cm)	Year	Mean kg ha-1	Std Err	N	Mean kg ha-1	Std Err	N	Mean kg ha-1	Std Err	N	Mean kg ha-1	Std Err	N	Mean kg ha-1	Std Err	N	Mean kg ha-1	Std Err	N
0-15	2001	68.1a	22.2	5	314.5a	51.5	5	403.5a	52.8	5	583.5a	50.5	5	1104.0a	122	5	494.7	76.1	25
	2004	103.4a	19.3	5	234.0a	25.6	5	359.4a	33.4	5	517.4a	24.6	5	879.8b	108.1	5	418.8	59	25
15-30	2001	53.7a	11.8	5	152.0a	37	5	214.6a	36.2	5	278.8a	51	5	425.9a	24.8	5	225.0	29.2	25
	2004	43.5a	10.8	5	132.0a	22	5	196.5a	16.5	5	241.9a	38.1	5	437.2a	46.1	5	210.2	29.5	25
30-60	2001	30.4a	2.8	5	67.9a	16.6	5	104.5a	15.6	5	128.8a	42	5	186.6a	35.4	3	96.5	14.7	23
	2004	27.1a	8.2	5	72.0a	15.8	5	143.8a	74.9	5	122.9a	49.8	5	296.2a	92.7	5	132.4	30.2	25
60-90	2001	22.1a	0.5	5	39.0a	5.5	5	31.8a	6.4	5	53.9a	19.5	5	81.7a	20.1	5	45.7	6.8	25
	2004	17.3a	1.8	5	19.2a	1	5	21.2a	4.3	5	19.0a	6.1	5	27.6a	6.7	5	20.9	2	25
90-120	2001	15.3a	2.3	5	33.2a	11.3	5	31.7a	8.5	5	32.1a	7.1	5	49.0a	12.9	5	32.3	4.3	25
	2004	12.5a	2.4	5	12.8a	1.6	5	9.5a	1.3	4	8.1a	1	4	12.4a	2.3	5	11.3	0.9	23
120-150	2001	7.0a	2.1	5	8.1a	2.2	5	19.2a	5	5	21.5a	9.1	5	26.8a	7.3	4	16.1	2.8	24
	2004	8.1a	1.2	5	8.7a	1.9	5	13.8a	4.1	5	44.8a	25.1	5	69.6a	18	5	29.0	7.6	25

† Mean values in each column followed by the same letter are not significantly different (*P*<0.05).

growing season. A similar phenomenon occurred in the 20 Mg ha^{-1} manure treatment, with modest increases occurring only in the 30-60 cm (GLM = 8.08, DF = 8, p = 0.0002) and 120-150 cm (GLM = 2.93, DF = 8, p = 0.0320) depths in the soil profile. The K levels increased in the 30 to 60 cm by 3.7 mmolc L^{-1}, and by 10.9 mmolc L^{-1} within the 120 to 150 cm depth for the 20 Mg ha^{-1} manure treatment (GLM = 2.93, DF = 8, p = 0.0320). Similar minor increases were noted in the 40 Mg ha^{-1} manure treatment at depths of 60 - 90 cm, a small increase of 8.1 kg ha^{-1} (GLM 2.65, DF = 8, p = 0.0460) and 120-150 cm (GLM = 2.93, DF = 8, p = 0.0320). None of these changes were found to be statistically significant, but are part of a trend worth noting.

The 60 Mg ha^{-1} manure treatment exhibited a decrease in water soluble K between 2001 and 2004 in all soil depths except for 120-150 cm (GLM = 2.93, DF = 8, p = 0.0320). This treatment had two depths where K decreased sufficiently to be statistically significant. Potassium levels in 2001 were measured at 400 mmolc L^{-1} in 2001 and had decreased to 184.9 mmolc L^{-1} by 2004. The 30-60 cm soil depth also changed significantly, from 336.9 mmolc L^{-1} in 2001 to 255.3 mmolc L^{-1} in 2004 (GLM = 8.08, DF = 8, p = 0.0002). The other two soil depths decreased, but not enough to be statistically significant in the 3 year interval.

The 120 Mg ha^{-1} exhibited decreases through the soil profile between 2001 and 2004, with the exception of the 120-150 cm depth which increased modestly during this time period (GLM = 2.93, DF = 8, p = 0.0320). Within the top 15 cm of soil, water soluble K levels were measured at 632.7 mmolc L^{-1} in 2001 and

Table 4.3 Water soluble potassium levels in coarse textured site†

		Manure Treatment (Mg ha^{-1})																	
		0			20			40			60			120			ALL		
Depth	Year	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N
(cm)		mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}		
0-15	2001	44.0a	3.1	5	205.1a	40.9	5	246.2a	13.5	5	400.0a	45.1	5	632.7a	53.7	5	305.6	43.3	25
	2004	52.5a	5.1	5	110.2a	18.4	5	122.4a	9.2	5	184.9b	24.3	5	286.0b	27.0	5	151.2	17.9	25
15-30	2001	33.8a	4.8	5	98.3a	16.0	5	140.6a	17.2	5	277.5a	23.3	5	459.5a	46.5	5	201.9	32.6	25
	2004	26.6a	3.0	5	77.2a	12.9	5	126.2a	12.1	5	241.2a	12.9	5	392.1a	32.1	5	172.7	27.6	a
30-60	2001	24.7a	7.4	5	82.3a	26.4	5	139.6a	32.0	5	336.9a	70.2	5	824.7a	105.4	5	281.7	64.2	25
	2004	30.5a	8.5	5	86.0a	23.6	5	123.0a	18.2	5	255.3b	62.8	5	596.6b	94.8	5	218.3	46.7	25
60-90	2001	10.8a	0.7	5	29.3a	6.7	5	21.9a	3.9	5	90.7a	39.1	5	485.2a	208.8	5	127.6	53.6	25
	2004	12.2a	1.3	5	17.4a	4.9	5	30.0a	15.1	5	72.2a	31.9	5	280.8b	130.0	5	82.5	32.2	25
90-120	2001	15.4a	2.3	5	42.0a	9.0	5	32.4a	4.4	5	71.6a	31.4	5	75.0a	16.7	5	47.3	8.2	25
	2004	24.7a	5.0	5	14.6a	2.3	5	14.1a	2.2	5	35.2a	16.0	5	52.9a	17.4	5	28.9	5.5	25
120-150	2001	27.1a	7.3	5	31.5a	8.0	5	33.6a	5.2	5	63.3a	13.8	5	129.5a	39.5	5	57.0	11.2	25
	2004	37.7a	11.9	5	42.4a	7.9	5	35.5a	3.7	5	83.0a	23.2	5	151.8a	23.1	5	70.1	11.2	25

† Mean values in each column followed by the same letter are not significantly different ($P<0.05$).

decreased to 286.0 mmolc L^{-1} in 2004, a statistically significant decrease of 346.7 mmolc L^{-1} (GLM = 23.05, DF = 8, p = <0.0001). The decrease in the 30-60 cmdepth was also statistically significant, decreasing from 824.7 mmolc L^{-1} in 2001 to 596.6 mmolc L^{-1} in 2004 (GLM = 8.08, DF = 8, p = 0.0002). The same occurred in the 60-90 cm depth (GLM = 2.65, DF = 8, p = 0.0460) with a decrease of 204.4 mmolc L^{-1} (485.2 mmolc L^{-1} in 2001 to 280.8 mmolc L^{-1} in 2004).

The trend in the water soluble K reflected the trends found in N and P, where the highest rates of K were found in the plots with the highest rates of manure application. The control showed a strong tendency toward increasing K levels with a return to normal farming practices after 2001.

4.1.4 Electrical conductivity

Electrical conductivity (EC) is an indirect method to measure of salts in the soil. Manure contains large amounts of salts, and so increases in EC may be linked to repeated manure applications to the soil. The measured electrical conductivity (EC) levels which were highest in 2001 were also the highest in 2004 (Table 4.4). The trend from 2001 to 2004 was a decrease in the EC levels, particularly in the top 15 cm of soil, except for the control which showed minor increases at most soil depths between 2001 and 2004. Despite the trend, there were only 2 samples that showed statistically significant decreases in the interim 3 year period between sampling.

The control treatment exhibited minor increases at all soil depths, except within the 30-60 cm depth which remained constant between 2001 and 2004 (GLM = 2.23, DF = 8, p = 0.0817). None of the increases were statistically significant.

The 20 Mg ha^{-1} manure treatment also showed some minor changes between 2001 and 2004 sample dates. The EC decreased in the 0-15 cm, 30-60 cm and 60-90 cm soil depths. The 15-30 cm depth did not change in the 3 year hiatus in manure application (GLM = 15.73, DF = 8, p = <0.0001). There were very minute increases in the lower two soil depths, increasing from 0.6 dS m^{-1} to 0.7 dS m^{-1} at each soil depth. None of the changes in the 20 Mg ha^{-1} were statistically significant.

The 40 Mg ha^{-1} manure treatment also exhibited changes in EC during the 3 year period after manure treatments were discontinued. The EC decreased from 0.7 dS m^{-1} in 2001 to 0.6 dS m^{-1} in 2004 in the top 15 cm of soil (GLM = 5.78, DF = 8, p = 0.0015), and remained constant in the 15-30 cm soil depth (GLM = 15.73, DF = 8, p = <0.0001). The EC decreased in all soil depths below 30 cm, as outlined in Table 4.4. There were no statistically significant changes at any soil depth for the 40 Mg ha^{-1} manure treatment.

The 60 Mg ha^{-1} manure treatment decreased in all soil depth between 2001 and 2004. There was one statistically significant decrease in this treatment in the 15 – 30 cm depth, from 0.9 dS m^{-1} in 2001 and dropped 0.6 dS m^{-1} in 2004 (GLM = 15.73, DF = 8, p = <0.0001). There was a drop from 1.1 dS m^{-1} in 2001 to 0.8 dS m^{-1} in 2004 in the top 15 cm (GLM = 5.78, DF = 8, p = 0.0015) and slight drops in the three soil depths below 60 cm. None of these were statistically significant except for the 15-30 cm soil depth in this treatment.

A similar trend was evident in the 120 Mg ha^{-1} manure treatment, with decreases in all soil depths and one that was statistically significant. The statistically significant decrease was in the top 15 cm of soil, where the measured EC

Table 4.4 Electrical Conductivity levels in coarse textured site†

		Manure Treatment (Mg ha^{-1})																	
		0			20			40			60			120			ALL		
Depth (cm)	Year	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N
0-15	2001	0.4a	0.02	5	0.7a	0.07	5	0.7a	0.04	5	1.1a	0.12	5	1.4a	0.12	5	0.9	0.07	25
	2004	0.5a	0.04	5	0.6a	0.04	5	0.6a	0.02	5	0.8a	0.05	5	1.0b	0.08	5	0.7	0.04	25
15-30	2001	0.3a	0.02	5	0.5a	0.02	5	0.5a	0.02	5	0.9a	0.13	5	1.1a	0.09	5	0.7	0.06	25
	2004	0.5a	0.02	5	0.5a	0.03	5	0.5a	0.02	5	0.6b	0.02	5	0.8a	0.04	5	0.6	0.03	25
30-60	2001	0.4a	0.02	5	0.6a	0.08	5	0.6a	0.04	5	1.1a	0.23	5	1.2a	0.17	5	0.8	0.09	25
	2004	0.4a	0.03	5	0.4a	0.05	5	0.4a	0.01	5	0.8a	0.25	5	0.8a	0.07	5	0.6	0.06	25
60-90	2001	0.4a	0.01	5	0.6a	0.08	5	0.8a	0.16	5	1.5a	0.27	5	1.4a	0.17	5	0.9	0.11	25
	2004	0.5a	0.08	5	0.5a	0.04	5	0.5a	0.06	5	1.2a	0.31	5	1.1a	0.23	5	0.7	0.10	25
90-120	2001	0.4a	0.01	5	0.6a	0.10	5	0.9a	0.16	5	1.6a	0.22	5	1.7a	0.13	5	1.0	0.12	25
	2004	0.9a	0.43	5	0.7a	0.14	5	0.7a	0.10	4	1.2a	0.19	5	1.2a	0.32	5	0.9	0.12	24
120-150	2001	1.0a	0.62	5	0.6a	0.08	5	1.0a	0.20	5	1.2a	0.17	5	2.0a	0.31	5	1.2	0.17	25
	2004	1.3a	0.66	5	0.7a	0.17	5	0.9a	0.14	5	0.9a	0.14	5	1.0a	0.21	5	0.9	0.14	25

† Mean values in each column followed by the same letter are not significantly different (*P*<0.05).

was 1.4 dS m^{-1} in 2001 and decreased to 1.0 dS m^{-1} in 2004 (GLM = 5.78, DF = 8, p = 0.0015). Each of the five other soil depths showed decreases between 2001 and 2004, but none of them were statistically significant.

4.2 Long-term Sites – Medium Textured Soil

4.2.1 Nitrate-nitrogen

The trend of NO_3-N levels in the medium textured soil was similar to the trend found in the coarse textured soil, where the lowest NO_3-N rates were associated with the lowest rates of manure application and increased as manure rates increased (Table 4.5). This trend occurred in 2001 and continued in 2004 except for the control, which exhibited increases in NO_3-N with a return to normal farming practices.

Measured NO_3-N rates in control treatment (0 kg ha^{-1}) increased at all soil depths between 2001 and 2004. The largest increase was in the 0-15 cm soil depth, increasing from 2.8 kg ha^{-1} in 2001 to 16.8 kg ha^{-1} in 2004 (GLM = 1.35, DF = 8, p = 0.2889). The smallest increase was in the 120-150 cm soil depth where NO_3-N only increased from 1.0 kg ha^{-1} in 2001 to 1.1 kg ha^{-1} in 2004 (GLM = 3.03, DF = 8, p = 0.0282). None of the increases in the control treatment was statistically significant between 2001 and 2004.

The 20 Mg ha^{-1} manure treatment experienced decreases in NO_3-N rates at all soil depths, none of which were statistically significant. The largest observed decrease was in the 30-60 cm soil depth, where the NO_3-N dropped from 8.7 kg ha^{-1} in 2001 to 2.9 kg ha^{-1} in 2004 (GLM = 17.96, DF = 8, p = <0.0001). The smallest decrease of 2.9 kg ha^{-1} occurred in the top 15 cm of soil (GLM = 1.35, Df = 8, p = 0.2889). The other soil depths also showed modest decreases between 2001 and 2004.

Nitrate-nitrogen rates in the 40 Mg ha^{-1} manure treatment showed the same trend as the 20 Mg ha^{-1} manure treatment. The NO_3-N rates decreased at all soil depths and none of the decreases was statistically significant. In this treatment, the highest decrease of 29.6 kg ha^{-1} was also in the 30-60 cm soil depth, decreasing from 36.0 kg ha^{-1} in 2001 to 6.4 kg ha^{-1} in 2004 (GLM = 17.96, DF = 8, p = <0.0001). The next largest decrease was in the top 15 cm of soil, decreasing from 37.3 kg ha^{-1} in 2001 to 13.4 kg ha^{-1} in 2004 (GLM = 1.35, DF = 8, p = 0.2889). The smallest decrease, 8.6 kg ha^{-}1, was in the 90-120 cm soil depth (GLM = 4.24, DF = 8, p = 0.0068). The other depths decreased between 10.0 kg ha^{-1} and 15.2 kg ha^{-1} during the 3 years after the initial study in 2001.

The 60 Mg ha^{-1} manure treatment also exhibited decreases in NO_3-N rates between 2001 and 2004, and is the first treatment in this soil texture to have statistically significant differences in NO_3-N rates. The first soil depth, 0-15 cm, was the first to show a statistically significant change (GLM = 1.35, DF = 8, p = 0.2889). The NO_3-N rate dropped from 64.1 kg ha^{-1} in 2001 to 15.3 kg ha^{-1} in 2004, a change of 48.8 kg ha^{-1}. In the next soil depth, 15-30 cm, the NO_3-N rate dropped by 53.2 kg ha^{-1} in the three years between samples (GLM = 2.95, DF = 8, p = 0.0312). This was also a statistically significant result. The largest decrease observed for this manure treatment was in the 30-60 cm soil depth (GLM = 17.96, DF = 8, p = <0.0001). In this section of soil, measured NO_3-N rates decreased from 187.1 kg ha^{-1} in 2001 to 17.2

Table 4.5 Nitrate-nitrogen levels in medium textured site[†]

		Manure Treatment (Mg ha^{-1})																	
		0			20			40			60			120			ALL		
Depth (cm)	Year	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N	Mean kg ha^{-1}	Std Err	N
0-15	2001	2.8a	0.7	5	13.5a	3.6	5	37.3a	7.6	5	64.1a	8.8	5	71.1a	6.5	5	37.7	6.0	25
	2004	16.8a	5.2	5	10.6a	1.5	5	13.4a	1.4	4	15.3b	2.1	5	24.2b	2.9	5	16.2	1.6	24
15-30	2001	1.5a	0.6	5	6.7a	1.5	5	20.6a	6.1	5	58.0a	9.9	5	101.1a	14.0	5	37.6	8.3	25
	2004	3.1a	0.5	5	3.1a	0.5	5	5.4a	1.3	5	4.8b	1.3	5	9.6b	1.7	3	4.8	0.6	23
30-60	2001	1.2a	0.4	5	8.7a	3.2	5	36.0a	13.1	5	187.1a	69.7	5	327.1a	88.4	5	112.0	33.2	25
	2004	2.8a	0.6	5	2.9a	0.7	5	6.4a	1.6	5	17.2b	12.1	5	136.3b	16.5	5	33.1	11.2	25
60-90	2001	0.9a	0.3	5	6.4a	3.5	5	14.9a	2.8	5	70.5a	12.9	5	282.1a	31.4	5	75.0	22.6	25
	2004	1.5a	0.4	5	1.5a	0.4	5	2.0a	0.5	5	9.9b	4.9	5	133.9b	32.9	5	29.8	12.3	25
90-120	2001	1.2a	0.3	5	5.9a	3.5	5	10.4a	1.9	5	37.7a	11.4	5	218.2a	22.9	5	54.7	17.5	25
	2004	5.9a	3.8	5	1.7a	0.4	5	1.8a	0.7	5	6.8a	4.8	5	105.2b	36.7	5	24.3	10.7	25
120-150	2001	1.0a	0.2	5	6.1a	3.4	5	11.5a	1.6	5	33.7a	10.5	5	135.0a	32.4	5	37.5	12.0	25
	2004	1.1a	0.2	5	1.2a	0.3	5	1.5a	0.6	5	3.5a	1.6	5	16.7b	2.9	3	3.8	1.2	23

[†] Mean values in each column followed by the same letter are not significantly different ($P<0.05$).

kg ha^{-1} in 2004, a decrease of 169.9 kg ha^{-1} during that three-year interval. The final statistically significant NO_3-N decrease was in the 60-90 cm depth. In this depth of soil, NO_3-N rate dropped from 70.5 kg ha^{-1} in 2001 to 9.9 kg ha^{-1} in 2004, a decrease of 60.6 kg ha^{-1} (GLM = 7.93, DF = 8, P = 0.0068). The two lowest soil depths also decreased between 2001 and 2004, but neither was statistically significant.

The highest manure rate, 120 Mg ha^{-1}, exhibited statistically significant decreases in NO_3-N rates at all soil depths. The smallest decrease of NO_3-N was found in the top 15 cm, decreasing by 46.9 kg ha^{-1} between 2001 and 2004 (GLM = 1.35, DF = 8, p = 0.2889). It was also the smallest decrease of the 6 soil depths for this treatment. The highest measured decrease occurred in the 30-60 cm soil depth. The 2001 NO_3-N rate was 327.1 kg ha^{-1} and it decreased to 133.9 kg ha^{-1} in 2004, a change of 190.8 kg ha^{-1} (GLM 17.96, DF = 8. P = <0.0001). Nitrate-nitrogen rates decreased by 91.5 kg ha^{-1} in the 15-30 cm soil depth, the second lowest decrease for this treatment (GLM = 2.95, DF = 8, p = 0.0312). Within the 90-120 cm depth, the measured NO_3-N rate changed from 218.2 kg ha^{-1} in 2001 to 105.2 kg ha^{-1} in 2004 (GLM = 4.24, DF = 8, p = 0.0068). The bottom layer of soil (120-150 cm) that was measured exhibited a decrease from 135.0 kg ha^{-1} in 2001 to 16.7 kg ha^{-1} 2004 (GLM = 3.03, DF = 8, p = 0.0282).

4.2.2 Plant Available Phosphorus

The lowest plant available P rates were associated with the lowest rates of manure application and increased as manure rates increased (Table 4.6). This trend occurred in both 2001 and 2004, but there was no noticeable trend of increases or decreases in any treatment or soil depth during this time period. The measured rates of plant available P did show some increases and decreases in specific treatments and depths, but none were found to be statistically significant.

The measured plant available P in control treatment (0 Mg ha^{-1}) increased at all depths. The largest increase was within the top 15 cm of soil, where P was measured at 37.5 kg ha^{-1} in 2001 and increased to 50.1 kg ha^{-1} in 2004 (GLM = 22.11, DF = 8, p = <0.0001). The other 5 soil depths had increases of less than 10.0 kg ha^{-1} in the three years between samplings. None of the changes were statistically significant.

The 20 Mg ha^{-1} manure treatment showed less of a pattern than the control. Within the top 15 cm of soil, P rates decreased from 196.0 kg ha^{-1} in 2001 to 149.3 kg ha^{-1} in 2004 (GLM = 22.11, DF = 8, p = <0.0001). The next two sampling depths, 15-30 cm (GLM = 9.61, DF = 8, p = <0.0001) and 30-60 cm (GLM = 3.87, DF = 8, p = 0.0103) exhibited slight increases during the same time period, but both were less than 5.0 kg ha^{-1}. There were no statistically significant changes in this treatment.

As with the previous treatment, the 40 Mg ha^{-1} manure treatment varied between depths. Plant available P increased by 17.5 kg ha^{-1} in the top 15 cm of soil (GLM = 22.11, DF = 8, p = <0.0001), and then decreased a small amount in the next two depths, 15-30 cm (GLM = 9.61, DF = 8, p = <0.0001) and 30-60 cm (GLM = 3.87, DF = 8, p = 0.0103). There was a very modest increase of 1.4 kg ha^{-1} in the 60-90 cm depth (GLM = 3.12, DF = 8, p = 0.0250), and slightly larger increases in the next two depths. None of the aforementioned changes was found to be statistically significant.

In the 60 Mg ha^{-1} manure treatment, there were modest decreases in the top three soil depths. The uppermost layer, 0-15 cm, showed a decrease of 55.7 kg ha^{-1} between 2001 and 2004 (GLM = 22.11, DF = 8, p = <0.0001). The next two layers 15-30 cm (GLM = 9.61, DF = 8, p = <0.0001) and 30-60 cm (GLM = 3.87, DF = 8, p = 0.0103) were both below 10.0 kg ha^{-1} and there was no measured change in the following layer, 60-90 cm (GLM = 3.12, DF = 8, p = 0.0250). Below 90 cm, both layers exhibited minor increases, but both were less than 6.0 kg ha^{-1}.

There was a large decrease in plant available P in the top 15 cm of soil for the 120 Mg ha^{-1} manure treatment (GLM = 22.11, DF = 8, p = <0.0001). The measured P was 1179.1 kg ha^{-1} in 2001 and dropped to 1003.5 kg ha^{-1} in 2004. Although the P dropped by 175.6 kg ha^{-1}, this decrease was not found to be statistically significant. In the following soil depth, 15-30 cm, the measured plant available P rate increased from 180.5 kg ha^{-1} in 2001 to 236.0 kg ha^{-1} in 2004 (GLM = 9.61, DF = 8, p = <0.0001). Again, this 55.5 kg ha^{-1} increase was not statistically significant. The next two soil depths, 30-60 cm (GLM = 3.87, DF = 8, p = 0.0103) and 60-90 cm (GLM = 3.12, DF = 8, p = 0.0250), both decreased slightly between 2001 and 2004. The bottom two soil depths increased slightly from 2001 to 2004.

Table 4.6 Plant available phosphorus in medium textured site[†]

		Manure Treatment (Mg ha-1)																	
		0			20			40			60			120			ALL		
Depth	Year	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N
(cm)		kg ha-1			kg ha-1			kg ha-1			kg ha-1			kg ha-1			kg ha-1		
0-15	2001	37.5a	5.4	5	196.0a	15.6	5	326.1a	51.3	5	543.4a	37.5	5	1179.1a	39.7	5	456.4	82.4	25
	2004	50.1a	10	5	149.3a	19.3	5	343.6a	48.8	5	487.7a	31	5	1003.5a	116.4	5	406.8	72.4	25
15-30	2001	3.4a	0.6	5	10.1a	2.6	5	25.3a	7	5	38.3a	14.8	5	180.5a	38.7	5	51.5	15.4	25
	2004	7.1a	0.7	5	12.5a	4.3	5	27.9a	8.6	5	31.2a	7.5	5	236.0a	47.9	5	62.9	19.9	25
30-60	2001	4.0a	0.6	5	9.9a	3.5	5	12.3a	2.6	5	18.1a	6.8	5	29.5a	4.4	5	14.8	2.4	25
	2004	9.5a	0.8	5	11.4a	2.2	5	12.2a	1.4	5	12.4a	1.2	5	18.2a	3	4	12.5	0.9	24
60-90	2001	3.7a	1.4	5	10.2a	3.2	5	8.3a	1	5	11.2a	2.7	5	14.3a	2.4	5	9.6	1.2	25
	2004	8.3a	1	5	9.6a	2.4	5	9.7a	1.1	5	11.2a	1.8	5	12.1a	1.8	5	10.2	0.7	25
90-120	2001	1.9a	0.9	5	7.6a	2.3	5	4.7a	0.8	5	5.2a	1	5	12.3a	2.4	5	6.3	1	25
	2004	9.5a	1.9	5	8.7a	2.2	5	8.6a	0.7	5	10.0a	1	5	14,0a	1.5	5	10.2	0.8	25
120-150	2001	1.3a	0.7	5	2.6a	0.4	4	4.4a	1.3	5	3.7a	0.4	5	6.5a	1.6	4	3.6	0.5	23
	2004	7.1a	0.6	5	7.5a	0.4	5	8.0a	0.3	5	9.3a	0.5	4	14.2a	3.4	5	9.2	0.9	24

† Mean values in each column followed by the same letter are not significantly different (*P*<0.05).

4.2.3 Water Soluble Potassium

Potassium is a vital nutrient in plant, and is the third most likely nutrient likely to cause poor plant growth after N and P. Although K is present in high levels in Western Canadian soils, it is also used in high amounts by plants for more than 80 fuctions. Measuring K, which is present at high levels in manure, is one way to determine if current manure management is effective.

The general trend in the medium textured soil was a decrease in water soluble potassium levels between 2001 and 2004 in all treatments except for the control (Table 4.7). There were a few soil depths and treatments that went against this trend and will be outlined in this section.

The control treatment (0 Mg ha^{-1}) exhibited increases in water soluble K at all soil depths. Within the top 15 cm of soil, the K increased from 20.5 mmol L^{-1} in 2001 to 27.6 mmol L^{-1} in 2004 (GLM = 38.57, DF = 8, p = <0.0001). The smallest increases were in the 15-30 cm (GLM = 22.26, DF = 8, p = <0.0001) and 30-60 cm depths (GLM = 6.70, DF = 8, p = 0.0007), where they increased by 0.4 mmolc L^{-1} and 0.3 mmolc L^{-1} respectively. The largest increase was in the 90-120 cm soil depth, where the K increased by 14.1 mmolc L^{-1} during the three year hiatus on manure application (GLM = 3.76, DF = 8, p = 0.0115). The 60-90 cm (GLM = 7.93, DF = 8, p = 0.0002) and 120-150 cm (GLM = 2.99, DF = 8, p = 0.0296) soil depths also showed modest increases of 1.0 mmolc L^{-1} and 3.0 mmolc L^{-1} respectively. None of the increases in the control treatment were found to be statistically significant.

In the 20 Mg ha^{-1} manure treatment, the trend was a decrease in K levels in the top 90 cm of soil, and modest increases below that depth to 150 cm. The largest decrease in this treatment was in the top 15 cm soil depth, where the water soluble K level dropped from 60.2 mmolc L^{-1} in 2001 to 33.6 mmolc L^{-1} in 2004 (GLM = 38.57, DF = 8, p = <0.0001). The lowest decrease was in the 15-30 cm soil depth where the K level decreased from 7.8 mmolc L^{-1} in 2001 to 6.3 mmolc L^{-1} in 2004, a difference of 1.5 mmolc L^{-1} (GLM = 22.26, DF = 8, p = <0.0001). Potassium levels dropped by 11.3 mmolc L^{-1} in the 30 -60 cm depth (GLM = 6.70, DF = 8, p = 0.0007),, and by 4.7 mmolc L^{-1} in the 60-90 cm depth between 2001 and 2004. Measured water soluble K levels in the 90-120 cm (GLM = 3.76, DF = 8, p = 0.0115) depth increased by 3.7 mmolc L^{-1} and K increased by 7.1 mmolc L^{-1} in the 120-150 cm soil depth during the same period (GLM = 2.99, DF = 8, p = 0.0296). None of the changed measured in this manure treatment were found to be statistically significant.

Water soluble potassium levels in the 40 Mg ha^{-1} manure treatment also decreased in all soil depths with the exception of 90-120 cm (GLM = 3.76, DF = 8, p = 0.0115), which exhibited a very minute increase in K (0.7 mmolc L^{-1}). The largest decrease was in the top 15 cm (GLM = 38.75, DF = 8, p = <0.0001), where K decreased by 32.6 mmolc L^{-1} between 2001 and 2004. The remaining four soil depths experienced modest decreases ranging from 1.6 mmolc L^{-1} in the 15-30 cm (GLM = 22.26, DF = 8, p = <0.0001) soil depth to 10.1 mmolc L^{-1} in the 30-60 cm depth (GLM = 6.7, DF = 8, p = 0.0007). As with the previous treatments, none of these changes was found to be statistically significant.

Measured levels of K decreased in the top 90 cm of soil and increased below that point in the 60 Mg ha^{-1} manure treatment for the medium textured soil. The decrease in the top 15 cm of soil was 101.3 mmolc L^{-1} between 2001 and 2004, the highest in this treatment and the only one that was statistically significant (GLM = 38.57, DF = 8, p = <0.0001). Potassium levels decreased by 6.8 mmolc L^{-1} in the next 15 cm (GLM = 22.26, DF = 8, p = <0.0001), and by 22.0 mmolc L^{-1} and 9.3 mmolc L^{-1} in the 30-60 cm (GLM = 6.7, DF = 8, p = 0.0007) and 60-90 cm (GLM = 7.93, DF = 8, p = 0.0002) depths respectively. None of these decreases was statistically significant. In the 90-120 cm depth, the K level went from 79.4 mmolc L^{-1} in 2001 to 83.4 mmolc L^{-1} in 2004 (GLM = 3.76, DF = 8, p = 0.0115). The last measured depth for this treatment increased by 20.1 mmolc L^{-1} during that same period of time (GLM = 2.99, DF = 8, p = 0.0296). Neither increase for these two depths was statistically significant.

Potassium levels measured in for the 120 Mg ha^{-1} manure treatment decreased at all soil depths except for the 30-60 cm depth. The 0-15 cm soil depth decreased from 495.9 mmolc L^{-1} in 2001 to 300.8 mmolc L^{-1} in 2004 (GLM = 38.57, DF =8, p =<0.0001). This was the only statistically significant change in this treatment. Measured decreases below 15 cm ranged from of 3.4 mmolc L^{-1} in the 90-120 cm (GLM = 3.76, DF = 8, p = 0.0115) depth to 22.1 mmolc L^{-1} in the 120-150 cm depth (GLM = 2.99, DF = 8, p = 0.0296). The increase in the 30-60 cm depth was from 57.2 mmolc L^{-1} in 2001 to 73.9 mmolc L^{-1} in 2004 (GLM = 6.7, DF = 8, p = 0.0007).

Although the overall trend was a decrease in K for all manure treatments other than the control, there were several depths that experienced minor increases in K levels. Statistically significant decreases only occurred in the two highest manure application rates and in the top 15 cm of soil.

Table 4.7 Water soluble potassium levels in medium textured site[†]

		Manure Treatment (Mg ha^{-1})																	
		0			20			40			60			120			ALL		
Depth	Year	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N	Mean	Std Err	N
(cm)		mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}			mmolc L^{-1}		
0-15	2001	20.5a	1.98	5	60.2a	4.77	5	129.1a	39.44	5	242.9a	28.56	5	495.9a	52.05	5	189.7	37.20	5
	2004	27.6a	10.87	5	33.6a	2.04	5	96.5a	18.57	5	141.6b	13.70	5	300.8b	21.61	5	120.0	21.25	5
15-30	2001	4.8a	0.38	5	7.8a	1.13	5	26.0a	13.84	5	48.0a	8.97	5	225.4a	24.93	5	62.4	17.79	5
	2004	5.2a	0.79	5	6.3a	0.73	5	24.4a	11.82	5	41.2a	12.47	5	219.7a	35.05	5	59.4	18.05	5
30-60	2001	11.0a	1.60	5	24.1a	7.62	5	25.0a	4.95	5	42.3a	4.65	5	57.2a	10.71	5	31.9	4.26	a
	2004	11.3a	1.60	5	12.8a	1.80	5	14.9a	3.43	5	20.3a	7.29	5	73.9a	19.23	5	26.6	6.19	5
60-90	2001	22.6a	2.90	5	28.0a	3.93	5	42.3a	7.61	5	51.6a	7.00	5	58.9a	9.96	5	40.7	3.94	5
	2004	23.6a	3.62	5	23.3a	3.53	5	33.0a	6.60	5	42.3a	8.66	5	46.3a	5.89	5	33.7	3.11	5
90-120	2001	41.7a	8.73	5	44.4a	8.12	5	59.2a	8.85	5	79.4a	8.65	5	83.8a	7.78	5	61.7	4.94	5
	2004	55.8a	9.30	5	48.1a	9.83	5	59.9a	8.44	5	83.4a	8.96	5	80.4a	9.91	5	65.5	4.75	5
120-150	2001	56.9a	8.23	5	73.2a	14.24	5	78.3a	9.93	5	98.0a	6.12	5	119.1a	18.40	5	85.1	6.64	5
	2004	59.9a	8.70	5	80.3a	14.63	5	76.6a	11.21	5	118.1a	26.48	5	97.0a	11.10	5	86.4	7.59	5

† Mean values in each column followed by the same letter are not significantly different (*P*<0.05).

4.2.4 Electrical Conductivity

As with the coarse textured soil, the measured electrical conductivity (EC) levels which were highest in 2001 in the medium textured soil were also the highest in 2004 (Table 4.8). Electrical Conductivity rates increased with higher manure application rates and directly correlated with manure application rates. The trend from 2001 to 2004 was a decrease in the EC levels, except for the control which showed minor increases at soil depth above 60 cm between 2001 and 2004. As with the coarse textured samples, there were only two samples that showed statistically significant decreases in the three year period between sampling.

Samples from the control treatment exhibited minor increases between 0.1 and 0.2 dS m^{-1} at all soil depths above 60 cm. The 60-90 cm soil depth did not change between 2001 and 2004 (GLM = 3.84, DF = 8, p = 0.0106). Below 90 cm, each of the two depths decreased by 0.1 dS m^{-1} during this period. None of the changes in this treatment were found to be statistically significant.

The trend in the 20 Mg ha^{-1} manure treatment was a decrease in EC at all soil depths. Within the top 15 cm of soil, the EC dropped from 0.9 dS m^{-1} in 2001 to 0.6 dS m^{-1} in 2004 (GLM = 4.7, DF = 8, p = 0.0041). During this same period, the EC level dropped by 0.5 dS m^{-1} in the 15-30 cm soil depth (GLM = 2.00, DF = 8, p = 0.1138) and 0.8 dS m^{-1} in both the 30-60 cm (GLM = 2.25, DF = 8, p = 0.0796) and 60-90 cm depths (GLM = 3.84, DF = 8, p =0.0106). In the next depth, 90-120 cm, EC dropped by 0.6 dS m^{-1} between 2001 and 2004 (GLM = 4.10, DF = 8, p = 0.0079). Electrical conductivity levels in the 120 -150 cm depth were measured at 2.9 dS m^{-1} in 2001 and decreased to 2.8 dS m^{-1} by 2004 (GLM = 3.09, DF = 8, p = 0.0262). None of the decreases recorded in this treatment were found to be statistically significant.

The 40 Mg ha^{-1} manure treatment exhibited decreases in EC at all soil depths as well. The smallest decrease was measured in the 0-15 cm (GLM = 4.7, DF = 8, p = 0.0041) and 15-30 cm (GLM = 2.00, DF = 8, p = 0.1138) soil depths, as EC only dropped by 0.1 dS m^{-1} in each. The 30-60 cm depth was measured at 2.2 dS m^{-1} in 2001 and dropped to 1.5 dS m^{-1} by 2004 (GLM = 2.25, DF = 8, p = 0.0796). The 90-120 cm soil depth also decreased by 0.7 dS m^{-1} during this time period (GLM = 4.10, DF = 8, p = 0.0079). The 60-90 cm (GLM = 3.84, DF = 8, p =0.0106) depth decreased by 0.5 dS m^{-1} and in the 120 -150 cm soil depth, the decrease was measured at 0.3 dS m^{-1} (GLM = 3.09, DF = 8, p = 0.0262). None of these decreases was found to be statistically significant.

The trend of decreasing EC levels from 2001 to 2004 continued in the 60 Mg ha^{-1} manure treatment. The EC levels in the top 15 cm soil depth were recorded at 1.2 dS m^{-1} in 2001 and dropped to 0.9 dS m^{-1} by 2004, a statistically significant difference of 0.3 dS m^{-1} (GLM = 4.7, DF = 8, p = 0.0041). Electrical conductivity levels dropped in all other soil depths as well, but were not statistically significant. The greatest decrease was measured in the 30-60 cm soil depth, where the measured EC was 3.2 dS m^{-1} in 2001 and dropped to 2.1 dS m^{-1} by 2004 (GLM = 2.25, DF = 8, p = 0.0796). The EC levels in both the 15-30 cm (GLM = 2.00, DF = 8, p = 0.1138) and 60-90 cm (GLM = 3.84, DF = 8, p =0.0106) soil depths decreased by 0.8 dS m^{-1} in the three years after treatments were completed. The 90-120 cm soil depth showed a decrease of 0.4 dS m^{-1} during this time (GLM = 4.10, DF = 8, p = 0.0079). In the 120-

Table 4.8 Electrical Conductivity levels in medium textured site†

		Manure Treatment (Mg ha^{-1})																	
		0			20			40			60			120			ALL		
Depth (cm)	Year	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N	Mean dS m^{-1}	Std Err	N
0-15	2001	0.6a	0.05	5	0.9a	0.09	5	0.9a	0.09	5	1.2a	0.10	5	1.7a	0.07	5	1.1	0.08	25
	2004	0.7a	0.08	5	0.6a	0.02	5	0.8a	0.06	5	0.9b	0.08	5	1.0b	0.08	5	0.8	0.04	25
15-30	2001	0.5a	0.02	5	1.2a	0.51	5	1.1a	0.20	5	2.2a	0.43	5	2.3a	0.28	5	1.4	0.19	25
	2004	0.6a	0.09	5	0.7a	0.13	5	1.0a	0.23	5	1.4a	0.53	5	1.4a	0.20	5	1.0	0.14	25
30-60	2001	0.5a	0.05	5	1.7a	0.70	5	2.2a	0.60	5	3.2a	0.48	5	3.7a	0.64	5	2.3	0.32	25
	2004	0.7a	0.17	5	0.9a	0.20	5	1.5a	0.59	5	2.1a	0.77	5	2.7a	0.38	5	1.6	0.25	25
60-90	2001	0.7a	0.11	5	1.8a	0.55	5	2.2a	0.56	5	3.2a	0.63	5	3.7a	0.41	5	2.3	0.29	25
	2004	0.7a	0.16	5	1.0a	0.18	5	1.7a	0.44	5	2.4a	0.64	5	2.8a	0.34	5	1.7	0.23	25
90-120	2001	1.5a	0.55	5	2.3a	0.68	5	2.8a	0.73	5	3.6a	0.86	5	4.5a	0.67	5	2.9	0.36	25
	2004	1.4a	0.52	5	1.7a	0.49	5	2.1a	0.59	5	3.2a	0.99	5	2.8a	0.33	5	2.2	0.29	25
120-150	2001	2.2a	0.62	5	2.9a	0.69	5	3.5a	0.80	5	4.3a	0.64	5	4.9a	0.63	5	3.6	0.34	25
	2004	2.1a	0.61	5	2.8a	0.73	5	3.2a	0.84	5	3.7a	0.74	5	3.5a	0.58	5	3.1	0.31	25

† Mean values in each column followed by the same letter are not significantly different ($P<0.05$).

150 cm soil depth, the EC was measured at 4.3 dS m^{-1} in 2001 and at 3.7 dS m^{-1} in 2004 (GLM = 3.09, DF = 8, p = 0.0262).

The 120 Mg ha^{-1} manure treatment exhibited the same trend of decreasing EC levels over the three years after treatments ceased. The EC level in 2001 was measured as 1.7 dS m^{-1} and decreased to 1.0 dS m^{-1} by 2004 in the top 15 cm of soil, the smallest decrease but also the only found to be statistically significant in this treatment (GLM = 4.7, DF = 8, p = 0.0041). The decrease in the 15-30 cm (GLM = 2.00, DF = 8, p = 0.1138) and 60-90 cm (GLM = 3.84, DF = 8, p =0.0106) soil depths was measured at 0.8 dS m^{-1} for each. In the 30-60 cm depth, EC was found to be 3.7 dS m^{-1} in 2001 and decreased to 2.7 dS m^{-1} in 2004 (GLM = 2.25, DF = 8, p = 0.0796). The largest decrease in this treatment was in the 90-120 cm soil depth, where EC levels decreased by 1.7 dS m^{-1} (GLM = 4.10, DF = 8, p = 0.0079). The 120-150 cm soil depth was measured at 4.9 dS m^{-1} in 2001 and decreased to 3.5 dS m^{-1} by 2004 (GLM = 3.09, DF = 8, p = 0.0262).

4.3 On farm Site

4.3.1 Nitrate-nitrogen Levels – On farm

The highest levels of NO_3-N for the on farm site were measured in west half of NE 1-11-20 W4, both halves of NE 12-11-20 and SE 14-11-20 W4 (Table 4.9). The lowest measured rate of NO_3-N was found in NE 1-11-20 W4 (East) and SE 14-11-20 W4 (North). Nitrate-nitrogen levels in west part of NE-1-11-20 W4 was measured at 57 kg ha^{-1} within the top 15 cm soil depth, 70 kg ha^{-1} in the 60-90 cm depth and at 90 kg ha^{-1} within the 30 to 60 cm section of soil. The NO_3-N was below 50 kg ha^{-1} in the 15-30 cm, 90-120 cm and 120-150 cm soil depths in this side of the field. In the east part of NE-1-11-20 W4, NO_3-N levels were substantially lower. Measured NO_3-N levels ranged from 1 kg ha^{-1} to 5 kg ha^{-1}, where the lowest level was in the 15-30 cm depth and the highest in the 90-120 cm depth.

In the west part of NE 12-11-20 W4, NO_3-N levels were highest in the 30-60 cm soil depth, measured at 96 kg ha^{-1}. The top 15 cm of soil contained 39 kg ha^{-1} NO_3-N and the measured NO_3-N level was 50 kg ha^{-1} in the 15-30 cm soil depth. Below 60 cm, NO_3-N levels were less than 50 kg ha^{-1}. In the east half of the field, NE 12-11-20 W4, NO_3-N levels measured highest in the 30-60 cm depth (76 kg ha^{-1}) and lowest in the top 15 cm of soil (19 kg ha^{-1}). All of the NO_3-N levels in the other four soil depths were measured at below 50 kg ha^{-1}.

In the South-west part of the SE 14-11-20 W4 quarter, the highest NO_3-N level was found in the 0 to 15 cm soil depth at 57 kg ha^{-1}. The NO_3-N levels in the 15-30 cm, 60-90 cm and 90-120 cm depths were all measured at 27 kg ha^{-1}. The 30-60 cm and 120-150 cm were measured at 34 kg ha^{-1} and 36 kg ha^{-1} respectively. In the north portion of SE 14-11-20 W4, NO_3-N levels were all found to be 5 kg ha^{-1} or less. The highest NO_3-N level in this part of the field was at the surface, and the lowest was in the 30-60 cm soil depth.

The NE 11-11-20 W4 field had moderate levels of NO_3-N (14 kg ha^{-1}) at the surface (0 to 15 cm) and levels below 6 kg ha^{-1} at soil depths below 15 cm. In the SE 11-11-20 field, the highest NO_3-N level of 15 kg ha^{-1} was found in the deepest soil depth, 120-150 cm. The NO_3-N in the top 15 cm soil depth measured 13 kg ha^{-1} and was less than 7 kg ha^{-1} in the other four sample depths.

Low NO_3-N levels were also measured in the NW 12-11-20 W4 field. Surface soil (0 to 15 cm) NO_3-N levels of were measured at 11 kg ha^{-1}. The highest level of NO_3-N (12 kg ha^{-1}) was measured in the bottom soil depth at 120-150 cm. All other soil depths exhibited NO_3-N levels of less than 9 kg ha^{-1}.

Similarly, low NO_3-N levels were also measured in SE 12-11-20 W4, where the highest level was 15 kg ha^{-1} in the 0-15 cm soil depth. Below 15 cm, the NO_3-N levels were all measured at 5 kg ha^{-1} or less.

4.3.2 Plant Available Phosphate Levels – On farm

Phosphate levels over 200 kg ha^{-1} were found in 7 of the 10 sites sampled for the on farm portion of this study (Table 4.9). The other 3 fields had P levels over 100 kg ha^{-1} in the top 15 cm of soil. Phosphate levels over 100 kg ha^{-1} are considered to be an environmental threshold and are of potential environmental concern.

The locations with the highest P levels were NE 11-11-20 W4 and SE 14-11-20 W4. In the top 15 cm, P levels were measured at 567 kg ha^{-1} and 562 kg ha^{-1} respectively. In NE 11-11-20 W4, P levels were all less than 100 kg ha^{-1}below 15 cm. In the SE 14-11-20 W4 field, P levels were 263 kg ha^{-1} in the 15-30 cm soil depth, and then were less than 100 kg ha^{-1} below 30 cm.

Table 4.9 Nutrient levels in each field on the Schuld farm by depth.

Field	Depth	Mean pH	Mean E.C.	Mean NO3-N	Mean PO4-P	Mean K
	cm		dS m^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
NE 1-11-20 W4 (West)	0 to 15	7.8	1.6	57	335	1269
	15 to 30	8.0	1.5	40	48	492
	30 to 60	8.1	1.7	90	28	542
	60 to 90	8.2	1.4	70	18	246
	90 to 120	8.3	1.2	46	17	211
	120 to 150	8.3	1.8	33	8	282
NE 1-11-20 W4 (East)	0 to 15	7.4	1.0	2	126	389
	15 to 30	7.8	0.6	1	37	217
	30 to 60	8.1	0.5	2	33	369
	60 to 90	8.2	0.5	2	11	304
	90 to 120	8.2	0.5	5	14	282
	120 to 150	8.3	0.5	3	8	220
SE 14-11-20 W4 (north)	0 to 15	7.4	0.81	5	562	549
	15 to 30	8.0	0.70	1	263	244
	30 to 60	8.2	0.80	0	94	296
	60 to 90	8.2	0.89	2	19	181
	90 to 120	8.1	0.85	2	18	141
	120 to 150	7.9	1.45	4	11	282
NE 12-11-20 W4 (West)	0 to 15	7.5	1.1	39	245	1182
	15 to 30	7.7	2.5	50	160	835
	30 to 60	7.8	2.9	96	23	1018
	60 to 90	8.0	3.8	43	12	509
	90 to 120	8.2	4.1	13	12	510
	120 to 150	8.0	4.6	6	11	581
SE 14-11-20 W4 (SW)	0 to 15	7.4	1.2	57	167	846
	15 to 30	7.7	0.7	27	65	290
	30 to 60	7.9	0.6	34	16	337
	60 to 90	7.9	1.6	27	11	222
	90 to 120	7.9	2.2	27	11	317
	120 to 150	8.0	2.7	36	9	352
NE 12-11-20 W4 (East)	0 to 15	7.6	2.2	19	567	2272
	15 to 30	7.9	4.7	47	97	1384
	30 to 60	7.9	6.0	76	93	1897
	60 to 90	7.8	5.5	29	95	1084
	90 to 120	7.7	4.1	31	45	985
	120 to 150	7.7	4.1	25	42	915
NE 11-11-20 W4	0 to 15	7.4	0.7	14	131	473
	15 to 30	7.5	0.6	5	95	286
	30 to 60	7.7	0.8	6	67	378
	60 to 90	7.9	0.8	5	24	263
	90 to 120	8.2	0.9	3	15	255

Table 4.9 continued

Field	Depth	Mean pH	Mean E.C.	Mean NO3-N	Mean PO4-P	Mean K
	cm		dS m^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
SE 11-11-20 W4	0 to 15	7.4	0.7	13	239	732
	15 to 30	7.6	0.7	4	102	665
	30 to 60	7.9	0.9	5	40	435
	60 to 90	8.0	1.4	4	14	275
	90 to 120	8.0	2.4	7	12	471
	120 to 150	8.2	1.5	15	9	471
NW 12-11-20 W4	0 to 15	7.4	0.8	11	202	766
	15 to 30	7.8	0.8	4	88	438
	30 to 60	8.0	2.2	8	21	361
	60 to 90	8.2	3.5	9	9	287
	90 to 120	8.2	3.5	3	9	396
	120 to 150	8.0	5.4	12	9	563
SE 12-11-20 W4	0 to 15	7.6	0.9	15	275	778
	15 to 30	7.9	1.2	5	120	844
	30 to 60	8.1	2.3	5	31	1026
	60 to 90	8.1	2.8	2	13	435
	90 to 120	8.1	2.8	1	9	440
	120 to 150	8.1	2.1	2	7	431

The next highest level of P measured in this study was on the west part of NE 1-11-20 W4. In the 0-15 cm soil depth, P levels were found to be 335 kg ha^{-1}. Below 15 cm, P levels all measured less than 50 kg ha^{-1}.

Phosphate levels in SE 12-11-20 W4 were measured at 275 kg ha^{-1} in the top 15 cm of soil, and 120 kg ha^{-1} in the 15-30 cm soil depth. Below 30 cm, the remaining 4 sample depths all had P levels measured at less than 30 kg ha^{-1}.

In NE 12-11-20 W4 and SE 11-11-20 W4, P levels in the top 15 cm of soil were measured at 245 kg ha^{-1} and 239 kg ha^{-1} respectively. In the 15-30 cm soil depth, P levels were 160 kg ha^{-1} in NE 12-11-20 W4 and 102 kg ha^{-1} in SE 11-11-20 W4. For both locations, P levels were measured at less than 50 kg ha^{-1} at soil depths below 30 cm.

Phosphate levels in NW 12-11-20 W4 were measured at 202 kg ha^{-1} in the 0-15 cm soil depth, and 88 kg ha^{-1} in the 15-30 cm depth. Below 30 cm, all P levels were measured at 21 kg ha^{-1} or less.

Phosphate levels on SE 14-11-20 W4 were below the environmental threshold level at 167 kg ha^{-1} in the top 15 cm soil depth. Below 15 cm, P levels were 65 kg ha^{-1} or less for this site. The P levels on the top 15 cm of soil on NE 11-11-20 W4 and NE 1-11-20 W4 were 131 kg ha^{-1} and 136 kg ha^{-1} respectively. In the 15-30 cm soil depth for NE 11-11-20 W4, P levels were measured at 95 kg ha^{-1} and at 37 kg ha^{-1} in NE 1-11-20 W4 in the same soil depth. Below 30 cm, P levels were less than 70 kg ha^{-1} for both sites.

4.3.3 Water Soluble Potassium Levels – On farm

Potassium is considered by many to be of little environmental consequence when present in high levels. It has an agronomic impact when available in high levels in the soil and is taken up luxuriously by plants. The site with the highest level of water soluble K was the east half of NE 12-11-20 W4 (Table 4.9). In the top 15 cm of soil, K was measured at 2272 kg ha^{-1}. In the 15-30 cm depth, the K level was measured at 1384 kg ha^{-1} and 1897 kg ha^{-1} in the 30-60 cm depth. Potassium levels remained high below 60 cm for this site. In the 60-90 cm depth, K measured 1084 kg ha^{-1}, and was over 900 kg ha^{-1} in each of the bottom two depth.

The site with the next highest levels of K was NE 1-11-20 W4. Potassium levels in the top 15 cm of soil were measured at 1269 kg ha^{-1}. Below 15 cm, K levels dropped below 500 kg ha^{-1}, and were lowest (211 kg ha^{-1}) in the 90-120 cm depth.

Water soluble potassium in NE 12-11-20 W4 was measured at 1182 kg ha^{-1} in the top 15 cm, 835 kg ha^{-1} in the 15-30 cm depth and 1018 kg ha^{-1} in the 30-60 cm depth. Potassium levels measured in the 60-90 cm depth were the lowest for this field at 509 kg ha^{-1} but were close to K measured at 510 kg ha^{-1} in the 90-120 cm depth. In the deepest sample depth, K levels were 581 kg ha^{-1}.

On the SE 14-11-20 W4 site, K levels were measured at less than 1000 kg ha^{-1} at all soil depths. The highest K level was in the surface (0-15 cm) soil depth, measured at 846 kg ha^{-1}. The next highest K level of 352 kg ha^{-1} was located in the 120-150 cm soil depth. The lowest level was in the 60-90 cm depth, and was 222 kg ha^{-1}.

The K levels were highest in the 30-60 cm soil depth on SE 12-11-20 W4, measured at 1026 kg ha^{-1}. The K levels measured in the 0-15 cm and 15-30 cm depths were 778 kg ha^{-1} and 844 kg ha^{-1} respectively. Below 60 cm, all K levels were measured at less than 450 kg ha^{-1}.

Potassium levels in SE 11-11-20 W4 and NW 12-11-20 W4 were highest in the top 15 cm of soil, measured at 732 kg ha^{-1} and 766 kg ha^{-1} respectively. The K levels were measured at less than 700 kg ha^{-1} below 15 cm of soil for both of these sites.

The fields with the lowest measured levels of K were SE 14-11-20 W4, NE 11-11-20 W4 and NE 1-11-20 W4. The K levels in the top 15 cm were 549 kg ha^{-1}, 473 kg ha^{-1} and 389 kg ha^{-1} respectively. Potassium levels below 15 cm were all measured at less than 370 kg ha^{-1} for all three fields.

4.3.4 Electrical Conductivity – On farm

Electrical conductivity levels above 2 dS m^{-1} begin to impact crop growth. Many of the fields in this study were below 2 dS m^{-1}, but there were several that were higher than that level at some soil depth (Table 4.9).

There were three fields that had EC levels below 2 dS m^{-1} at all soil depths. These were the East and West parts of NE 1-11-20 W4 and the north part of SE 14-11-20 W4. The EC levels in these fields ranged between 0.5 dS m^{-1} and 1.7 dS m^{-1}. One other field (NE 11-11-20 W4) had EC levels below threshold level at all soil depths except for the 120-150 cm depth, which measured 2.9 dS m^{-1}.

There were four fields where EC in the surface soils were less than 2 dS m^{-1} but where EC increased at some depth. This was the case in the Southwest part of SE 14-11-20 W4, where the EC ranged from 0.6 to 1.6 dS m^{-1} in the top 90 cm, but increased below that. In the 90-120 cm depth of this site, the EC level was 2.2 dS m^{-1} and 2.7 dS m^{-1} in the 120-150 cm depth. The site at SE 11-11-20 W4 had a similar EC range, but only had one soil depth where the EC measured at 2.4 dS m^{-1} (90-120 cm). Both NW 12-11-20 W4 and SE 12-11-20 W4 exhibited EC levels below 2 dS m^{-1} in the top 30 cm, and EC levels higher than 2 dS m^{-1} below that soil depth. The EC level in the 60-90 cm and 90-120 cm depth in NW 12-11-20 W4 was measured at 3.5 dS m^{-1} and 5.4 dS m^{-1} in the 120-150 cm soil depth.

The EC levels in west part of NE 12-11-20 W4 measured at 1.1 dS m^{-1} in the top 15 cm of soil, and increased below 15 cm. The 60-90 cm soil depth had a measured EC level of 3.8 dS m^{-1} and in the 120-150 cm depth the EC level was 4.6 dS m^{-1}. In the east part of NE 12-11-20 W4, EC levels were over 2 dS m^{-1} at all soil depths. This field had the highest measured soil EC for the on farm site. Electrical conductivity was measured at 6.0 dS m^{-1} in the 30-60 cm soil depth for this site. The EC level was slightly lower in the next soil depth (5.5 dS m^{-1}) and decreased slightly in the next two soil depths, to 4.1 dS m^{-1}.

4.4 On farm Site - Manure Analysis

The results from the manure sampling are summarized in Table 4.10. There were 150 dairy cows, 100 dairy heifers and calves and 1800 head of finishing cattle on the farm over the year, consuming feed and producing manure. The amount of manure produced for each type of animal is summarized in Table 4.8. The average level of N, P and K produced in the manure is also stated in the table.

The farm at full capacity of feedlot and dairy production will produce roughly 18,300 tonnes of manure each year. The cow/calf portion will only contribute manure to confined pens for half of the year, dropping this value to 17,600 tonnes $year^{-1}$.

This manure is then applied on land under cultivation, approximately 240 acres per year, resulting in approximately 75 Mg of manure applied to each acre of land each year. Approximately 1000 kg $acre^{-1}$ N, 790 kg $acre^{-1}$ P and 990 kg $acre^{-1}$ K are applied in manure form each year to the soil.

4.5 On farm Site - Plant and Feed

The estimated crop removal of nutrients for the on farm site is illustrated in Table 4.11. There was 215 kg N removed per year by alfalfa bales, 82 kg yr^{-1} N removed in corn silage and 79 kg yr^{-1} removed by barley silage.

The barley and corn are fed to the dairy and feedlot cattle, and two-thirds of the alfalfa was exported off farm. This means that 141 kg N was exported from the farm each year as alfalfa. The remaining 232 kg was returned to the farm as feed in the form of alfalfa hay, barley silage and corn silage. Phosphorus exported from the farm amounted to 12 kg yr^{-1} and K at a rate of 118 kg yr^{-1}.

Table 4.10 Livestock production statistics from Schuld farm. Nutrient content based average values from manure sample collected in 2004, livestock production based on national numbers.

Type	Number	Milk Production	Beef Production	Manure produced daily	Manure produced yearly		N content in manure	P content in manure	K content in manure
		Liters	pound of gain	kg	kg yr^{-1}	Mg yr -1	kg yr^{-1}	kg yr^{-1}	kg yr^{-1}
Dairy Cows	150	1200000	n/a	45	2463750	2463.75	33507	25869	32522
Dairy Heifer and Calves	100	n/a	n/a	19	693500	693.5	9432	7282	9154
Finished Cattle	1800	n/a	1170000	21	13797000	13797	187639	144869	182120
Cow Calf Pair	190	n/a	n/a	20	1387000	1387	18863	14564	18308

Table 4.11 Average crop yields and removal

		Average nutrients removed					
Crop	Average dry yield tonne/ha	Nitrogen		Phosphorus		Potassium	
		%	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}
Alfalfa bales	5.5	3.9	215	0.33	18	3.22	177
Corn silage (68% moisture)	5.44	1.5	82	0.465	25	2.42	132
Barley silage (65% moisture)	3.675	2.14	79	0.33	12	2.37	87

Chapter 5 Discussion

5.0 Introduction

This chapter will discuss the results presented in Chapter 4. The long-term results are discussed first and are organized by texture and then nutrients. The on farm site is organized by nutrients and a discussion of the nutrient balance for the on farm site is included. This study was undertaken for two purposes. The first was to study two long term trials from 1993 to 2001 to determine changes in soil nutrient levels three years after the initial long-term study terminated. The second component of this research involved the investigation of an intensive livestock operation, including both dairy and confined cattle feeding components, within the Battersea Drain Watershed. The purpose was to determine the status of soil nutrients after repeated manure applications and to recommend future manure management options. A comparison of the results from both parts of this study will be presented, and conclusions about the future of manure handling procedures in the Battersea Drain area will be presented.

As stated in the Results chapter (Section 4.1.1) nitrate-nitrogen levels were found to be lowest in treatments with the lowest rates of manure application in both 2001 and 2004. This observation remained constant regardless of the nutrient being observed, or depth of soil sample. In short, application of manure controlled the nutrient levels in the soil. The control treatment in each of the samples showed increases in each nutrient measured between 2001 and 2004 sampling dates.

The coarse textured site was returned to alfalfa production after 2001, while the medium textured soil was seeded to annual cereal crops before returning to alfalfa production prior to 2004. Alfalfa will produced roots to a depths of 3 to 9 meters in different soil types and water table conditions (Albert Agriculture 1981), and cereal crops will produce root systems that extend to approximately 1 m under irrigated conditions. The difference in rooting depth impacts nutrient use within the soil profile. Over the 8 years of the trial, some nitrogen may have been deposited from ammonia in the air due to the large number of feedlots in the immediate area, and via mineralization processes occurring in the soil (McGinn et al. 2003).

5.1 Coarse Textured Site

5.1.1 Nitrate-Nitrogen

The control treatment in 2001 reflects the nutrient status of the soil without manure nutrient inputs. By 2004, with a return to normal farming practices, NO_3-N levels began to increase in the control plots, but not enough to be statistically significant. There were no statistically significant differences in the control, 20 Mg ha^{-1} or 40 Mg ha^{-1} treatments, although N levels did decrease for the plots where manure was applied.

Although the differences in these treatments were not significant, there was a definite trend of decreasing NO_3-N levels in both the 20 Mg ha^{-1} and 40 Mg ha^{-1} treatments. This was especially noted in the lowest soil depth (120-150 cm) in the 40 Mg ha^{-1} treatment, where NO_3-N levels dropped from 106.4 kg ha^{-1} in 2001 to 5.0 kg ha^{-1} in 2004. The possible fate of the 101.4 kg ha^{-1} of NO_3-N may have been to several processes. The NO_3-N may have been leached to below 150 cm, denitrified under saturated soil conditions or utilized by the alfalfa crop especially during the establishment year. Similar decreases in NO_3-N at the same soil depth for other treatments seem to indicate that one or more of these processes were occurring over the three year hiatus of sampling.

The 60 Mg ha^{-1} treatment had significant NO_3-N decreases in most soil depths between 2001 and 2004. Significant changes occurred in the top 30 cm and between 60 and 120 cm. The largest change was within the 90 to 120 cm depth, decreasing by 118 kg ha^{-1}. Similar trends emerged with the highest manure treatment, 120 Mg ha^{-1}, with the greatest nitrate reduction within the 120 to 150 cm depth. This change was a mean of 160 kg ha^{-1} to 20 kg ha^{-1}. These changes indicated that there was a decrease of nitrate within the system, likely due to alfalfa uptake and possibly some leaching as discussed above.

Leaching of NO_3-N due to irrigation was not a statistically significant factor in the observed decreases in NO_3-N, as the coarse textured site was located on a pivot corner and was not irrigated after 2001. The groundwater depth in the coarse textured site was on average 2.06 meters below the soil surface during the research study period (1993 to 2001) for the long term trials (Olson et al. 2003).

Fluctuations in groundwater occurred, with the shallowest depth recorded on August 23, 1999 at 1.45 meters and deepest on March 18, 1996 at a depth of 2.70 meters (Olsen *et al.* 2003). Groundwater depth was not measured for this study but was expected to be below 2 m as no irrigation water was applied after 2001. Drought in 2000 and 2001 followed by heavy rains in 2002 may have had some impact on downward movement of nitrates in the course textured soil and depth to the water table.

Leaching was potentially a factor in the nitrate decreases observed at this site, but the deep rooted alfalfa crop most likely had the greatest influence on nitrate change. Denitrification was not likely a major factor for most of the three years between samples, since the water table usually was below 200 cm and the soil was coarse textured and well drained.

Choice of crop in the intervening three years likely had a significant effect on nitrate levels. Alfalfa has a deep root system that extends to below 200 cm and it was the crop grown at this site from 2001 to 2004. Nitrates moving downward in the soil profile would have been available for uptake by alfalfa roots, even at depths below what other shallower rooted crops could utilize. Alfalfa roots were found in core samples to a depth of 150 cm during the fall 2004 sampling period.

The long term study concluded in 2001, and at that time nitrate levels were very high in the plots treated with higher levels of manure. For both the 60 and 120 Mg ha^{-1}, there were high rates of nitrates present in 60 to 90, 90 to 120 and 120 to 150 cm depths.

These significant changes indicate that even with high rates of manure application, it was possible to have significant reductions in nitrate levels once manure applications cease. Using a deep rooted crop such as alfalfa and without additional manure applications, it was possible to reduce nitrate levels from what would be considered excessive levels to well below maximum allowable levels in the soil. This is very important to intensive livestock operators that may have excessive levels of nitrates in their soil.

5.1.2 Plant Available Phosphorus

The ratio of N to P in cattle feedlot manure is 4:1 or 5:1, significantly lower than for crops where the ratio is 6:1 to 8:1 (Whalen and Chang 2001). Manure in Alberta has long been managed and applied based on N content. Long term application of cattle feedlot manure based on N rate in manure to crop N requirements had led to accumulations of P in the soil (Chang *et al.* 1994; Whalen and Chang 2001). High rates of manure from high density feedlots applied to the soil contain P in excess of crop needs. This results in increased soil-P tests and soil P saturation (Simard *et al.* 2001) and an accumulation over time. Studies conducted in southern Alberta by Whalen and Chang (2001) concluded that P leaching to below 150-cm occurred after long term manure application and were impacted by the water table and irrigation water management.

The P levels increased in the control treatment with the return to normal farming practices, but in all other treatments, P levels decreased between 2001 and 2004 with a few exceptions. Although not statistically significant, it was interesting to note that P levels dropped at most soil depths and treatments once manure application ceased. Levels of P in the top 30 cm were still considered to be quite high in 2004. Within the 30-60 cm depth of 20 Mg ha^{-1}, 40 Mg ha^{-1} and 120 Mg ha^{-1} manure treatments, P levels increased modestly and may have been related to soil texture at that depth.

There was no significant impact as a result of discontinuing manure applications on the coarse-textured site except on one manure treatment, 120 Mg ha^{-1}. There was a significant decrease of 224.2 kg ha^{-1} for this treatment within the top 15 cm and no significant changes throughout the rest of the soil profile. Assuming dryland alfalfa production of 4.5 kg ha^{-1}, crop removals would amount to 22.5 kg ha^{-1} per year, for a total of 66.5 hg ha^{-1} over the three years. This crop removal accounts for part of the P decrease, and immobilization by soil organisms to the immobilized P (Pi) portion of the P cycle may help account for the other 157.7 kg ha^{-1}. Slight increases in the 15 to 30 and 30 to 60 kg ha^{-1} may also account for some of the change, if P moved downward through the soil by diffusion. However, this is not a likely scenario since the coarse textured plots were located on a dryland pivot corner.

5.1.3 Water Soluble Potassium

Many of the soils in western Canada have adequate levels of plant available K in their natural state (AAFC 1998). Additions of K in manure impact not only plant available K but also the salt concentration of the soil, and high application rates can eventually contribute to salinity issues, especially in areas with high EC levels (Hao and Chang 2003).

Water soluble K decreased in all treatments except the control, but statistically significant changes in water soluble K were found only in the 60 Mg ha^{-1} and 120 Mg ha^{-1} manure treatments. In the 60 kg ha^{-1} treatment there was a change of 215.1 kg ha^{-1} within the top 15 cm. There was also a decrease of 81.6 kg ha ha^{-1} in the 30 to 60 cm depth. The decreases at both depths were likely due to crop uptake, since alfalfa was harvested and the K was not replenished from residue. An alfalfa crop that removes 4.5 tonnes ha^{-1} of dry matter would remove approximately 89 kg ha^{-1} of K per year. Over three years, 267 kg ha^{-1} of K would be used by alfalfa. The crop requirements for K would have been satisfied by these two. Potassium not utilized by the crop, approximately 30 kg ha ha^{-1}, would have moved to the soil solution K.

The 120 Mg ha^{-1} manure treatment showed a significant decrease in the top 15-cm of soil, decreasing from 632.7 kg ha^{-1} in 2001 to 286 kg ha^{-1} in 2004. This decrease was likely due to plant uptake, but may also have been due to movement to the exchangeable pool or leaching. Alfalfa uptake of 267 kg ha^{-1} of K, based on a 4.5 tonne ha^{-1} per year yield on non-irrigated soil, would result in an excess of nearly 80 kg ha^{-1} of K in the top 15 cm. Significant decreases also occurred in the 30 to 60 and 60 to 90 cm depths. The K in excess of plant requirements in these depths would have become part of the exchangeable and non-exchangeable K pools in the soil or leached. There was a slight accumulation of K in the 120 to 150 cm soil depth over the three years, which may have been due to leaching over that time.

Plant use by alfalfa, with a high K requirement, was likely a significant factor in the decreases observed for these manure treatments. There was a definite increase in soil K in the 0 to 15 cm depth with increasing rates of manure treatment. The change observed between 2001 and 2004 had a trend that showed greater decreases with depth and correspondingly higher manure application rates. The changes from 2001 to 2004 were not always significant, but the general trend was a decline in water soluble K in the coarse textured site.

5.1.4 Electrical Conductivity

Electrical conductivity of a soil can have an impact on crop growth. Soils that have a high EC (over 4 dS m^{-1}) begin to have limits on which crops can be grown (Ab Ag 2007). The EC levels measured in the coarse textured site were all below 2 dS m^{-1} and would have no impact on most crops. The overall trend for all the treatments was a decrease in EC levels, but most of these decreases were not significant. In the control treatment, EC levels increased very slightly, but were not statistically significant. The only treatment that showed statistically significant difference between 2001 and 2004 was 120 Mg ha^{-1}, which was measured at 1.4 dS m^{-1} in 2001 and decreased to 1.0 dS m^{-1} in 2004. The change in EC was likely due to a reduced level of salt additions to the soil once manure application ceased.

5.2 Medium Textured Site

5.2.1 Nitrate-Nitrogen

The medium textured site was seeded to cereal crops after the long term trials ended in 2001, and were subsequently seeded to alfalfa prior to sampling in 2004. Cereal crops have shallower rooting systems than alfalfa, and were only able to utilize nitrates present within the down to 90-cm depths.

There was no significant change noted for the control, 20 and 40 Mg ha^{-1} manure treatments. Significant changes occurred in the 60 and 120 Mg ha^{-1} treatments.

Significant changes occurred to a depth of 90 cm for the 60 Mg ha^{-1} treatment. The largest change appeared to occur within the 30 to 60 cm layer for this treatment, a decrease of 169.9 kg ha^{-1}. This was likely due to plant uptake and possibly some leaching. There were saturating rains in June of 2002, where approximately 300 mm of rain fell in June 2002, which may have contributed to some denitrification. The medium texture of the soil would have a much lower hydraulic conductivity rate versus the coarse textured site and would have stayed in a saturated condition longer than the coarse textured soil, contributing to anaerobic conditions and potential denitrification.

For the 120 Mg ha^{-1} treatment, there were significant decreases throughout the soil profile. The highest rate of change was within the 30 to 60 and 60 to 90 cm depths, although there were also significant decreases within the 90 to 120 and 120 to 150 cm depths as well. Crop uptake was likely the major factor in this decrease, but as mentioned in the previous paragraph, other factors likely contributed to this change, such as leaching and potential denitrification during saturated conditions in 2002.

5.2.2 Plant Available Phosphorus

The medium textured soil was seeded to cereals after 2001 before returning to alfalfa production by 2004. The shift from deep rooted alfalfa for 8 years prior to

2001, to shallower rooted crops and then back to deep rooted alfalfa impacted nutrient use at different soil depths.

There were no significant changes in P levels for any treatment at any soil depth. High rates of manure applications such as for the 60 and 120 Mg ha^{-1} manure treatments resulted in high accumulations of P by the end of the long term trials in 2001. In the three years after that trial ended and this study was conducted, there were changes in P levels in the top 15 cm of soil for these treatments but not sufficiently high to be statistically significant.

Crop uptake of P likely accounted for the decreases in the top 15 cm and illustrates the difficulty of reducing P levels in some soil types. The use of a cereal in this rotation likely had some effect on the P decreases between 2001 and 2004. An irrigated barley crop can remove approximately 25 kg ha^{-1} P and alfalfa can remove 45 kg ha^{-1} P. Over three years, with one year of barley and two of alfalfa, approximately 95 kg ha^{-1} P would be removed. Three years of alfalfa would have removed 135 kg ha^{-1}. The high levels of P in 2001 would require more years of irrigated alfalfa production with no P added to reduce P levels to the control treatment level.

5.2.3 Water Soluble Potassium

The medium textured soil had higher clay content than the coarse textured soil, increasing the rate of adsorption to the exchangeable K pool and fixation to the fixed K pool. With the higher clay content and resulting high cation exchange capacity of the soil, the leaching potential would be much lower in the medium textured versus the coarse textured soil. The medium textured soil had a lower hydraulic conductivity than the coarse textured soil. The potential for leaching in the medium textured soil was lower as a result.

There were no significant decreases in K except for the 0 to 15 cm depths of 60 and 120 Mg ha^{-1} manure treatments. The decrease was 101.3 kg ha^{-1} and was most likely due to crop uptake although there may have been small amounts of leaching taking place. Assuming alfalfa production of 9 tonnes ha^{-1} year^{-1}, 530 kg ha^{-1} of K would be required by the crop. Since this is greater than the reduction in the top 15 cm, the required K had to come from the exchangeable K pool.

The highest manure treatment, 120 Mg ha^{-1}, also had a significant decrease in the top 15-cm. Crop uptake accounted for most of this decrease, assuming an alfalfa crop that produces 9 tonnes ha^{-1} and removes 531 kg ha^{-1}. Less than half of this requirement was provided by the 195 kg ha^{-1} of K change between 2001 and 2004. The remainder of the crop requirements would have come from exchangeable K in the soil K pool.

The highest values for K were within the top 30 cm of soil and under the highest rates of manure applications. There was evidence of increased in K levels in the 90 to 120 and 120 to 150 cm soil depths, but was not considered to be significantly different. This may be due to slowly available soil K being released through release of mineral particles or leaching.

5.2.4 Electrical Conductivity

Electrical conductivity levels were between 0 and 2.3 dS m^{-1} within the top 30 cm of all treatments. These levels pose little threat to crop production. There are elevated levels of EC (over 3 dS m^{-1}) below 30 cm, particularly in the higher manure treatments in the 2001 results, and many decreased by 2004 but not significantly.

5.3 On Farm Site

5.3.1 Nitrate-nitrogen Levels

The nitrate-nitrogen levels for the on farm sites show evidence of leaching in SE 11-11-20 W4 and NW 12-11-20 W4. There were levels of 12 kg ha^{-1} and 15 kg ha^{-1} respectively at a depth of 120 to 150 cm, which are relatively low and not a great concern. This may indicate that with manure application and irrigation, some nitrogen is moving through the soil profile and below the root zone of the crops. This may be remediated with alfalfa in crop rotation.

Several of the fields had high nitrate-nitrogen levels at all depths, with the NE 1-11-20 W4 being highest. This field showed some evidence that nitrate-nitrogen may be moving down in the soil profile since the highest level of nitrate-nitrogen was within the 30 to 60 cm depth. It was also over 70 kg ha within the 60 to 90 cm depth of this field. This field exhibited the highest level of nitrate-nitrogen on the farm and the most accumulation at depths below 30 cm. From an agronomic standpoint, none of these nitrate-nitrogen values would be considered excessive and could be drawn down easily in one crop season.

Several of the fields were deficient in nitrate-nitrogen, including the east half of NE 1-11-20 W4 and SE 14-11-20 W4. Both of these fields are under permanent grass cover and don’t receive regular manure applications except what is dropped by grazing cattle.

5.3.2 Plant Available Phosphorus

The P levels in many of the fields in the on farm study are of concern from an environmental standpoint. Only the east half of NE 1-11-20 W4 and NE 11-11-20 W4 were below 150 kg ha^{-1}. The south-west corner of SE 14-11-20 W4 was just above 150 kg ha^{-1}, and could become an environmental concern if manure is applied in the future. All of the other fields had P levels over 200 kg ha^{-1} and had the potential to contribute to surface water contamination if water runoff takes place and the P moves into surface waters. From an agronomic standpoint, the fields over 500 kg ha^{-1} could potentially negatively impact some crop yields. These fields include the north half of SE 14-11-20 W4 and the east half of NE 12-11-20 W4. Additions of manure to fields over 150 to 200 kg ha^{-1} from the perspective of P levels would not be recommended from a best management practices standpoint.

5.3.3 Plant Available Potassium

Potassium in livestock manure is generally not scrutinized the same as N and P because it is considered to have little significant impact on the environment. Presently there does not seem to be much concern with high soil K levels, and plants will uptake K luxuriously when it is available. This luxurious uptake can be problematic in alfalfa that is being fed to dairy cattle as it can result in problems discussed in Chapter 2 such as milk fever.

Potassium levels on the farm were as low as 388 kg ha^{-1} and as high as 2272 kg ha^{-1} within the top 15 cm of soil. There were three fields that were over 1000 kg K ha^{-1}. The east half of NE 12-11-20 W4 had levels over 1000 kg ha^{-1} to a depth of 90 cm. This field also had very high EC levels at all depths. It is likely that the high potassium content of cattle manure has contributed to the increased EC values on this field. The field also had the highest P level within the top 15 cm and increased N at depths below 30 cm. Additions of manure to this field would not be recommended based on all of these factors. Utilizing a crop such as alfalfa to draw down levels of all nutrients would be a good management option.

The other fields with levels over 1000 kg ha^{-1} were associated with elevated EC and higher P levels. The west half of NE 1-11-20 W4 had the second highest K level and third highest P level on the farm. The EC levels were below 2 dS m^{-1} on this field, but were over 1 dS m^{-1}. The west half of NE 12-11-20 W4 had K of 1182 kg ha^{-1}, and P value of 246 kg ha^{-1}. The EC values were over 2 dS m^{-1} within the top 30 cm of soil. Both of these fields would not benefit from additional manure application until P and K levels are drawn down and EC levels are brought down. Choice of crops such as alfalfa, corn or cereal silage would be the best choices to assist with nutrient drawdown.

5.3.4 Electrical Conductivity and pH

The elevated EC levels on NE 12-11-20 W4, NW 12-11-20 W4 and SE 12-11-20 W4 indicate areas of concern for crop growth. The EC level in NE 12 -11-20 W4 is of greatest concern, having values over 2 dS m^{-1} within the top 30 cm would impede salt sensitive crops. Additions of manure to this site where the manure has an EC of over 50 dS m^{-1} could serve to increase soil salinity and could over time decrease crop productivity.

The other sites with elevated EC had levels over 2 dS m^{-1} at depths below 30 cm and could impact crop growth at this point. However, the EC levels within the top 30 cm for both of these fields were approaching 1 dS m^{-1}, and if manure is applied too frequently, the EC levels could climb into a range that would begin to impact crop growth.

The other fields had EC values that ranged from 0.6 to 1.6 dS m^{-1} within the top 30 cm. Although the impact on most crops would be negligible at 0.6 dS m^{-1}, more sensitive crops could exhibit some salinity intolerance at levels approaching 2 dS m^{-1}. The pH values for all the fields fall within the range of 7.4 to 8.0 within the top 30 cm of soil and would not adversely affect crop growth.

5.4 Nutrient Status

Exports of alfalfa hay were approximately 500 tonnes in 2004. Nutrient removal by crops was calculated in Table 4.11. Table 5.1 shows the nutrients which were removed, returned to the system and purchased at the Schuld Farm in 2004.

Table 5.1 Nutrient status of the farm based on crop removal, exports and imports

Nutrient	Removed and exported (tonne)	Retained (tonne)	Imported (tonne)	Status (+/-)
N	19.5	17.4	0.2	-1.9
P	1.7	2.5	0.1	+0.9
K	16	17.8	0.1	+1.8

Overall, more N was removed by alfalfa exports than was returned to the farm by imported or home grown feed. Manure application to the farm was approximately 74 Mg ha^{-1} resulting in a return of 1.0 tonne N, 0.8 tonne P and 1.0 tonne K to the soil. Nitrogen levels in the soil were significantly lower than would be expected based on this application rate. Crop uptake during the growing season and losses of N during manure handling and application likely accounted for some of these differences.

Phosphorus and K levels were high in many of the on farm site fields. Table 5.1 helps explain why these levels have risen after many years of manure application. There was a net export of N but a net addition of P and K to the system.

Chapter 6 - Conclusions

6.0 Summary

Long term application of cattle manure on a limited land base will lead to a buildup of plant nutrients in excess of plant needs, and can result in salinization of the soil. The discontinuation of manure application can result in the gradual reduction of high nutrient levels, as long as proper management practices are followed.

6.1 Long-term sites

The hypothesis stated that there had been significant changes in plant available soil N nutrient levels and little change in soil P and K nutrient levels since the long-term trial ended. The hypothesis was true for N in the higher rates of manure application (60 and 120 Mg ha^{-1}) but was not true for manure application rates of 40 Mg ha^{-1} or less. The second part of the hypothesis held true for the lower manure application rates, but there was significant changes in P and K levels within the top 15 cm of soil at the higher rates of manure application. Three years without manure applications were not sufficient to reduce nutrients such as P and K that had accumulated to rates above crop requirements.

6.2 On farm site

It is likely that in the future, manure application rates will be based on P rather than N, with supplemental N applications necessary to meet crop requirements. This change will dramatically impact the way manure is handled in areas with intensive livestock production. If P limits in the soil were set at 150 kg

ha^{-1} for example, the on farm site would be limited to manure application on two fields, both of which are currently under permanent cover and would not allow for incorporation of manure. This would mean that manure would have to be exported to a region with P levels below the threshold determined by the regulatory bodies.

The potential change to P based manure applications would have a profound effect on the intensive livestock operations in the Picture Butte area. Manure applications have generally occurred close to these operations due to the concentration of these operations and the costs associated with hauling manure. Using the on farm site as an example, P levels on most land close to the feedlots would be over allowable limits. This will require hauling manure to another area. However, the cost of trucking fresh manure out of the area is prohibitive, so other solutions for handling manure would be necessary. Composting of the manure and selling it to urban markets might be one solution. Another solution could include anaerobic digestion and methane production. These solutions would require the operators to work cooperatively.

The on farm site has had manure applied based on the N content, which over time has resulted in the buildup of P and K in soils. The NO_3-N levels in the soil were not found to be excessive and many of the fields require N application for optimal crop yield. Nitrogen losses during handling and application of manure, as well as crop removal contributed keeping N levels in the soil low. The use of deep rooted crops such as alfalfa in the rotation helped to utilized NO_3-N that may have leached below the reach of annual cereal crop roots.

Phosphorus and K levels of the soil indicated that additions of P and K have exceeded crop removals for several and a buildup of these nutrients has occurred. This could be a concern in the future if the basis for manure application changes from N to P levels of the manure.

6.3 Conclusions

It is vital that intensive livestock operators be aware of potential changes to manure application rates and what it would mean for their operations. In areas where the operations occupy a limited land base, it is inevitable that changes must occur to prevent nutrients from manure from having a negative environmental impact on surface waters. By being aware of the nutrient balance on their own land, operators of the intensive livestock operations can plan for the future and prevent negative impacts on both the environment and the image of their industry.

Through management using appropriate crop choices, monitoring and not applying additional manure for as little as three years, significant decreases in nitrate levels can be achieved, in a coarse textured soil in southern Alberta.

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