Determination of the Effect of Nutrient Management Plans on Nitrate Concentrations in the Soil and Water Below the Root Zone in Commercial Potato Production.

by

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Abstract

Nitrate leaching from research and commercial potato rotations was evaluated using stainless steel zero tension lysimeters, tile drainage and soil samples. The effect of nutrient management versus conventional fertility on marketable potato yield was also investigated. Neither the lysimeters nor the tile lines were able to detect a significant treatment effect on the concentration of NO_3^--N in collected water samples. However, trends in the NO_3^--N concentration conformed to nutrient application. Soil samples detected similar trends in soil NO_3^--N at the research site. Nutrient management fertility had no significant effect on marketable potato yield or soil NO_3^--N at the commercial sites. A significant crop effect on soil NO_3^--N was detected. Fall soil samples indicated excess NO_3^--N in the soil following potato harvest suggesting an overuse of nitrogen fertilizer.

List of Abbreviations and Symbols Used

200N	200 kg N ha^{-1} Treatment
300N	300 kg N ha^{-1} Treatment
ADP	Adenosine Diphosphate
ATP	Adenosine Triphosphate
DCD	Dicyandiamide
C	Carbon
CON	Conventional Fertility
CK	Check Treatment
cm	Centimeter
FPS	Fine Particle Suspension
K_2O	Potash
KCl	Potassium Chloride
kj	Kilojoules
MAN	Liquid hog manure applied at a rate equivalent to 200 kg N ha^{-1}
mol	Mole
NMP	Nutrient Management Fertility
N	Nitrogen
N_2	Dinitrogen
N_2O	Nitrous Oxide
NO	Nitric Oxide
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_3^--N	Nitrate-Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium
P_2O_5	Phosphate
Pi	Inorganic Phosphate
PVC	Polyvinyl Chloride
WTM	Water Table Management

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Chapter 1 - Introduction

Prince Edward Island is the only province in Canada to derive all of its drinking water from groundwater sources (Bukowski et al. 2001). Groundwater is therefore a critical limited resource and its conservation and protection from environmental impacts is essential for the Province's economy.

Potato production on Prince Edward Island generates approximately $200 million each year and is the number one cash crop grown (Prince Edward Island Department of Agriculture 2007). From 1986 to 2006 the total area of cropped farm land on Prince Edward Island averaged 165 550 hectares (Statistics Canada 2008). In 2006 and 2007 the total area of land seeded in potatoes was 39499 and 38851 hectares, respectively, (Prince Edward Island Department of Agriculture 2007).

With this high percentage of land being seeded to potatoes each year public concerns have arisen about the impact the potato production industry has on water quality, namely elevated nitrate levels in local ground water. The recommended application rate of commercial fertilizer for potato production ranges from 135 to 208 kg N ha^{-1} and varies depending on variety (Thompson et al. 2007). However, the actual amount of applied fertilizer can exceed 300 kg N ha^{-1} in some locations. The concerns associated with the heavy use of commercial fertilizer has led to the implementation of nutrient management processes, as well as a crop rotation regulation, namely the legislative requirement for the use of a three year potato-grain-hay rotation for potato production, to conserve the Island's soils and soil nutrients, as stated in Chapter A-8.01 Agricultural Crop Rotation

Act (Agriculture crop rotation act R.S.P.E.I. Chapter A-8.01. 2001). Public concern regarding elevated nitrate concentrations in drinking water is not a new concern (Somers, 1998). Although it has received less media attention over the last 10 years than other water quality issues, such as pesticide residues, the concern for water nitrate levels has been brought to the forefront in the last 2-3 years on Prince Edward Island.

The main issue with high nitrate levels in drinking water is methemoglobinemia, more commonly known as "Blue-Baby Syndrome". This condition usually affects infants who are less than 6 months old and are bottle fed. When nitrate is consumed by the infant, it can be reduced to nitrite by gastrointestinal bacteria which is then rapidly absorbed into the blood stream. Once in the blood the nitrite oxidizes the iron in hemoglobin to the ferric state producing methemoglobin. The problem occurs during the transport of oxygen from the blood to the cells, or in the case of methemoglobin the lack of oxygen transport, methemoglobin cannot function in oxygen transport and cellular anoxia results. The lack of oxygen in the cells results in the skin of the infant turning pale blue which is where the name "Blue-Baby syndrome" comes from. If more than 50% of the blood hemoglobin becomes oxidized, coma or death will more than likely occur (Knobeloch et al. 2000). Although this syndrome is a major concern, it has never been reported on Prince Edward Island (Government of Prince Edward Island 2008).

There are other health concerns related to high nitrate levels in drinking water and food that pose a risk to humans such as a link between high nitrate levels and cancer. When nitrate is ingested, a process called nitrosation can take place that converts the nitrate into

N-nitroso compounds. These N-nitroso compounds have been found to be carcinogens in animals and the concern is that they may have the same effect on humans. However, there is no solid evidence that suggests this is the case (Eichholzer and Gutzwiller 1998).

In addition to the health concerns relating to elevated levels of nitrate in drinking water, high nitrate concentrations in surface water may exacerbate eutrophication. As a result of eutrophication, excessive growth and death of algae and aquatic weeds causes oxygen shortages which can result in fish kills (Carpenter et al. 1998). Increased exposure and high nitrate concentrations can also be toxic to aquatic invertebrates (Camargo et al. 2005).

Nitrate leaching is considered to be the major environmental impact that results from the use of commercial fertilizer in the agriculture industry (Astatkie et al. 2001). Measuring nitrate leaching is not easily achieved (Ramos and Kücke 2001) and can become expensive. This thesis project is part of a larger study on potato production and has the objective of comparing two methods of measuring nitrate leaching and assessing the effects of fertility rates based on nutrient management versus conventional fertility rates on potato yield, and marketable weight and on soil NO_3^- leaching. The specific project objectives are:

(i) to determine whether zero tension lysimeters are an effective method of sample collection for the determination of NO_3^--N concentration in water leaving the root zone in agricultural systems compared to tile line systems;

(ii) to determine whether the use of zero tension lysimeter, tile line systems and fall soil samples can be used to help predict the potential for soil NO_3^--N leaching.

(iii) to investigate the effect of fertilizer rates based on nutrient management versus conventional fertilizer rates on the concentration of NO_3^--N in the water leaving the root zone of crops in commercial potato rotations;

(iv) to investigate the effect of fertilizer rates based on nutrient management versus conventional fertilizer rates on the concentration of NO_3^--N in the soil of fields in a commercial potato rotation; and

(v) to investigate whether or not fertility recommendations based on a nutrient management plan can produce similar marketable potato yields compared to those produced using a conventional fertility plan.

Chapter 2 - Literature Review

2.1 Introduction

Concerns related to elevated concentrations of nitrate in groundwater and surface water in Canada are not new and research relating to nitrate leaching has been investigated by numerous groups (Richards et al. 1990; Milburn et al. 1997; Zebarth et al. 1998; Gasser et al. 2002b). Elevated nitrate concentrations in drinking water have been linked to adverse health effects on humans, namely infants (Knobeloch et al. 2000; Powlson et al. 2008), and have been suggested to be related to the incidence of various types of cancer (Eichholzer and Gutzwiller 1998). High nitrate concentrations in surface waters can also have harmful effects on aquatic life (Carpenter et al. 1998; Camargo et al. 2005).

Nitrate leaching has been said to be the major environmental impact that stems from the use of commercial fertilizer in the agriculture industry (Astatkie et al. 2001; Ramos and Kücke 2001). It is the same characteristics of Prince Edward Island's soil and climate that make the Island famous for potato production that facilitate nitrate leaching (Milburn et al. 1997). Nitrate leaching is one of the main environmental issues to date on Prince Edward Island.

Periods when precipitation and/or irrigation exceed evapotranspiration, combined with the accumulation of nitrate in the soil, are indicative of nitrate leaching (Richards et al. 1990; Milburn et al. 1997). Precipitation cannot be controlled, however irrigation and nitrogen application, and subsequently soil nitrate levels, can be controlled. It is for these reasons that there has been an extensive effort in investigating beneficial management

practices with respect to nitrogen application in the potato production industry, in an attempt to reduce the adverse environmental impacts that can arise from the over use and miss use of commercial fertilizers (Westermann and Davis 1992; Zebarth et al. 1999; Davenport et al. 2005; Zebarth and Rosen 2007).

2.2 Nitrogen Cycle

Before one can attempt to control and reduce nitrate leaching, it is helpful to first understand the nitrogen cycle. With respect to agriculture, the nitrogen cycle is a complex multi-process cycle that consists of a number of reactions that add, remove, transform and translocate plant available nitrogen. The processes involved in the cycle are; nitrogen fixation, mineralization, nitrification, denitrification, ammonia volatilization, immobilization, plant uptake and leaching.

2.2.1 Nitrogen Gains

2.2.1.1 Nitrogen Fixation

Nitrogen fixation, the reduction of N_2 to amino nitrogen ($R\text{-}NH_2$), is the first step in the process of the biosynthesis of amino acids. The triple bond of N_2 is very resistant to chemical attack and has a bond energy of 945 kJ mol^{-1} (McMurry and Fay, 2001). Despite being extremely unreactive, the combination of nitrogen with hydrogen to form ammonia is thermodynamically favorable, although kinetically difficult due to unstable reaction intermediates (Berg et. al. 2007).

Higher organisms are unable to fix atmospheric nitrogen into useful forms and the oxygen-sensitive process is carried out by both free-living and symbiotic microorganisms

(Mylona et al. 1995). It has been estimated that these microorganisms are responsible for about 60% of earth's newly fixed nitrogen. Lightning and ultraviolet radiation make up 15% and the remaining 25% is fixed by industrial processes (Berg et. al. 2007).

In 1910 Fritz Haber devised a process of nitrogen fixation, which is still used in industrial processing today. The process, $N_2 + 3H_2 \rightarrow 2NH_3$, is usually carried out by mixing N_2 gas with H_2 gas over an iron catalyst at 500°C and a pressure of 300 atmospheres (McMurry and Fay 2001).

Free-living microorganisms fix a small yet significant amount of nitrogen in agriculture soils (Ledgard and Gilelr 1995) whereas the major source of biological nitrogen fixation is the result of symbiotic relationships between legumes and *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium*, *Azorhizobium*, *Mesorhizobium* and *Allorhizobium* bacteria (Graham and Vance 2000). These species of symbiotic bacteria invade the roots of leguminous plants, forming nodules that act as an oxygen protection system (Mylona et al. 1995). Inside the nodules the bacteria differentiate into a nitrogen-fixing form, after entering the plants' cytoplasm (Chen et al. 2003). The energy required to carry out the nitrogen fixation process is provided by the plant. Once the nodules are established, the bacteria begin to synthesize the enzyme, nitrogenase, to begin the reduction of nitrogen and in return for the supplied energy, supply the plant with ammonium (Mylona et al. 1995). Nitrogenase is a complex enzyme that has multiple redox centers needed to overcome the kinetic difficulties in breaking the N-N triple bond (Berg et. al. 2007). This enzyme consists of two proteins: a homodimeric Fe protein (Mylona et al. 1995), referred to as reductase,

which provides electrons with high reducing power (Berg et. al. 2007), and nitrogenase, a tetrameric molybdenum-iron protein (Mylona et al. 1995), which uses these electrons to reduce N_2 to NH_3 (Berg et. al. 2007). The transfer of electrons from the reductase to nitrogenase coincides with the hydrolysis of ATP by the reductase. Electrons flow from reduced ferredoxin to the reductase to nitrogenase in order to reduce nitrogen to ammonia. The hydrolysis of ATP within the reductase drives the conformational changes that are necessary for the transfer of electrons. This heterotetramer protein consists of two α subunits and two β subunits, the protein also contains two copies of two types of clusters; the P cluster and the FeMo cofactor. It is at the FeMo cofactor where nitrogen fixation occurs. Since the nitrogenase complex can be shutdown by O_2, leguminous plants bind O_2 to leghemoglobin to maintain a very low concentration of O_2 in their nodules (Berg et. al. 2007).

In theory the reduction of N_2 to NH_3 is a six electron process:

$$N_2 + 6e^- + 6H^+ \rightarrow 2NH_3$$

The actual biological reaction creates at least 1 mol of H_2 as part of the nitrogenase mechanism (Mylona et al. 1995) along with the 2 mol of NH_3 for each mol of N_2, and therefore the addition of two other electrons are required, giving the following equation:

$$N_2 + 8e^- + 8H^+ \rightarrow 2NH_3 + H_2$$

Commonly in nitrogen-fixing microorganisms these eight high-potential electrons come from reduced ferredoxin, generated by photosynthesis or oxidative processes (Berg et. al. 2007). Each electron transfer requires two molecules of ATP, and therefore a minimum

of 16 ATP molecules are hydrolyzed to ADP for each molecule of N_2, giving the final equation:

$$N_2 + 8\ e^- + 8\ H^+ + 16\ ATP + 16\ H_2O \rightarrow 2\ NH_3 + H_2 + 16\ ADP + 16\ P_i$$

It should be made clear that ATP hydrolysis is not required to make nitrogen reduction more favorable thermodynamically, however it is necessary to reduce the activation energy throughout the reaction pathway and makes the reaction kinetically possible (Berg et. al. 2007).

2.2.1.2 Mineralization

Mineralization is the conversion of organic nitrogen to an inorganic form (Harris 1988). Essentially all heterotrophic microorganisms convert organically bound nitrogen into ammonium and release it to the surrounding soil as a waste product. Ammonium is the end point in the process of breaking down protein used by the organism; and any excess ammonium not used for cell synthesis is released as waste. The product of mineralization can be considered a more efficient nitrogen source to plants since it isn't as easily lost from the soil compared to nitrate and is used more efficiently within the plant (Harris 1988).

2.2.1.3 Nitrification

Nitrification is a two step process that converts ammonium to nitrite and nitrite to nitrate. Each step involves different autotrophic microorganisms; in the first step *Nitrosomonas* bacteria oxidize ammonium to nitrite, and the second step involves *Nitrobacter* bacteria oxidizing nitrite to nitrate (Wrage et al. 2001).

The two step conversion of ammonium to nitrate involves two oxidation processes, and an overall change in oxidation state of nitrogen from its most reduced form of -3 to its most oxidized form of +5. The first step carried out by the *Nitrosomonas* bacteria is the oxidation of ammonium (NH_4^+) to nitrite (NO_2^-):

$$NH_4^+ + 1^1/_2\, O_2\, (6e^-) \rightarrow NO_2^- + 2H^+ + H_2O$$

The second step carried out by the *Nitrobacter* bacteria is the oxidation of nitrite (NO_2^-) to nitrate (NO_3^-):

$$NO_2^- + {}^1/_2\, O_2\, (2e^-) \rightarrow NO_3^-$$

The second step is a two electron shift and the oxidation state of the nitrogen changes from +3 to +5, the reaction is controlled by a NO_2^- oxidase enzyme system in which electrons are moved to O_2 via cytochromes leading to the generation of ATP. It should be noted that the third oxygen atom in NO_3^- is derived from water (Kumar et al. 1983). Since there are essentially only two groups of microorganisms involved in nitrification, external factors such as temperature, moisture and pH will have a greater impact on the nitrification process than similar processes with a greater number of microorganisms involved. It should also be stated that since nitrification requires ammonium as the starting material, anything that effects mineralization will also effect nitrification.

2.2.2 Nitrogen Losses

2.2.2.1. Denitrification

Microbial denitrification is an anaerobic sequence of steps that reduces nitrate or nitrite to nitrous oxide and dinitrogen, it plays a major role in the loss of nitrogen from a soil system (Falkowski 2001). The sequence of reductions can be expressed as follows:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

There are a wide variety of microorganisms that carry out these processes, most of which are facultative anaerobes, including *Pseudomonas*, *Thiobacillus*, *Bcillus* and *Propionibacterium* (Wrage et al. 2001).

The ratio of the two end products, nitrous oxide and dinitrogen, is dependant on a number of factors. Increased amounts of available nitrate will lead towards the release of more nitrous oxide compared to dinitrogen. In more acidic conditions the ratio of nitrous oxide to dinitrogen also increases as the enzyme that reduces nitrous oxide to dinitrogen is inhibited at low pH. The process of denitrification can only occur under essentially anaerobic conditions or very low oxygen levels because the enzymes that are involved in the reduction process and the synthesis of these enzymes are extremely sensitive to oxygen. When oxygen levels begin to rise nitrous oxide is released more so than dinitrogen (Wrage et al. 2001).

2.2.2.2. Immobilization

Nitrogen immobilization is simply the uptake and assimilation of mineral nitrogen by microorganisms (Milburn et al. 1997). When there is adequate carbon, microorganisms assimilate ammonium and nitrate into amino acids and proteins for the same purposes as plants (Harris 1988). An indication of whether mineral nitrogen will become immobilized by microorganisms is the carbon:nitrogen ratio (C:N). At a ratio greater than 30 there is a limited amount of available organic nitrogen and immobilization occurs resulting in the

uptake of mineral nitrogen from the soil and a loss of plant available nitrogen from the soil system (Milburn et al. 1997).

2.2.2.3. Plant Uptake

Plant uptake of mineral nitrogen is essential for plant growth. Nitrogen plays a vital role in regulating plant growth, and is consumed in greater quantities than any other macronutrient (Crawford and Glass 1998). The forms of nitrogen that are most readily absorbed from the soil by plants are nitrate (NO_3^-) and ammonium (NH_4^+), however NO_3^- is the form that is usually available to plants due to the rapid nitrification of NH_4^+ to NO_3^- in most soil conditions (Schenk 1996). In conditions that do not favor nitrification, such as soils with low pH or low oxygen levels, ammonium is the main form of available nitrogen (Haynes, 1986).

2.2.2.4. Nitrate Leaching

Nitrate leaching from the soil to groundwater has negative environmental, health and economic effects (Bukowski et al. 2001). Nitrate leaching from agricultural land can be the dominate form of nitrogen loss from the soil profile (Haynes, 1986). Nitrate is the main form of nitrogen that can be lost from the soil profile via leaching. Ammonium is held to soil particles as a result of the electronic attraction of the positively charged ion to the negatively charged surface of the soil particles. Organic nitrogen compounds are usually not lost as a result of leaching due to their very low solubility. The sources of nitrate that can be leached from a system are nitrate from the mineralization of soil

organic matter, crop and animal residues and fertilizer nitrate remaining in the soil that was not used by crops (Haynes, 1986).

2.3 Measuring Nitrate Leaching

It is apparent based on the large amount of literature that relates to nitrate leaching in agriculture that nitrate leaching as a result of agriculture practices is of great interest to researchers (Singh and Sekhon 1978/1979; Spalding and Exner 1993). While nitrate leaching is an area of interest with such significant environmental and health implications, its measurement is not always easy (Ramos and Kücke 2001).

In order to accurately measure nitrate leaching for a given period of time one must determine the flow of water through the soil profile below the root zone and obtain the average nitrate concentration of the water being transported (Ramos and Kücke 2001). Methods of directly measuring water flow in the field, such as drainable lysimeters and tile drainage, require large amounts of soil disturbance and do not necessarily capture all of the water movement through the soil profile (Thomas and Barfield 1974; Milburn et al. 1990). The limitations associated with the direct measurement of water flow has led to the development of indirect methods; such as methods that require the measurement of hydraulic gradient and hydraulic conductivity, water balance equations, mathematical computer models and methods based on salt or chloride balance (Ramos and Kücke 2001). Methods for sampling drainage water in order to determine nitrate content include soil coring and sampling, lysimeters and tile drainage. All of the mentioned sampling methods have their own advantages and disadvantages.

2.3.1 Soil Sampling

There are a variety of methods that use soil coring and soil sampling to estimate nitrate leaching. Howatt (2008) estimated nitrate leaching as the difference between the soil mineral nitrogen content in a 45 cm profile sampled in the fall and the following spring. The problem with this method is that it does not take into account the other possible nitrogen loss pathways such as denitrification (Ramos and Kücke 2001). Other methods use deep soil cores to evaluate nitrate leaching from the movement of nitrate peaks in the profile (Ramos and Kücke 2001). The major disadvantage to this method is that it simply just describes the location of the nitrate in the profile it reveals no information about its production, consumption or movement. However if repeated cores are taken over extended periods of time it can be used to estimate movement.

The other drawbacks of using soil cores is that they are time consuming to collect, and require heavy machinery to acquire deep cores that can increase soil compaction affecting its natural hydraulic properties. Over time repeated soil sampling can actually alter the soil of interest (Ramos and Kücke 2001). The advantages to soil sampling are that it is usually less invasive and disruptive as compared to installing tile drainage or large pan lysimeters, and it can be a more cost effective method if the cores and soil samples are taken by hand instead of using heavy machinery.

2.3.2 Lysimeters

Lysimeters are devices that are used for sampling soil water under field conditions. There are a number of different types of lysimeters which include suction lysimeters, pan lysimeters, capillary or wick lysimeters and drainable lysimeters.

Suction lysimeters are typically made of porous ceramic cups; however this is not always the case. Smith and Carsel (1986) describe a suction lysimeter that consists of a stainless steel tube with a high-flow porous ceramic cup attached by epoxy adhesive. Bredemeier et al. (1990) describe a stainless steel lysimeter that is used as a mobile, soil solution sampler. This lysimeter has a porous tube rather than a porous cup. After sample collection is complete the porous tube is replaced with a clean tube and the probe can then be used for further sample collection. Miller et al. (2006) use a suction lysimeter that is entirely made of stainless steel in their work relating to nitrogen transformations in soil and aquifers.

The major advantages of suction lysimeters is that when continuous suction is applied they can be used for continuous sampling over a given period, they allow for sampling to occur at various depths, and the ease of installation results in minimal damage to the surrounding soil profile (Grossmann and Udluft 1991).

The disadvantages include the major influence that the spatial variability of the area of interest can have on the collected samples, and high number of replication is required in order to overcome this spatial variation (Alberts et al. 1977; Grossmann and Udluft

1991). Another limitation of the suction lysimeter is that water flow can bypass the samplers as it moves through macropores (Barbee and Brown 1986). Hansen and Harris (1975) reported that sorption, leaching, diffusion and filtering can influence the composition of the sample and that nitrate concentration was influenced by the intake rate, sampler plugging, sampler depth and the type of vacuum system used to apply the suction.

Poss et al. (1995) experimented with three types of ceramic lysimeters to investigate solute movement in the root zone of a wheat crop. Two of the samplers collected soil solution samples by the use of suction and the third sampler relied on diffusion for sample collection. They reported that the lysimeter that used diffusion to collect samples gave an integrated estimate of soil solution composition over several days, whereas the suction samplers gave the daily soil solution composition. They also reported that there was no difference in the NO_3^--N concentration between the two types of suction samplers.

Pan lysimeters are continuous collection systems of drainable water. Barbee and Brown (1986) describe a pan lysimeter that was compared to a suction lysimeter for monitoring chloride movement through 3 types of soils. They reported that the pan lysimeters worked in all three soils and that the suction lysimeters did not work in the well structured clay soil. This was attributed to the water by passing the suction lysimeters as it moved through large pores, this did not effect the pan samplers ability to collect samples as they were able to intercept the macropore flow. Pan lysimeters require that the

soil above the sampler is saturated in order to collect samples; this can lead to a diversion of flow away from the pan sampler (Ramos and Kücke 2001). The major disadvantage with respect to the pan lysimeters is that the installation process requires a great deal of soil disturbance that could alter the natural flow of the soil water.

Passive capillary or wick lysimeters generally consist of a fiberglass wick and a sampling container. One end of the wick is in contact with the soil while the other end hangs in a sample collection container. The wick draws pore water from the soil into the collection container (Ramos and Kücke 2001). Landon et al. (1999) describe a wick sampler that is made up of a fiber mat placed on a glass plate with a center fiber wick that drains pore water into a glass collection bottle. Wick lysimeters can collect water from both micropores and macropore flow (Ramos and Kücke 2001). Landon et al. (1999) report the majority of water collected using wick lysimeter was mobile water. As was the case with pan samplers the main disadvantages to using wick samplers is that the installation process is virtually identical to pan lysimeters and results in major soil disruption (Ramos and Kücke 2001).

Perhaps the most effective lysimeter for measuring leaching are drainable lysimeters (Ramos and Kücke 2001). There are a variety of types of drainable lysimeters Gasser et al. (2002a) describe a drainable lysimeter that was composed of a PVC geomembrane reservoir with a slopped bottom where the collected water would drain via a hose into a sampling reservoir that was accessed through a vertical well. Other drainable lysimeters such as those used by Pakrou and Dillon (2000) and Webster et al. (1993) are referred to

as monolith lysimeters or undisturbed lysimeters where a block of soil is excavated and placed into a drainage collection chamber. Pakrou and Dillon (2000) also describe a repacked or disturbed soil lysimeter that consists of a collection chamber that is pack with soil that is removed layer by layer. The main advantage of drainable lysimeters is that leaching is measured constantly, however the disadvantage is the cost of construction (Ramos and Kücke 2001).

2.3.3 Tile Drainage

Using tile drainage to measure and quantify leaching is not as easily achievable as previously mentioned methods, but it is still used none the less. Milburn and MacLeod (1991) reviewed 14 subsurface drainage-water quality studies, examining a wide range of study parameters. The review examined the method and frequency of drainage measurement and water sample collection, drainage plot size, the number of drains per plot, land use replication, length of the study and if data was collected during throughout the winter and spring.

The main advantage of tile drainage is that it allows for year round sampling however the cost and soil disruption associated with the installation are extremely high. The other aspect of tile drainage monitoring that has been criticized is the inability to accurately quantify the amount of flow that is not collected and lost between the tile drains (Thomas and Barfield 1974), this can lead to an under estimate of nutrient loss (Milburn et al. 1990).

2.4 Nitrate Leaching in Agriculture

Nitrate leaching if a function of soil water movement and the accumulation of NO_3^- in the soil profile. The factors which effect either of these processes have the potential to influence the magnitude of NO_3^- leaching. Soil mineral N and NO_3^--N leaching can be significantly effected by previous crop and current land use practices (Shepherd and Lord 1996; Francis et al. 2003) rate of nitrogen application (Baker and Johnson 1981; Thomsen et al. 1993; Jaynes et al. 2001) and source of nitrogen application (Zvomuya et al. 2003; Bergström and Kirchmann 2006).

Reducing nitrate leaching in the agriculture industry is not an easy task but is achievable. Some methods used in the past are: the application of nitrification inhibitors to delay NO_3^- formation, water table management and fall cover crops. A recent study by Di and Cameron (2005) reduced nitrate leaching from a grazed pasture using a fine particle suspension (FPS) nitrification inhibitor dicyandiamide (DCD). They reported that the application of DCD as a FPS significantly reduced the annual average NO_3^--N concentration of the drainage water collected using monolith lysimeters from 43 mg N L^{-1} down to 18 mg N L^{-1}. They also reported that the use of DCD as a FPS was just as effective in reducing NO_3^--N leaching as DCD applied as a solution.

Water table management (WTM) has been proven to be an effective method of reducing NO_3^--N leaching. Elmi et al. (2005) combined WTM treatments with variable nitrogen fertilizer treatments in a corn field to investigate the effects on yield and NO_3^--N leaching. They reported that WTM treatment and fertilizer treatment had no significant

effect on corn yield. They also reported that maintaining a water table level of approximately 0.6 m below the soil surface using sub irrigation reduced soil NO_3^--N concentration by up to 50% over two years compared to a free drained field.

The use of cover crops following fall harvest to effectively reduce NO_3^--N leaching has been demonstrated using models (Feyereisen et al. 2006) and in field studies. In New Zealand McLenaghen et al. (1996) investigated the ability of five cover crops to reduce NO_3^--N leaching following a fall ploughing of a grass ley. When compared to a bare fallow soil rye, corn and ryegrass reduced the NO_3^--N leached from monolith lysimeters over the course of the winter from 33 kg N ha^{-1} down to 2.5 kg N ha^{-1}. They concluded that the plant uptake of mineralized N was the driving mechanism behind the reduction in NO_3^--N leaching. Strock et al. (2004) reported that the use of a winter rye cover crop following corn reduced the flow-weighted average NO_3^--N concentration of the subsurface drainage and reduced overall NO_3^--N loss in comparison to winter fallow. However the exact magnitude of the reduction in leaching varied with annual precipitation.

In addition to the effectiveness of a winter wheat cover crop Milburn et al. (1997) evaluated the ability of lightly incorporated straw mulch to reduce NO_3^--N leaching following early harvested potatoes on Prince Edward Island. In the first year of the study both techniques significantly reduced the average flow-weighted NO_3^--N concentration of the collected drainage discharge compared to the untreated treatment. However the incorporated straw was the only technique to significantly reduce NO_3^--N leaching in the

second year; which lead to the conclusion that the relatively short time period that is available after potato harvest can greatly effect the extent of crop development which in turn effects its ability to reduce NO_3^--N leaching.

A major difficulty associated with controlling and reducing nitrate leaching from agricultural systems is selecting the most appropriate method to use, which is generally site specific. What works in one area will not necessarily mean that it will have equal success in another. There is a need on Prince Edward Island to measure NO_3^- leaching under commercial potato production practices in a practical, non-invasive manner. The objectives for this study were chosen to determine whether zero-tension lysimeters and soil samples will provide comparable estimates of NO_3^- leaching to tile drainage, a method that has been shown to give reasonable estimates of NO_3^- loss.

Chapter 3 - Comparison of Soil Water Sampling Systems for Nitrate-N Analysis

3.1 Introduction

Nitrate leaching from the use of commercial fertilizer in the agriculture industry poses serious health implications to both humans and aquatic life (Carpenter et al. 1998; Eichholzer and Gutzwiller 1998). The challenges associated with accurately measuring nitrate leaching involve the measurement of soil water flow and nitrate concentration (Ramos and Kücke 2001). Prince Edward Island's soil and climatic conditions make it susceptible to nitrate leaching (Milburn et al. 1997), and there is need for a method of in field soil water collection to aid in research on nitrate leaching from commercial potato production systems.

Methods of collecting soil water for the determination of nutrient content are numerous and there is no single method that is clearly superior to the rest, and the most appropriate method tends to be site specific. Barbee and Brown (1986) compared the effectiveness of porous cup samplers and a pan lysimeter in monitoring chloride movement through 3 types of soils (loamy sand, silt loam and clay). The suction cups did not work in the well structured clay soil which they attributed to the water flowing past the cups as the water leached through large pores, whereas the pan sampler was efficient in collecting water samples in all three soils types.

The integrity of the composition of water samples collected with porous cup samplers is often questioned. Hansen and Harris (1975) performed field and lab tests to determine if the nitrate and phosphate content of samples collected using these porous cup samplers

were representative of the soil water. They reported that sorption, leaching, diffusion and filtering phosphate altered the phosphorous composition of the samples and that nitrate content is affected by sample intake rate, sampler plugging, sampler depth and the type of vacuum system used to apply the suction.

Nitrate leaching resulting from agriculture production is not restricted to Canada and monitoring nitrate leaching occurs world wide. At the University of Florida Plant Science Research and Education Unit in the United States, Zotarelli et al. (2007) evaluated the ability of suction lysimeters, subsurface drainage and soil cores to measure NO_3^--N leaching in mulched drip-irrigated zucchini, pepper and tomato production systems; soil type was Tavares sand. They reported that NO_3^--N leaching values measured with the suction lysimeters were lower than the drainage lysimeters and the soil cores. However, the overall trend in nitrate concentration was similar for all methods when nitrate concentrations and the volume that was leached were low.

In Mikasa, Hokkaido, Japan (43° 14'N, 141° 50'E) Pampolino et al. (2000) compared the ability of a mixed-bed ion exchange capsule, suction lysimeter, pan lysimeter and subsurface drainage to measure nitrate leaching from a fine, mesic, mollic Fluvaquent soil. They reported higher NO_3^--N concentrations in the suction lysimeters compared to the pan lysimeters in the top soil, but, at lower depths, the NO_3^--N concentrations were higher in the subsurface drainage and pan lysimeters than the suction lysimeters.

The objectives of this study were to determine whether the NO_3^--N concentration of water samples collected using zero-tension lysimeters were similar to water samples collected from drainage tiles located at similar depths in a potato rotation research plot. Also to determine whether the use of zero tension lysimeter, tile line systems and fall soil samples can be used to help predict the potential for soil NO_3^--N leaching.

3.2 Methodology

3.2.1 Site Description

This study was conducted at the Agriculture and Agri-Food Canada Research Farm located at Harrington, PE (46°21'N, 63° 9'W). The site consists of twelve 0.5 hectare subsurface tile drained plots and a discharge monitoring system, as described by Milburn and MacLeod (1991). The 6 hectare block was in a three year potato-grain-hay rotation, with clover in the 2006 growing season and potatoes in the 2007 growing season.

3.2.2 Treatments

During the 2007 growing season, four fertility treatments were applied to a crop of Russet Burbank potatoes in an attempt to observe a difference in NO_3^--N concentrations in the water leaving the root zone of each plot. The four targeted treatments were ammonium nitrate applied at rates of 300 kg N ha^{-1} (300N) and 200 kg N ha^{-1} (200N), liquid hog manure applied at a rate equivalent to 200 kg N ha^{-1}(MAN) and a control treatment consisting of no applied N (CK). Each treatment was replicated three times for a total of twelve plots. The fall ploughed clover from 2006 credited all plots with 40 kg N

Table 3.1 Fertility treatment nutrient application and credit at Harrington research farm.

	Target Nutrient Application			Actual Nutrient Application			Plough Down Nutrient Credit			Total Nutrients		
Fertility Treatment	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	(kg ha^{-1})			(kg ha^{-1})			(kg ha^{-1})			(kg ha^{-1})		
300N	300	300	300	294	319	340	40	0	0	**334**	**319**	**340**
200N	200	300	300	210	319	340	40	0	0	**250**	**319**	**340**
MAN	200	300	300	174	154	149	40	0	0	**214**	**154**	**149**
CK	0	300	300	0	319	340	40	0	0	**40**	**319**	**340**

ha^{-1}. All plots, except those that received liquid hog manure, received 300 kg ha^{-1} of P_2O_5 and K_2O (Table 3.1).

3.2.3 Collection of Tile Drainage Samples

When established in 1987, all plots were independently tiled with 10 cm diameter drainage tiles located at approximately 80 cm depth. Plots are hydrologically isolated with additional drainage lines which collect and remove water at plot boundaries. Each drainage plot had its own dedicated tipping bucket to monitor flow and sample collection system located in the discharge hut (Milburn and MacLeod 1991). Automated water samplers ISCO 6712 ; (ISCO Inc. Lincoln, Nebraska) were used to collect water samples from the tile lines daily. Tipping bucket flow data were recorded by a CR10X Campbell Scientific data logger (Campbell Scientific, Edmonton, Alberta) via magnetic relay switches located on the tipping bucket gauge, however a shortage in battery power occurred in February of 2008 and the data logger lost power for 3 months losing all flow data for that time frame. During flow events, the ISCO 6712 samplers were programmed to take one 250 mL sample per day from the water discharged from the tile lines. Every 24, days samples were transferred from samplers to 50 mL disposable centrifuge tubes and stored at 3°C until analysis was performed. All samples were automatically preserved

using concentrated sulfuric acid, each collection bottle in the samplers had 200 μL of concentrated sulfuric acid added to lower the pH of the water sample to below 2.0. The automated samplers were activated in May 2006 and sample collection began on a daily basis until the tile lines stopped flowing in early June 2006. The samplers were idle throughout the summer months of 2006 and into the early fall; the tile lines began to resume flow in mid October 2006. Samples were collected on a daily basis throughout the rest of the fall, over the winter months and throughout the spring until the tiles again stopped flowing in late May 2007. As previously mentioned, the fertilizer treatments were applied at planting in May 2007 and therefore the NO_3^--N concentrations in the samples collected prior to treatment application are not reported. The samples collected prior to treatment application were used in a laboratory study comparing preservatives and storage temperatures to aid in determining appropriate storage temperature and conditions as well as proper sampling handling procedures. The combination of preservative and storage temperature that did not alter the NO_3^--N concentration of the sample over the course of 5 weeks was selected as the most appropriate.

3.2.4 Lysimeter Design, Placement and Sampling

The lysimeters used in this study were stainless steel SW-071 zero-tension lysimeters (Soil Measurement Systems, Tucson, Arizona. Dr. P. J. Wierenga, United States Patent 5,035,149). The welded 304 stainless steel lysimeters were 27 cm in length and 5 cm in diameter. A 0.3 μm porous section spans 9.4 cm, and the collection reservoir has a 260 mL capacity. Each lysimeter has two, 0.6 cm diameter, stainless steel outlets, 10 cm and 16.5 cm in length, used for sample transfer to a collection bottle; the top of the lysimeter

is threaded to allow for the connection of PVC pipe to enclose the stainless steel tube outlets (Soil Measurement Systems, Tucson, Arizona. Dr. P. J. Wierenga, United States Patent 5,035,149). Each lysimeter has two brass fittings to allow attachment of the stainless steel outlets to plastic tubing (Figure 3.1). The lengths of the plastic tubing and PVC pipe varied depending on installation depth.

This design of lysimeter was chosen for ease of installation and durability. The installation and sampling procedures required much less soil disruption when compared to other designs such as pan lysimeters. This minimized soil and crop disturbance during installation, and allowed for installation to occur after planting. Lysimeter removal was also easily achieved and can occur before fall harvest without damaging the crop. The stainless steel construction resulted in a more durable sampler relative to ceramic and porcelain lysimeters. This allowed the lysimeters to be left in the ground year round with less risk of damage from ice build up or pressure resulting from soil compaction.

Two stainless steel SE-071 lysimeters, (Fig. 3.1; Soil Measurement Systems, Tucson, Arizona.) were installed in each drainage plot in the spring of 2006. The lysimeters were located between the two main drain tiles. Each lysimeter was installed at a depth such that the collection reservoir was sitting in the top of the C horizon of the soil profile (parent material) leaving the porous section sitting at the base of the B horizon, on top of the parent material. This depth was chosen to ensure that each lysimeter was in a similar

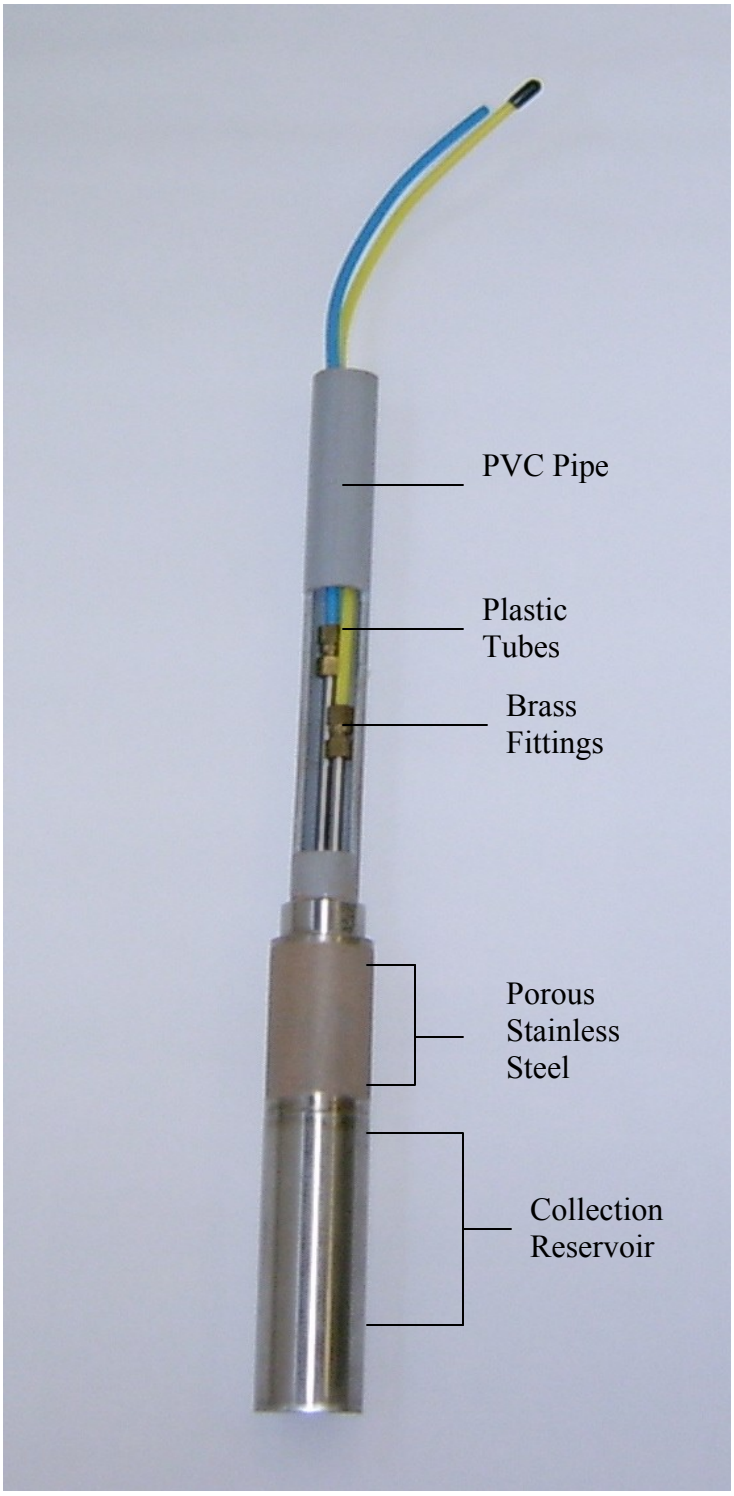

Figure 3.1 Stainless steel SW-071 zero tension lysimeter (Soil Measurement Systems, Tucson, Arizona).

hydrologic situation in soil profile and thus was equally likely to collect water draining from the B horizon. This depth varied for each lysimeter and ranged from 60 - 80 cm. The parent material or C horizon was identified based on soil structure, color and texture. Water samples were collected and subsequently analyzed for NO_3^--N.

Lysimeters were installed by using a Dutch auger (1 m x 2.5 cm diameter) to auger through the soil profile down to the parent material. Once the parent material was reached, a further 15cm of soil was removed. The lysimeter was then inserted into the hole and a slurry mixture consisting of the soil removed from the hole and water, was poured into the hole around the lysimeter to establish hydrologic contact between the surrounding soil and the lysimeter. In 2007, the lysimeters were installed through the top of the potato hills as close as possible to the original 2006 location.

Lysimeters were installed on May 11, 2006 and were sampled on a weekly basis until May 22, 2008. Water samples were extracted using compressed air to displace the water sample into a collection bottle. The volume of sample was recorded and the samples were stored at 3°C until analysis was performed. Throughout the two years of sampling, the lysimeters were removed and re-installed in the fall of 2006 to allow for plowing of the red clover, in May 2007 to allow for planting and again in the fall of 2007 to allow for potato harvest. Fertilizer treatments were applied at the time of planting in May of 2007, and therefore the samples collected from the first year of sampling were used to gain an understanding as to how well the lysimeters would perform and the NO_3^--N concentrations were not reported.

3.2.5 Chemical Analysis of Water Samples

All water samples were analyzed for NO_2^--N + NO_3^--N concentration as described by QuickChem Method 10-107-04-1-A using a Lachat QuickChem QC 8500 Automated Ion Analyzer (Lachat Instruments Inc., Loveland, Co.). Briefly, the sample is drawn into the system by a peristaltic reagent pump; the nitrate in the sample is reduced to nitrite via a copperized cadmium reduction column. The nitrite in the sample mixes with sulfanilamide under acidic conditions to form a diazonium cation, this cation then couples with N-(1-napthyl) ethylenediamine dihydrochloride producing a magenta coloured water-soluble azo dye, the absorbance of which is read at 520 nm (Lachat Instruments 2003).

3.2.6 Field Data Collection and Analysis

In addition to soil water sample collection, the site was equipped with a rain gauge to continuously monitor rainfall. Rainfall data was reported on a weekly basis. Soil samples were collected monthly from May to November in 2006 and 2007 from three depths (0-15 cm, 15-30 cm and 30-45 cm) using a Dutch auger. In 2007 the soil samples were taken from the top of the potato hill. Soil samples consisted of a single sub-sample obtained from mixing 4 auger soil cores per plot. NO_3^--N was extracted from the soil samples using 2 M KCl as described by Gasser et al. (2002b) and analyzed for NO_3^--N using the method previously described for water samples in Section 3.2.5. Throughout the growing season, potato petiole tissue samples were collected on a bi-weekly schedule for 6 weeks staring in mid July, these samples were analyzed for NO_3^--N by the P.E.I. Soil and Feed Lab using a Lachat QuickChem QC 8000 Automated Ion Analyzer following

QuickChem Method 12-107-04-1-B (Lachat Instruments Inc., Loveland, Co.; Lachet Instruments, 1995).

Potato yield data were collected on October 15, 2007. Four 3 m strips per plot were harvested using a single row digger. Harvested potatoes were graded for size, disease and defects in order to obtain a marketable yield.

3.2.7 Statistical Analysis

Potato fertility treatment effect on NO_3^--N concentration in the lysimeter samples and tile line samples was evaluated using repeated measures analysis using Minitab version 15 software. The mean NO_3^--N concentration in each plot was calculated and the resulting values were analyzed using a two-way ANOVA, with fertility treatments and the experimental site's historical previous treatments as factors. To compare the two sampling systems non-parametric correlations were used in an attempt to correlate the NO_3^--N concentration of the lysimeter and tile line water samples. A correlation was calculated for each fertility treatment as well as all treatments combined. On the dates that samples were collected from the lysimeters, the NO_3^--N concentration was compared to the average NO_3^--N concentration of the samples collected from the corresponding tile lines on the same day of lysimeter sampling and the previous six days, representing the time period over which samples were accumulating in the lysimeter. These values were than given a rank and the Spearman rank correlation coefficient was calculated (Snedecor and Cochran, 1989). In addition to the non-parametric correlations a test for equal variance was preformed for the two systems using an F-test for equal variance.

Fertility treatment effect on soil sample NO_3^--N concentration collected over the course of the sampling season was determined using repeated measures analysis. For each plot, mean NO_3^--N concentrations were calculated and analyzed using a two -way ANOVA at a significance level of $\alpha = 0.05$. Treatment effect on the NO_3^--N concentration of the fall soil samples was evaluated using a two-way ANOVA for each combination of month and depth, at a significance level of $\alpha = 0.05$. To compare treatments a Pairwise Comparison of treatments was preformed using a Tukey Simultaneous test. To evaluate how the amount of NO_3^--N in the soil for the entire site changed with each month, a two-way ANOVA was preformed using $\alpha = 0.05$ for all three depths (0-15, 15-30 and 30-45 cm)as well as the sum of all depths. Fertility treatment effect on total and marketable yields was evaluated using a one-way ANOVA.

All data sets were tested for normality using the Anderson-Darling Normality Test. All data transformations were verified using the Box-Cox Transformation (Christensen 1996).

3.3 Results and Discussion

3.3.1 Lysimeters

During the first year of sampling, no samples were collected from May to November 2006 which was a result of no net drainage from the plots. This was also reflected in a lack of flow from the tile lines. In November 2006 water began to move into the lysimeters and the frequency of sample events increased throughout the winter and spring until May 2007. During the first year of sampling, the main sampling issue that needed to

be addressed was water freezing in the collection tubes; this reduced the number of sample events. In the second year of sampling, this was rectified by breaking through the ice in the collection tubes with a welding rod prior to sample collection.

After planting in May of 2007, the lysimeters were re-installed and the weekly sample monitoring continued until May 22, 2008. There was no water accumulation in the lysimeters throughout the growing season (May 22 - October 14 2007). This was likely the result of no net drainage and is consistent with the observed lack of flow from the tile lines, which is consistent with work reported by Milburn et al. (1990) and Milburn et al.(1997). Sample collection events started on January 7, 2008. Analysis of the lysimeter data revealed that there was no significant treatment effect on the NO_3^--N concentration, $p = 0.341$, $\alpha = 0.05$ (Figure 3.2).

The trend of the average NO_3^--N concentration of the lysimeter samples (Figure 3.2) followed the same order as the amounts of fertilizer N applied; this same trend was also observed by Cambouris et al. (2008). While there were no significant differences in monthly mean NO_3^--N concentrations among treatments, the 300N treatment tended to have the highest average values followed by similar values for the 200N and the MAN treatments and finally the CK treatment displayed the lowest average NO_3^--N concentration values (Table 3.2). Cambouris et al. (2008) also reported no nitrogen fertility rate effect on the mean NO_3^--N concentration in water samples collected using a pours suction lysimeter in the first year of their study. Grossmann and Udluft (1991) suggest that the variation within each plot can be eliminated by adequate replication.

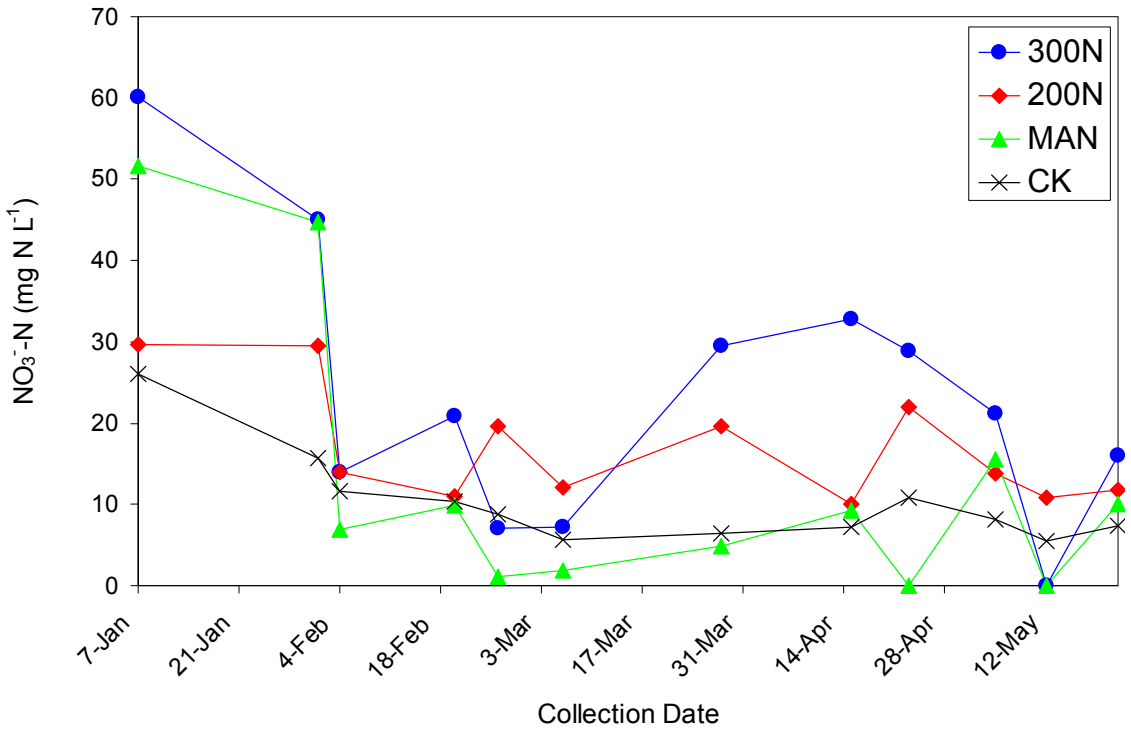

Figure 3.2 Mean NO_3^--N concentration (mg N L^{-1}) of lysimeter water samples collected from January 7, 2008 to May 22, 2008. No significant difference detected between treatments $p = 0.341$ $\alpha = 0.05$.

Table 3.2 Average (AVE.), Maximum (Max.), and Minimum (Min.), NO_3^--N concentrations (mg N L^{-1}) of lysimeter water samples collected from January 7, 2008 to May 22, 2008 and tile line water samples collected from September 12, 2007 to June 1, 2008.

Treatment	Ave. NO_3^--N (mg N L^{-1})		Max. NO_3^--N (mg N L^{-1})		Min. NO_3^--N (mg N L^{-1})	
	Lysimeter Samples	Tile Line Samples	Lysimeter Samples	Tile Line Samples	Lysimeter Samples	Tile Line Samples
300N	26a[1]	18a[1]	60	38	7	5
200N	17a	16a	30	36	10	5
MAN	16a	16a	52	33	1	7
CK	10a	12a	26	20	5	4

[1]Values followed by the same letter within each column are not significantly different at the 0.05 significance level.

Hence the lack of statistical significance between the four fertility treatments can be attributed to the high variability of the samples and the small number of treatment replications resulting in a small sample size. It is believed that the main source of this variation is the lysimeters' sensitivity to the spatial variation within the plot. Alberts et al. (1977) reported high spatial variation in NO_3^--N concentration when comparing soil core sampling and porous ceramic cup samplers. This sensitivity is both a strength and shortcoming of this technique. It is a strength, in that it is sensitive to within field variability, it is a shortcoming in that more samplers are required to detect statistically significant different treatment differences in spatially variable processes such as NO_3^- leaching.

3.3.2 Tile Lines

After treatment application and planting in May 2007, the samplers were turned on, but remained idle as there was no net drainage throughout the growing season. This lack of net drainage is consistent with work reported by Milburn et al. (1990) and Milburn et al. (1997). Flow resumed briefly on September 12, 2007 and continued for 10 days, stopping on September 21. On October 4, flow resumed and continued for the entire fall, winter and spring months, stopping only for a few days at different times during the winter. Samples were collected on a daily bases, with the exception of the six instances when the samplers lost power as a result of drained batteries. There was no significant fertility treatment effect on the NO_3^--N concentration in the tile line water samples, $p = 0.869$, $\alpha = 0.05$ (Figure 3.3). The lack of statistical significance can be attributed to the small number of treatment replications, and therefore the plot to plot variation within each

treatment was too great to indicate statistical differences between treatments. However, the sample collection period did have a significant effect on the NO_3^--N concentration, $p < 0.001$, $\alpha = 0.05$ (Table 3.3). NO_3^--N concentrations were highest in November and December.

As seen with the lysimeters, the trend in NO_3^--N concentration followed the same order as the amount of fertilizer N applied; the 300N treatment displayed the highest NO_3^--N concentrations followed by the 200N and the manure treatments and again the check treatment displayed the lowest NO_3^--N concentrations (Table 3.3).

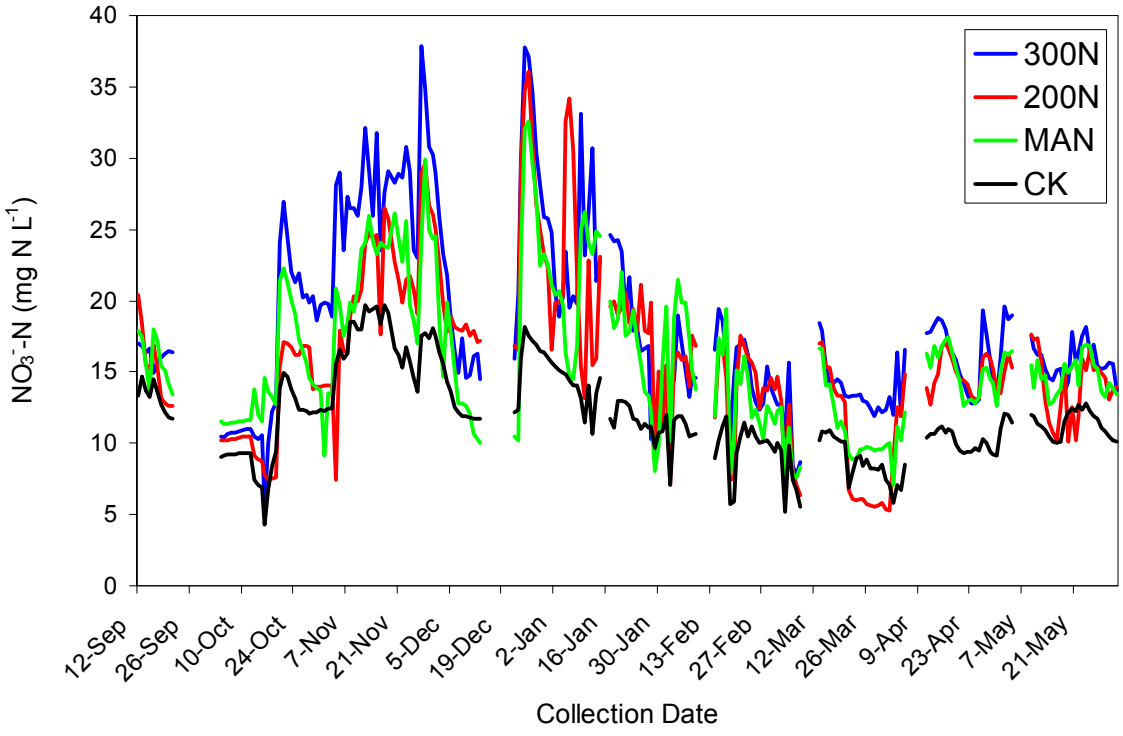

Figure 3.3 Mean NO_3^--N concentration (mg N L^{-1}) of tile line water samples collected from September 12, 2007 to June 1, 2008. No significant difference was detected between treatments $p = 0.869$, $\alpha = 0.05$.

Table 3.3 Monthly mean NO_3^--N concentration (mg N L^{-1}) of tile line water samples.

Collection Period	Mean NO_3^--N concentration (mg N L^{-1})
September	14.8bcd[1]
October	13.3cd
November	21.9a
December	19.2ab
January	16.0bc
February	13.6cd
March	10.6d
April	13.3cd
May	14.4bcd

[1]Values followed by the same letter are not significantly different at the 0.05 significance level.

This trend of increasing NO_3^--N concentration with increasing fertilizer application agrees with the work of Milburn et al. (1990) and Jaynes et al. (2001).

3.3.3 Sampling System Comparison

Both sampling systems experienced various degrees of success over the duration of the study, each encountering different problems. The lysimeters are susceptible to freezing and damage by wildlife; whereas the automated samplers connected to the tile lines can potentially lose power and therefore miss collection dates.

The average NO_3^--N concentrations (Table 3.2) collected from the two sampling systems are generally in good agreement. In the 300N treatment the average NO_3^--N concentrations were higher in the lysimeter sample than the tile line samples. The average NO_3^--N concentrations were essentially the same in the 200N and MAN treatments. In the CK plots the tile lines had higher average NO_3^--N concentrations than the lysimeters.

To compare the two sampling systems, non-parametric correlations were used in an attempt to correlate the NO_3^--N concentration of the lysimeter and tile line water samples (Figures 3.4 - 3.8). Although there was not an extremely strong correlation for any treatment, or for all treatments combined; all comparisons had a statistically significant positive correlation coefficient (p-values ranging from 0.034 to <0.001). The linear regression performed on each data set indicated that at high NO_3^--N concentration the lysimeter samples had greater NO_3^--N concentrations than the tile lines samples (slope > 1). This suggests that there may have been NO_3^--N losses or dilutions in the tile lines that did not occur in the lysimeters.

Although neither sampling system was able to detect statistically significant treatment effects on the NO_3^--N concentration in the water collected (Table 3.3), the variation in the samples collected from the tile lines was much less than the variation in the samples collected from the lysimeters.

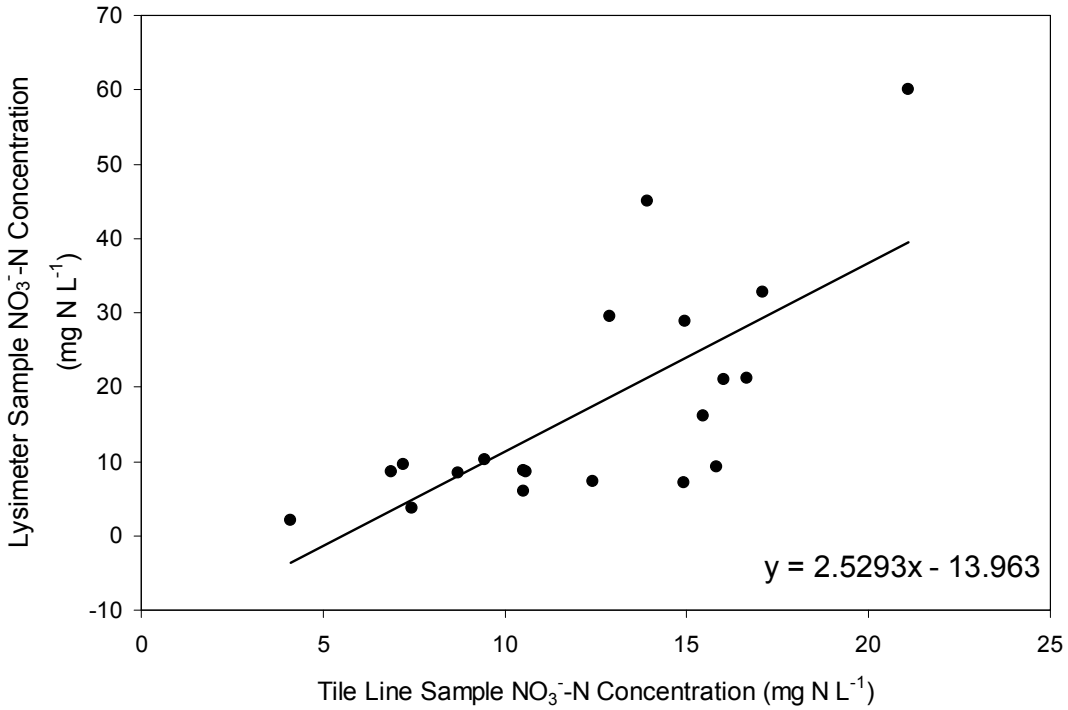

Figure 3.4 NO_3^--N concentration (mg N L^{-1}) correlation of lysimeter and tile line water samples for the 300N treatment. Spearman rank correlation coefficient = 0.689, p = 0.001.

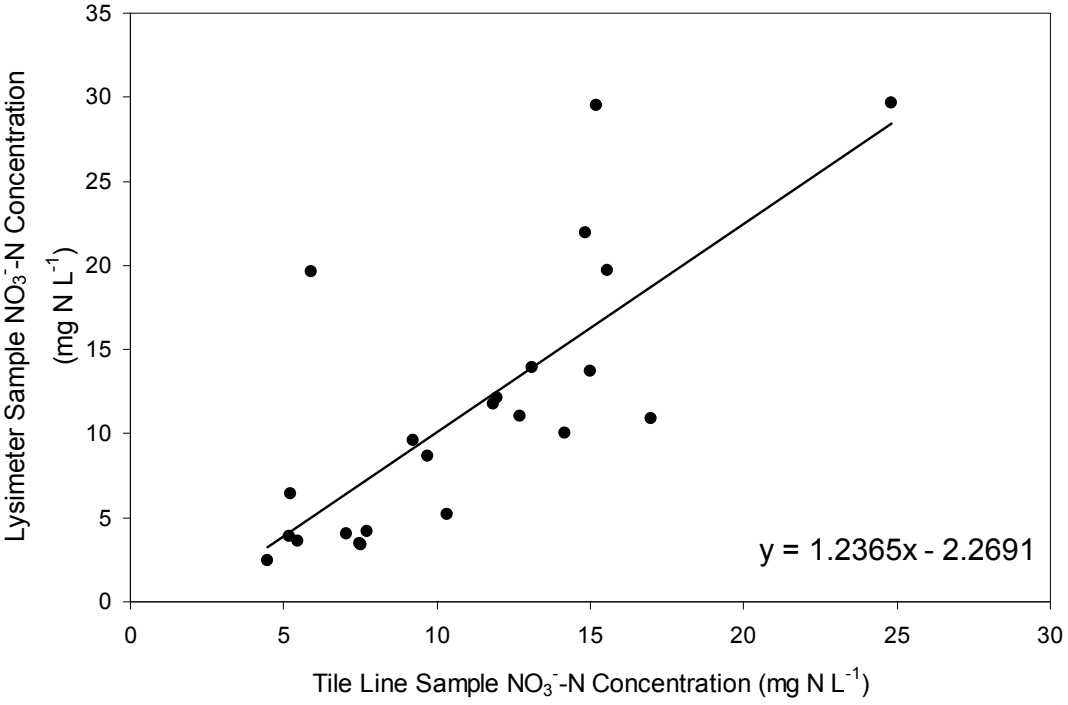

Figure 3.5 NO_3^--N concentration (mg N L^{-1}) correlation of lysimeter and tile line water samples for the 200N treatment. Spearman rank correlation coefficient = 0.777, p < 0.001.

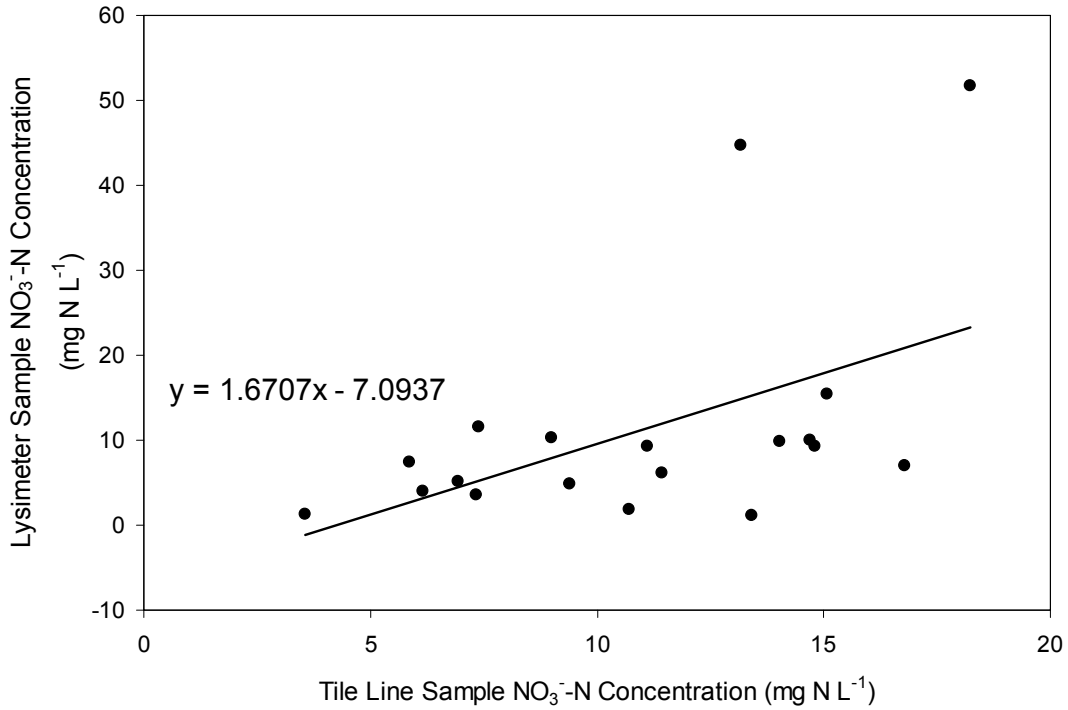

Figure 3.6 NO_3^--N concentration (mg N L^{-1}) correlation of lysimeter and tile line water samples for the MAN treatment. Spearman rank correlation coefficient = 0.488, p = 0.034.

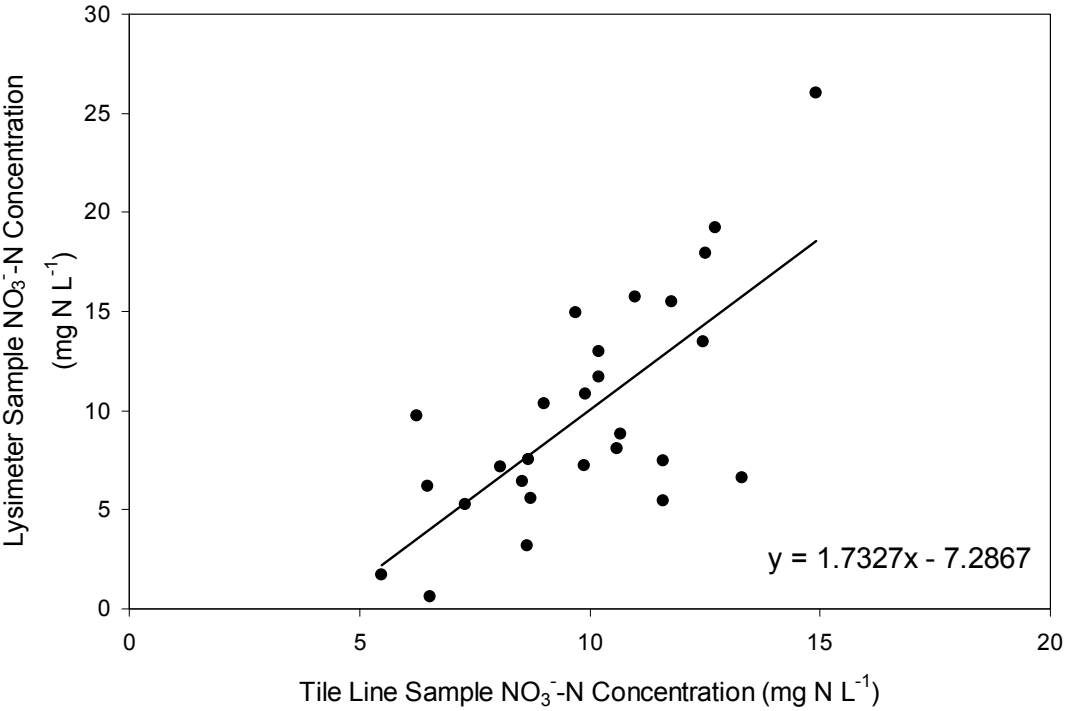

Figure 3.7 NO_3^--N concentration (mg N L^{-1}) correlation of lysimeter and tile line water samples for the CK treatment. Spearman rank correlation coefficient = 0.654, $p < 0.001$.

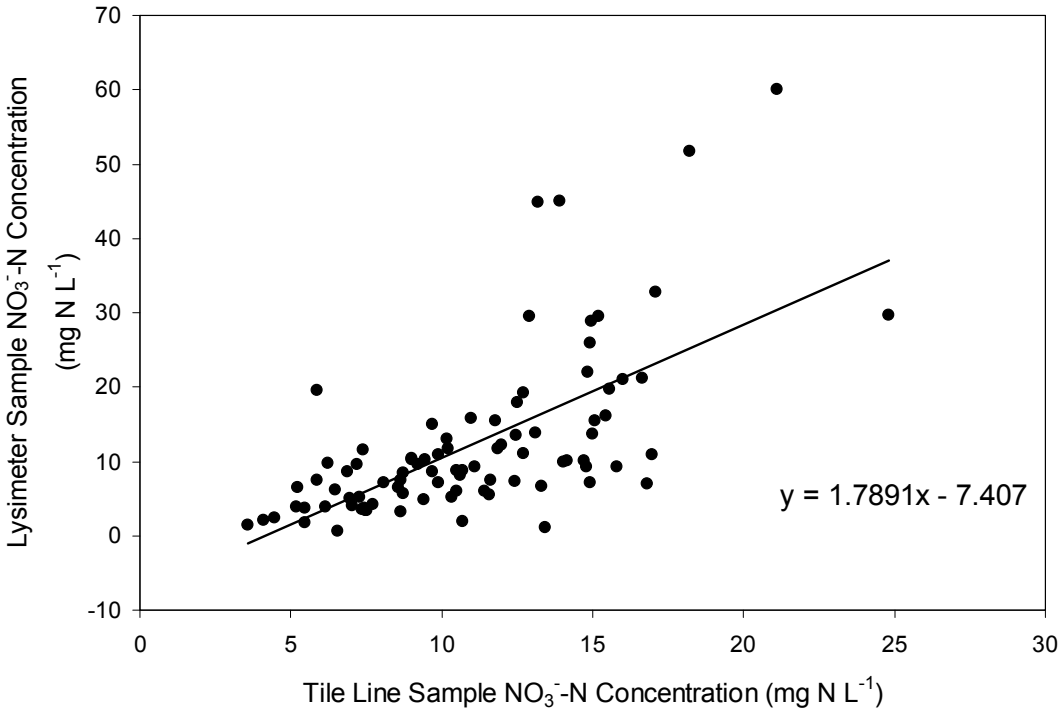

Figure 3.8 NO_3^--N concentration (mg N L^{-1}) correlation of lysimeter and tile line water samples for all treatments. Spearman rank correlation coefficient = 0.674, $p < 0.001$.

An F-test for equal variance was preformed for the two systems, the resulting p-value of 0.001 indicated a significant difference between the standard deviation of each system. The standard deviation of the lysimeter samples is approximately three times that of the tile line samples. The greater area sampled by the tile drainage system (~ 1000 m^2) relative to the lysimeter (~ 1 m^2) makes this system less sensitive to within field variability. The advantage of the known sampling concentration and volume of water discharged allows for direct calculation of flow weighted average concentration as was done by Milburn et al. (1997). In addition to the flow weighted average concentration, the tile line system allows for an estimate of nitrate lost from the area of interest by integrating the flow weighted average concentration with the drainage discharge of the defined area as described by Milburn et al. (1990). Further work, similar to that described

by Alberts et al. (1977), is needed to determine the appropriate number of lysimeters that are required to increase the number of samples taken per plot at any given time, to account for the spatial variation within the plot and reduce the variability of the sampling system to a level similar to the tile lines.

Lysimeters require indirect estimates of the volume of water draining from the profile to estimate the mass of NO_3^--N lost from the soil profile. Further it is not clear whether this NO_3^--N will be attenuated prior to reaching surface water or groundwater receptors. Another advantage of the tile line system over the lysimeter system is the time frame for which samples are able to be collected. Based on the time frames that the samples were collected, the data suggests that the lysimeters will begin to collect water from its surroundings only after the soil has reached or is approaching saturation. The ability of the tile lines to collect water from the soil for a longer time frame allows for a prolonged sampling season which increases the ability to monitor the nitrate dynamics of a particular cropping system.

Although the advantages of the tile lines appear to out weigh the advantages of the lysimeters, they have a major disadvantage. The installation of a system such as the one used in this study into a commercially used field is simply not practical based on the cost of installation and maintenance as well as the amount of soil disruption that would occur. Therefore the establishment of the appropriate number of lysimeter samples required to achieve the desired level of precision of that of the tile lines could prove to be a more cost

efficient method to gain a better understanding of the relative levels of NO_3^--N in the soil water that is being leached from a particular location.

3.3.4 Soil Samples

Soil sampling began in May 2007, before treatment application and planting, and continued monthly throughout the growing season and after harvest, ending in late November 2007. Over the course of 7 months, soil NO_3^--N concentrations were used to illustrate the NO_3^--N dynamics at three depths (0-15, 15-30 and 30-45 cm) within the soil profile.

Treatment had a significant effect on the soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) for all three depths (0-15 cm, 15-30 cm, and 30-45 cm), $p < 0.001$. Seasonal monitoring of soil NO_3^--N levels indicated a significant treatment effect at the 0-15 cm depth (Figure 3.9). The 300N treatment displayed the highest NO_3^--N levels followed by the 200N and the MAN treatments which had essentially equal levels and finally the CK treatment displayed the lowest NO_3^--N levels (Table 3.4) this was in agreement with the nutrients applied (Table 3.1). The treatment effects were smaller at the two lower depths, 15-30 and 30-45 cm (Figures 3.10 and 3.11), when compared to the 0-15 cm depth. At these two depths only the CK treatment had significantly lower NO_3^--N levels than the other three treatments, although the 300N treatment tended to have higher NO_3^--N levels than the 200N and MAN treatment (Tables 3.5 & 3.6).

Table 3.4 Average (AVE.), Maximum (Max.), and Minimum (Min.), soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) collected at depth 0-15 cm over the 2007 growing season.

Treatment	Ave. NO_3^--N (mg N (kg dry soil)$^{-1}$)	Max. NO_3^--N (mg N (kg dry soil)$^{-1}$)	Min. NO_3^--N (mg N (kg dry soil)$^{-1}$)
300N	52a[1]	92	8
200N	28b	48	8
MAN	26b	52	9
CK	6c	8	4

[1]Values followed by the same letter are not significantly different at the 0.05 significance level.

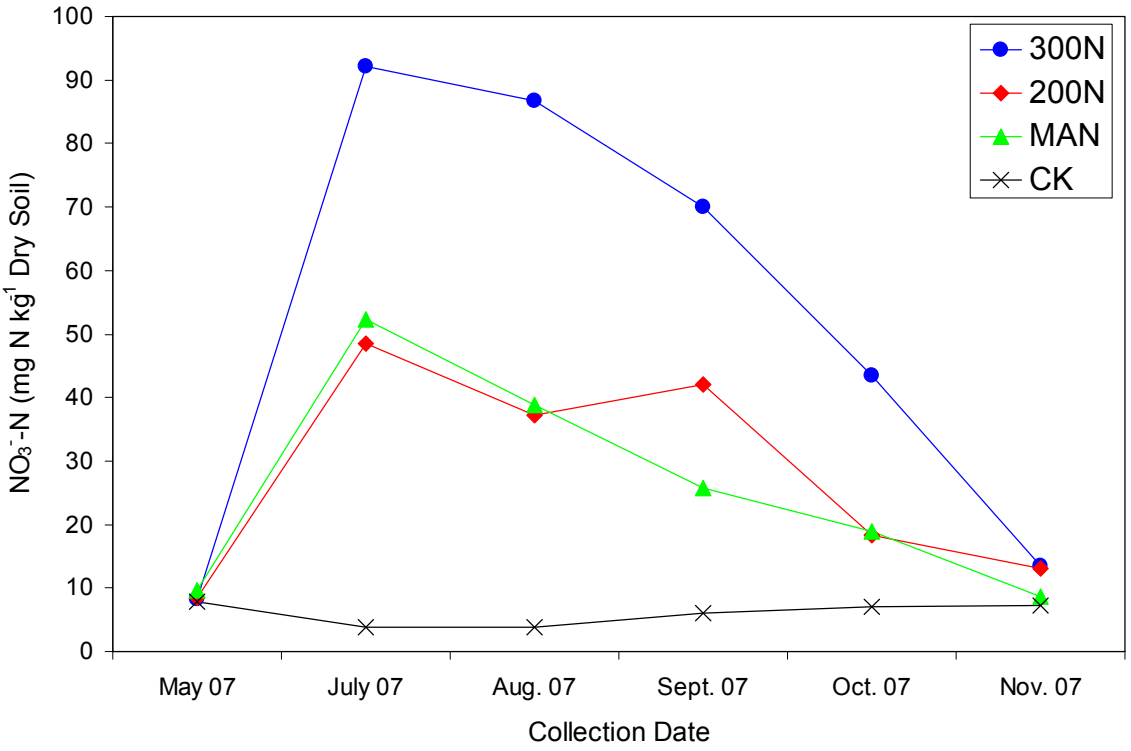

Figure 3.9 Mean soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) collected at depth 0-15 cm from May 2007 - November 2007.

Table 3.5 Average (AVE.), Maximum (Max.), and Minimum (Min.), soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) collected at depth 15-30 cm over the 2007 growing season.

Treatment	Ave. NO_3^--N (mg N (kg dry soil)$^{-1}$)	Max. NO_3^--N (mg N (kg dry soil)$^{-1}$)	Min. NO_3^--N (mg N (kg dry soil)$^{-1}$)
300N	51a[1]	68	36
200N	27a	49	18
MAN	28a	46	17
CK	8b	9	6

[1]Values followed by the same letter are not significantly different at the 0.05 significance level.

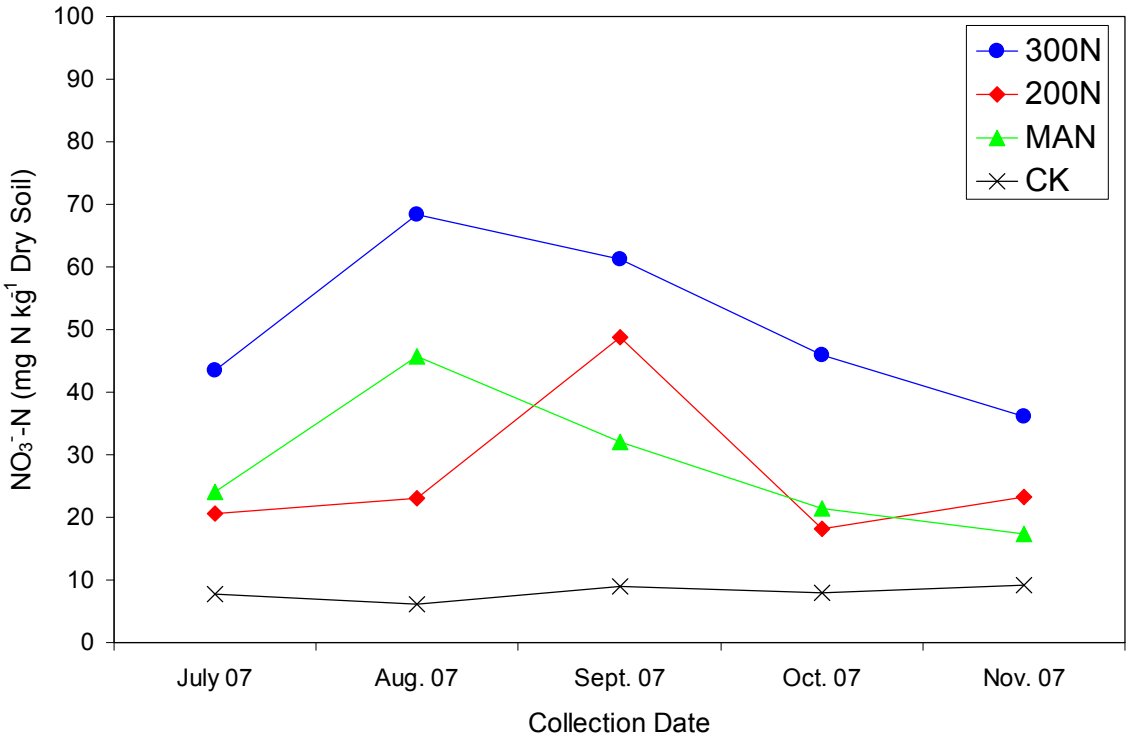

Figure 3.10 Mean soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) collected at depth 15-30 cm from July 2007 - November 2007.

Table 3.6 Average (AVE.), Maximum (Max.), and Minimum (Min.), soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) collected at depth 30-45 cm over the 2007 growing season.

Treatment	Ave. NO_3^--N (mg N (kg dry soil)$^{-1}$)	Max. NO_3^--N (mg N (kg dry soil)$^{-1}$)	Min. NO_3^--N (mg N (kg dry soil)$^{-1}$)
300N	32a[1]	36	25
200N	19a	37	9
MAN	17a	21	13
CK	5b	7	4

[1]Values followed by the same letter are not significantly different at the 0.05 significance level.

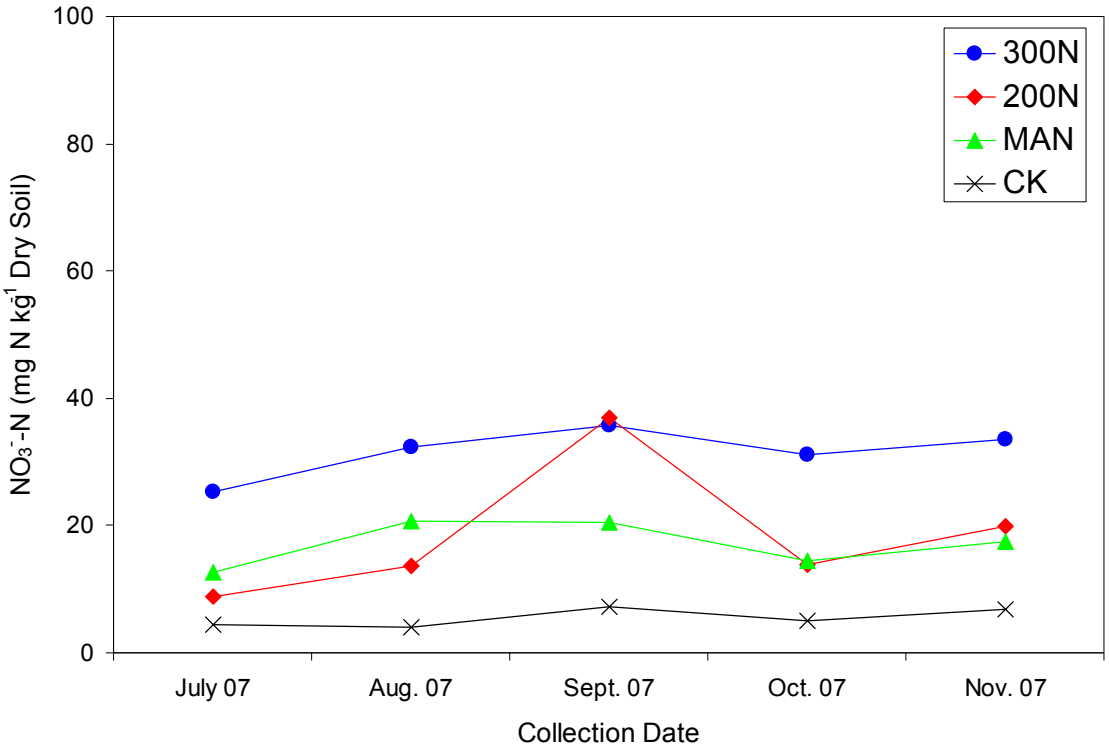

Figure 3.11 Mean soil NO_3^--N concentrations (mg N (kg dry soil)$^{-1}$) collected at depth 30-45 cm from July 2007 - November 2007.

The lack of statistical significance among the 300N, 200N and MAN treatments at the two lower depths can be attributed to the smaller magnitude of difference in applied nitrogen and the small number of treatment replications, and therefore the plot to plot variation at those depths within each treatment was too great to indicate statistical differences between the three treatments. The seasonal trend of an increase in soil NO_3^--N levels following fertilizer application and planting followed by a gradual decrease throughout the course of the growing season (Figures 3.9 and 3.10) is consistent with findings of Zebarth and Milburn (2003). The distinct difference and trends in NO_3^--N levels between the treated plots and the CK plots at the three depths is similar to the trends reported by Howatt (2008).

The ability to detect a treatment effect on the soil NO_3^--N levels in the top 0-15 cm, and to separate the CK treatment from the remaining three treatments at the lower depths over the growing season indicated that soil sampling may be a practical method for determining the potential for N losses relative to different fertilizer applications at a specific location. This resulted in investigating different sampling time points in the fall in an attempt to determine at what time and at what depth are the most appropriate to use soil samples as a means of predicting the relative potential for NO_3^--N leaching.

Soil samples taken in September, October and November 2007 were used in an attempt to test each treatment for the potential of nitrate leaching. For each month, the collected soil samples were used to estimate the amount of NO_3^--N in the soil at that particular depth. To convert the NO_3^--N in the soil samples from mg N kg^{-1} dry soil to kg N ha^{-1}, the bulk

density used for each depth were as follows: 1.1 g/cm^3 at depth 0-15 cm, 1.2 g/cm^3 at depth 15-30 cm and 1.3 g/cm^3 at depth 30-45 cm. These bulk densities were based on those presented by Carter et al. (2004) and those recommended by Dr. M.R. Carter (Dr. M.R. Carter, personal communication, Agriculture and Agri-Food Canada Research Center, Charlottetown, PE). In addition to estimating the amount of NO_3^--N present during each month at each depth, the three depths were combined to give a total monthly estimate for the amount of NO_3^--N that was potentially available for leaching and/or denitrification.

The overall trend of higher NO_3^--N in the soil for higher nitrogen application that was observed in the seasonal monitoring was also observed in the fall soil samples. At all three depths and the combination of the three, the amount of nitrate in the soil followed the same pattern as the amount of nutrient application (Figures 3.12 - 3.15). This trend of increasing residual soil NO_3^--N with increased nitrogen application was also observed by Zebarth et al. (2003).

The September soil samples display the same trend, in terms of ranking for the potential of NO_3^--N loss, at all four depths (Figures 3.13 - 3.16). The inability to statistically distinguish between the 300N and the 200N or the MAN treatments can be attributed to the smaller magnitude of difference in applied nitrogen. The small number of treatment replications and high plot to plot variability within treatments, which may stem from plot history, also could have affected the statistical differentiation among treatments. Belanger et al. (2003b) reported high variation when reporting residual soil NO_3^--N following

potato harvest from two sites in New Brunswick, Canada, and suggested that field history can be a source of variation. The October samples display the same ranking trend as the September samples at all four depths. However, at this time of sampling, the statistical comparison separates the 300N treatment from the other three treatments, with the exception of the 30-45 cm depth where the only separation is the 300N from the CK treatment. The trend in potential for N loss changes in November; by late November, the majority of the NO_3^--N has disappeared from the top 0-15 cm and all four treatments have approximately the same amount of NO_3^--N (Figure 3.13). The trend for NO_3^- loss at the remaining three depths (15-30, 30-45 and 0-45 cm) is consistent; the three fertilized treatments are significantly higher than the CK plots.

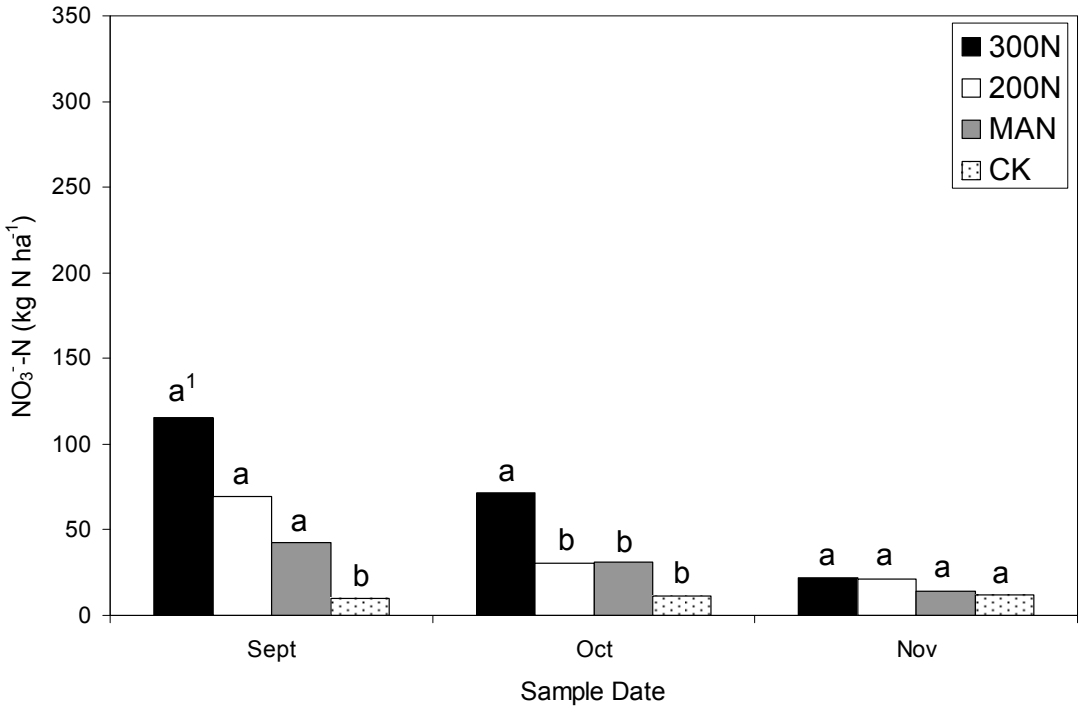

Figure 3.12 Monthly comparison of fall mean soil NO_3^--N levels (kg ha^{-1}) at depth 0-15 cm. [1]Different letters indicate statistical difference between treatments within each month at a significance level of 0.05.

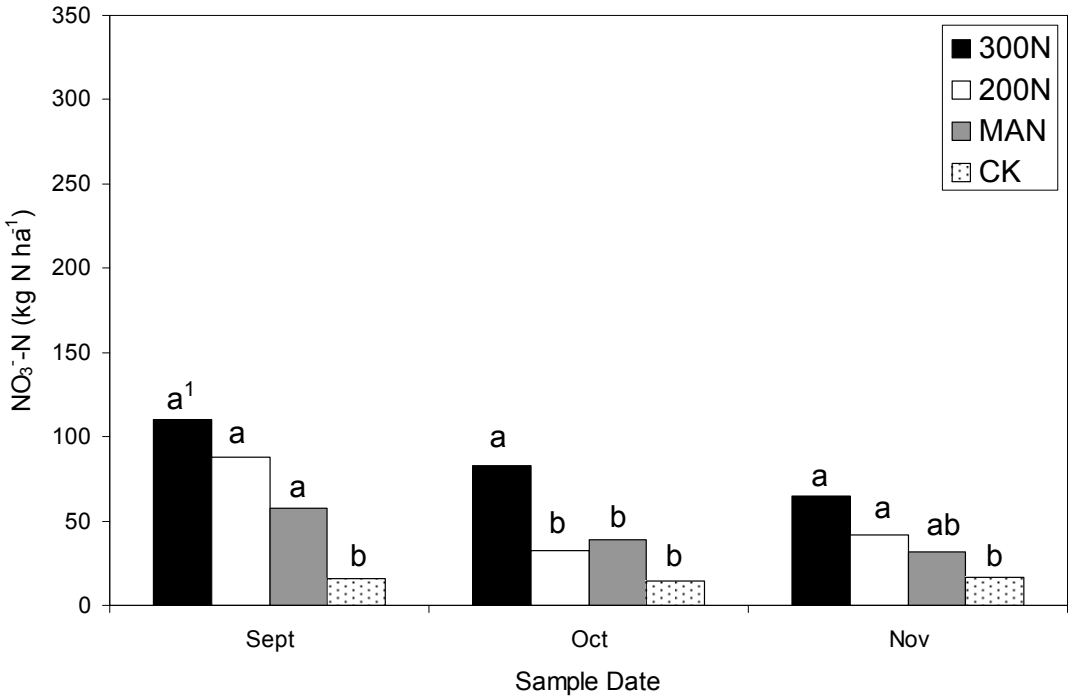

Figure 3.13 Monthly comparison of fall mean soil NO_3^--N levels (kg ha^{-1}) at depth 15-30 cm. [1]Different letters indicate statistical difference between treatments within each month at a significance level of 0.05.

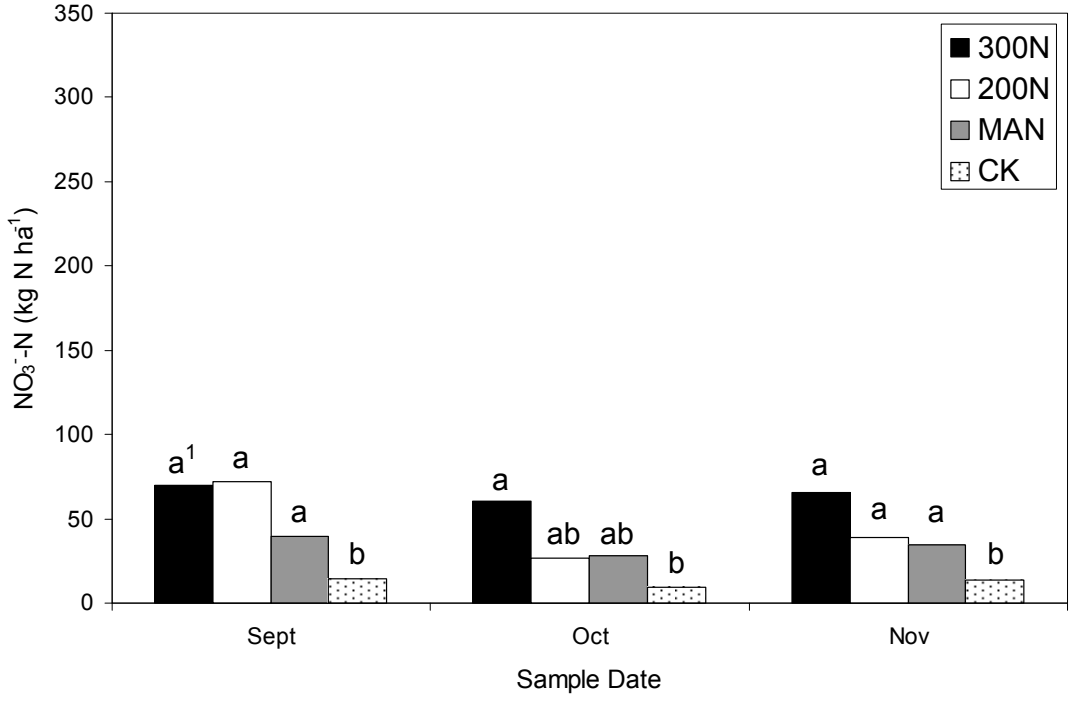

Figure 3.14 Monthly comparison of fall mean soil NO_3^--N levels (kg ha^{-1}) at depth 30-45 cm. [1]Different letters indicate statistical difference between treatments within each month at a significance level of 0.05.

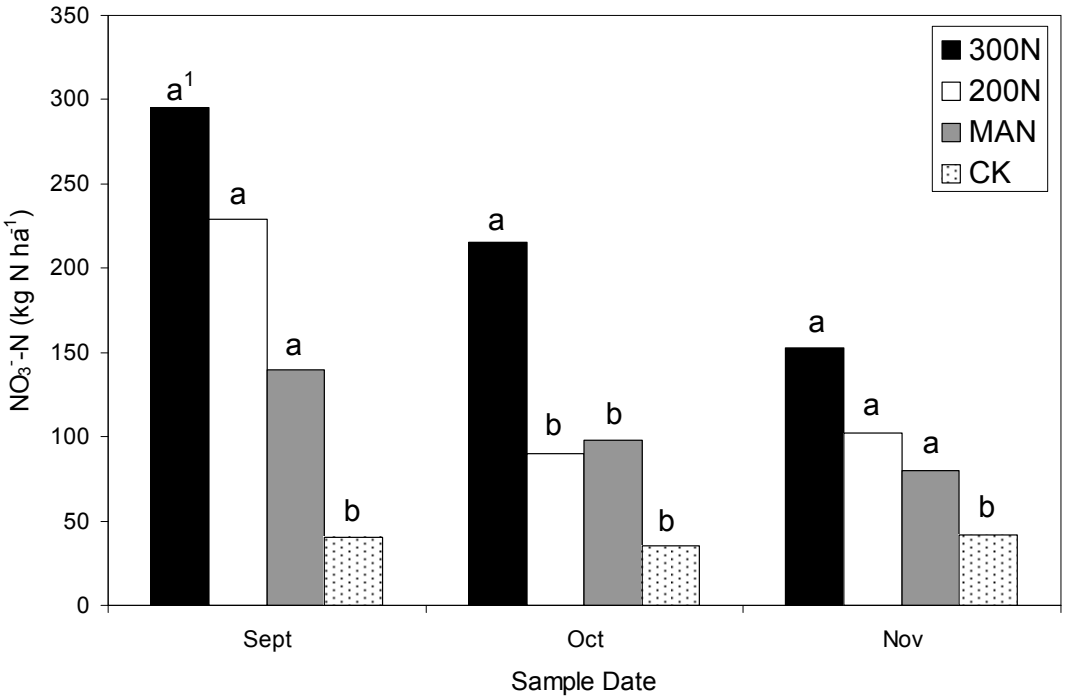

Figure 3.15 Monthly comparison of fall mean soil NO_3^--N levels (kg ha^{-1}) at depth 0-45 cm. [1]Different letters indicate statistical difference between treatments within each month at a significance level of 0.05.

The trend in the change in the average amount of soil NO_3^--N for all treatments combined was consistent at all four depths. NO_3^--N levels in September are the highest with a gradual decline through October and November. The only exception in this trend is at the 30-45 cm depth, in this instance the amount of NO_3^--N increases from October to November which is a result of leaching from the above soil (Table 3.7).

Table 3.7 Comparison of monthly influence on soil NO_3^--N levels at depths 0-15, 15-30, 30-45 and 0-45 cm.

Month	Monthly Average Soil NO_3^--N levels (kg ha^{-1})			
	0-15 cm	15-30 cm	30-45 cm	0-45 cm
September	59a[1]	68a	49a	176a
October	36ab	42b	31b	110b
November	18b	39b	38ab	94b

[1]Values followed by the same letter within each column are not significantly different at the 0.05 significance level.

The September samples were collected near the end of the month, after the plants had died and nitrogen uptake had stopped, therefore it is reasonable to suggest that any decrease in soil NO_3^--N that occurred from that point forward was a result of leaching and/or denitrification. After reviewing the trends in soil NO_3^--N at the three time points and at all four depths it appears that a September soil sample, or a sample collected after top killing, will give the best estimate for the relative potential for NO_3^--N leaching from that particular location. Zebarth et al. (2003) used the soil NO_3^--N content present at harvest as an indicator of potential for leaching and/or denitrification. The depth at which to sample appears to be subjective based on the consistent trend in terms of ranking and statistical comparison at all four depths, Zebarth et al. (2003) used the 0 - 30 cm depth in their study. Belanger et al. (2003b) also stated that the residual soil NO_3^--N content in the 0 - 30 cm depth can be used to indicate soils that have the potential to be environmentally harmful. It should be noted that this method is to be used only as a relative comparison of treatments at the same location.

3.3.5 Petiole Tissue Samples

Potato petiole tissue samples collected throughout the 2007 growing season were used to monitor plant NO_3^--N levels. All treatments experienced a general decrease in % NO_3^--N

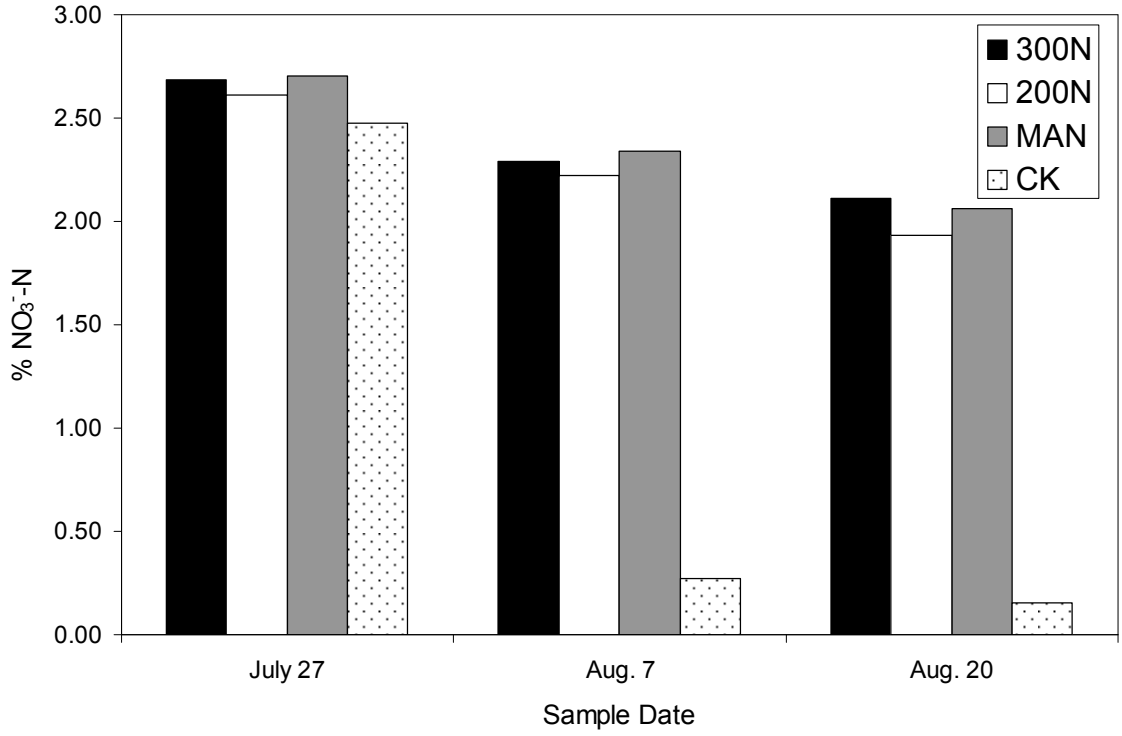

Figure 3.16 Potato petiole tissue NO_3^--N concentrations of biweekly samples collected from July 27 - August 20, 2007.

throughout the growing season; this decrease is consistent with results reported by Bélanger et al. (2003a). It can be seen that after July 27, 2007, the CK plots appeared to become nitrogen deficient (Figure 3.16).

3.3.6 Yield

Total and marketable yield data analysis indicated that there was no yield response to any of the four treatments. The presence of a good clover crop plough down in the fall of 2006 may have contributed more plant available N than previously predicted (Table 3.1). Total yield values ranging from 30426 - 34331 kg ha^{-1} (Figure 3.17) obtained in this study are in agreement with those reported by Bélanger et al. (2000); however the marketable yields ranging from 7124 - 10175 kg ha^{-1} (Figure 3.17) are considerably

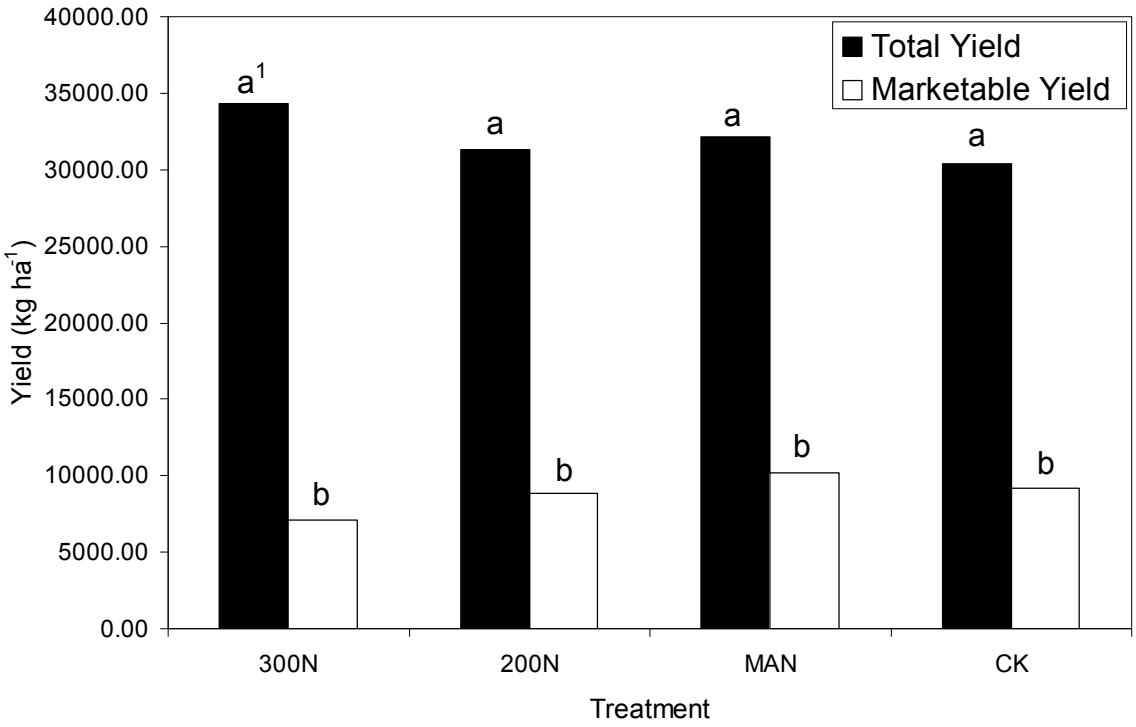

Figure 3.17 Effect of treatment on Russet Burbank total and marketable yields (kg ha^{-1}). [1]Different letters indicate statistical difference between means.

lower. The resulting p-values of 0.509 and 0.764, respectively, indicate that there was no yield response to any of the treatments.

The lower than expected marketable yields can be attributed to three specific factors; high percentage of pitted scab, high percentage of "small" tubers (less than 5 cm in diameter) and a low percentage of "large" tubers (greater than 284 g). The percentage of tubers infected with scab averaged 23.2% per plot and ranged between 7.85 - 60.8%. The average percent of small tubers per plot was 64.3% and ranged from 48.2 - 85.3%. The percentage of large tubers averaged 1.76% per plot and ranged between 0 - 4.95%.

Total yield for the 300N, 200N, MAN and CK treatments were not significantly different at the 0.05 significance level. Petiole tissue NO_3^--N levels (Figure 3.16) suggest that the CK treatment became NO_3^--N deficient after July 27, 2007 and the 300N, 200N and MAN treatments maintained sufficient levels throughout the growing season (Sanderson et al. 1999). Based on these values it would be expected that this low level of tissue NO_3^--N may limit the ability of the plants in this treatment to produce a yield of equal quality to the three other treatments (Sanderson et al. 1999). The yield data indicates that this was not the case and that the plants in the CK treatment were still able to acquire suitable quantities of NO_3^--N from the soil to produce an adequate yield compared to the three other treatments, suggesting that the 40 kg N ha^{-1}credited from the 2006 fall ploughed clover may have been a low estimate of available nitrogen.

3.4 Conclusion

While there were not statistically significant treatment effects on NO_3^- concentration of samples collected from lysimeters, the trends in the mean concentration of NO_3^--N conformed to expectation, with the 300N treatment being numerically greater followed by similar values for the 200N and the MAN treatments and finally the CK treatment had the least. The combination of the lysimeters' high sensitivity to the spatial variability of the plots and the small number of treatment replications limited the ability to separate the treatments statistically.

The tile line water samples also failed to detect statistically significant treatment effects but displayed the similar trends in mean NO_3^--N concentration. The small number of

treatment replications was not sufficient to detect differences given the high degree of variation between plots receiving the same treatment.

In terms of the lysimeters efficiency compared to the tile lines, they could prove to be a more cost effective method for sampling soil water for NO_3^--N analysis upon the establishment of the appropriate number of lysimeter samples required to achieve the desired level of precision of that of the tile lines.

The soil sampling method used in this study proved to have less variability than either the lysimeters or the tile lines, as it was possible to statistically separate the CK treatment from the other three. This may prove to be useful in acquiring an estimate of the potential for NO_3^--N loss when comparing treatments at a particular location. The disadvantage of this method is that it does not provide direct evidence of leaching. Losses could be due to leaching or denitrification.

Chapter 4 - Determination of the Effects of Implementing Nutrient Management Plans on NO_3^--N Concentrations in Soil and Soil Water in Commercial Potato Rotations

4.1 Introduction

Areas of intense agriculture land use, namely potato production, have been related to elevated concentrations of NO_3^--N in private wells in Prince Edward Island and New Brunswick, Canada (Richards et al. 1990; MacLeod et al. 2002). The effects of nitrogen fertilizer application rate, timing of application and nitrogen source are topics that are important to all areas of agriculture, and there has been extensive work done to monitor the effect of nitrogen application and land use management on NO_3^--N leaching (Bergstrom 1987; Thomsen et al. 1993; Jaynes et al. 2001).

The objectives of nutrient management practices relating to potato production are to optimize tuber yield and quality while reducing any adverse effects on the environment (Zebarth and Rosen 2007). Research into developing and studying the environmental effects of nutrient management practices has been well documented (Westermann and Davis 1992; Zebarth et al. 1999; Davenport et al. 2005; Munoz et al. 2005) and is an on going process world wide.

The objectives of this study were to asses the effects of fertility application rates based on a nutrient management plan on the concentration of NO_3^--N in the soil and in the water leaving the root zone of crops in potato rotations compared to traditional fertility rates. In addition, this project also investigated whether or not fertility recommendations based on

nutrient management can produce similar marketable potato yields compared to those produced using a conventional fertility plan.

4.2 Methodology

4.2.1 Overview

This study examined 14 commercial potato production fields located across central Prince Edward Island. All fields were in a three-year potato-grain-hay rotation. Each field had split nutrient application; with a control which comprised the growers traditional fertility rate (CON) applied to one half and a nutrient management recommended fertility rate (NMP), based on crop variety, nitrogen credits resulting from plow down crops and soil quality, applied to the other half. All fields were equipped with four stainless steel zero tension lysimeters, two per half field, installed to collect water samples to be analyzed for NO_3^--N.

4.2.2 Field Selection

Field selection was based on the following criteria: 1) Co-operation of growers - Possibly the most important criterion for the success of the study was the co-operation of the growers. Growers who are concerned with soil and water quality and were willing to allow access to their land for a two- year period were contacted to inquire about the study. Determining who to contact was based on previous relationships and interactions with staff at the Prince Edward Island Department of Agriculture. 2) Soil Type - After establishing a list of cooperators, fields were selected based on soil type within the available land provided by the grower. Moderately well to well drained sandy loam soils,

such as those of the Charlottetown and Alberry soil series (MacDougall et al. 1988), were chosen for this study as they are the two most common soil types on Prince Edward Island. 3) Location - In order to ensure that all fields experienced similar weather conditions, the fields selected were in relatively close proximity to one another. The size of each field ranged between 10 and 25 hectares. 4) Field History - a field history of at least three years was needed in order to develop proper nutrient management recommendations; this included previous crop rotations, plow down crops, organic and inorganic inputs.

4.2.3 Fertility Treatments

The NMP fertility recommendations used in this study (Table 4.1) were created by the PEI department of agriculture nutrient management specialist in conjunction with the co-operating producers. The normal rates of application these producers apply were relatively close to the prescribed nutrient management recommendation, which adds a source of bias when analyzing for treatment effects. However, in order to ensure cooperation and unlimited access to their land for the duration of the study, as well as reduce the risk of potential loss of profit, the NMP fertility recommendations were adjusted upward resulting in a smaller gap of applied nutrients than what would originally have been recommended.

4.2.4 Lysimeter Design, Placement and Sampling

The lysimeters used in this study were stainless steel SW-071 zero tension lysimeters (Soil Measurement Systems, Tucson, Arizona. Dr. P. J. Wierenga, United States Patent

5,035,149). The welded 304 stainless steel lysimeters were 27 cm in length and 5 cm in diameter. A 0.3 μm porous section spans 9.4 cm, and the collection reservoir has a 260 mL capacity. Each lysimeter has two, 0.6 cm diameter, stainless steel outlets, 10 cm and 16.5 cm in length, used for sample transfer to a collection bottle; the top of the lysimeter is threaded to allow for the connection of PVC pipe to enclose the stainless steel tube outlets (Soil Measurement Systems, Tucson, Arizona. Dr. P. J. Wierenga, United States Patent 5,035,149).

Table 4.1 Conventional (CON) and nutrient management planning (NMP) fertility treatment applications.

Site #	Crop Treatment	Nutrient Application					
		CON N	NMP N	CON P_2O_5	NMP P_2O_5	CON K_2O	NMP K_2O
		(kg ha^{-1})					
1	Potato	160	135	128	108	160	135
2	Potato	202	175	242	270	202	270
3	Hay	29	29	0	0	0	0
4	Grain	75	37	18	18	18	18
5	Potato	202	175	202	202	270	270
6	Grain	50	34	25	34	25	34
7	Potato	198	185	247	148	247	136
8	Grain	57	44	57	57	57	57
9	Hay	38	0	0	0	0	0
10	Potato	175	202	269	162	269	202
11	Grain	28	28	10	10	10	10
12	Potato	162	168	269	135	269	168
13	Grain	N/A*	0	N/A	0	N/A	0
14	Potato	202	189	202	202	269	242
15	Hay	0	0	0	0	0	0
16	Grain	50	42	25	42	25	42
17	Hay	51**	N/A	N/A	N/A	N/A	N/A
18	Grain	62	56	31	28	31	56
19	Hay	0	0	0	0	0	0
20	Potato	223	185	222	222	222	222
21	Grain	62	42	31	28	31	28

* Nutrient content not available as a result of manure application with no nutrient analysis performed prior to spreading.
** Actual value not known 112 kg Urea ha^{-1} + manure application with no nutrient analysis performed prior to spreading.

Each lysimeter has two brass fittings to allow attachment of the stainless steel outlets to plastic tubing (Figure 3.1). The lengths of the plastic tubing and PVC pipe varied depending on installation depth.

This design of lysimeter was chosen for ease of installation and durability. The installation and sampling procedures required much less soil disruption when compared to other designs such as pan lysimeters. This minimized soil and crop disturbance during installation, and allowed for installation to occur after planting. Equipment removal was also easily achieved and can occur before fall harvest without damaging the crop. The stainless steel construction resulted in a more durable sampler relative to ceramic or porcelain lysimeters. This allowed the lysimeters to be left in the ground year round with less risk of damage from ice build up or pressure resulting from soil compaction.

Lysimeters were installed by using a Dutch auger (1 m x 2.5 cm diameter) to drill through the soil profile down to the parent material. Depth to parent material was determined by visual inspection of the soil being removed from the hole and was identified based on soil structure, color and texture. Each lysimeter was installed at a depth such that the porous section was sitting on top of the parent material and the collection reservoir was sitting in the parent material of the soil profile. This depth was chosen to ensure that all lysimeters were in hydrologically similar locations with respect to the soil profile in all fields. This depth varied from field to field as well as within each field and ranged from 55 - 110 cm. The lysimeter was then inserted into the hole and a slurry mixture consisting of the soil removed from the hole and water, was poured into

the hole around the lysimeter to establish hydrologic contact between the surrounding soil and the lysimeter. At potato sites, the lysimeters were installed through the top of the potato hills.

Lysimeters were installed in fields 1-10 following planting in 2006 and sampled on a weekly basis until the spring of 2007. Throughout the course of the year, the lysimeters were removed and re-installed during times of potato harvest and plowing of clover fields, and were removed before field activity resumed in early 2007. Sites 11-21 had lysimeters installed following planting in 2007 and were monitored on a weekly basis until spring of 2008. Lysimeters were removed and re-installed at various times throughout the year for the same reasons as in fields 1-10. Water samples were extracted using compressed air to displace the water sample into a collection bottle. The volume of sample was recorded and the samples were stored at 3°C until analysis was performed.

4.2.5 Chemical Analysis of Water Samples

All water samples were analyzed for NO_2^--N + NO_3^--N concentration using a Lachat QuickChem QC 8500 Automated Ion Analyzer (Lachat Instruments Inc., Loveland, Co.; Lachet Instruments. 2003). Briefly, the sample is drawn into the system by a peristaltic reagent pump; the nitrate in the sample is reduced to nitrite via a copperized cadmium reduction column. The nitrite in the sample mixes with sulfanilamide under acidic conditions to form a diazonium cation, this cation then couples with N-(1-napthyl) ethylenediamine dihydrochloride producing a magenta coloured, water-soluble azo dye. The absorbance of the resulting azo dye was measured at 520 nm.

4.2.6 Soil Sample Collection and Analysis

In addition to soil water sample collection, soil samples were collected once in September, October and November respectively and used in an attempt to test treatments for the potential of nitrate leaching. Soil samples were collected to three different depths (0-15 cm, 15-30 cm and 30-45 cm) using a Dutch auger. In potato fields, soil samples were taken from the top of the potato hill, near all four lysimeters. Soil samples consisted of a single sub-sample obtained from mixing 4 auger soil cores per treatment. NO_3^--N was extracted from the soil samples via 2M KCl extraction as described by Gasser et al. (2002b) and analyzed for nitrate-N using the method previously described for water samples. For each month the collected soil samples were used to estimate the amount of NO_3^--N in the soil at that particular depth. To convert the NO_3^--N in the soil samples from mg N kg^{-1} dry soil to kg N ha^{-1} the bulk density used for each depth in the potato sites were as follows: 1.1 g/cm^3 at depth 0-15 cm, 1.2 g/cm^3 at depth 15-30 cm and 1.3 g/cm^3 at depth 30-45 cm. In the grain and hay sits the following bulk densities were used: 1.2 g/cm^3 at depth 0-15 cm, 1.3 g/cm^3 at depth 15-30 cm and 1.4 g/cm^3 at depth 30-45 cm. These bulk densities are based on those presented by Carter et al. (2004) and those recommended by Dr. M.R. Carter (Dr. M.R. Carter, personal communication, Agriculture and Agri-Food Canada Research Center, Charlottetown, PE). In addition to estimating the amount of NO_3^--N present during each month at each depth, the three depths were combined to give a total estimate for the amount of NO_3^--N that was available for potential leaching in the top 45 cm of the soil profile, resulting in a total of 4 estimates of NO_3^- leaching potential based sampled form 0-15, 15-30, 30-45 and 0-45 cm soil depths.

4.2.7 Potato Petiole Sample Collection and Analysis

Throughout the growing season, potato tissue petiole samples were collected on a bi-weekly schedule for 6 weeks staring in mid July, these samples were analyzed for NO_3^--N by the P.E.I. Soil and Feed Lab (Lachet Instruments, 1995).

4.2.8 Crop Yield Measurements

Yield data was obtained from the grain and potato sites. Before grain sites were harvested by the grower four $1m^2$ blocks of grain, per half field, were harvested from areas near the lysimeters, thrashed and analyzed for total grain yield. Potato yields were taken from four 3m strips per half field near the lysimeters. The harvested potatoes were graded for size, disease and defects to determine marketable yields.

4.2.9 Statistical Analysis

Repeated measures analysis was used to determine treatment effect on the NO_3^--N concentration of the lysimeter water samples using Minitab version 15 software. The average NO_3^--N concentrations were analyzed using a matched paired t-test. To test the effect of fertility treatment on the amount of NO_3^--N in the soil a paired sample t-test was performed for each crop, during each month at each depth. To determine the effect of crop treatment on the potential for nitrate leaching a One-Way ANOVA was performed for each month at all 4 areas of interest. Yield data was analyzed using a Two-Way ANOVA to determine fertility treatment effect for total and marketable yields for both years with treatment and field as factors. All data sets were tested for normality using the

Anderson-Darling Normality Test. All data transformations were verified using the Box-Cox Transformation (Christensen 1996).

4.3 Results and Discussion

4.3.1 Lysimeter Samples

There was no significant fertility treatment effect on the NO_3^--N concentration in the lysimeter water samples, $p = 0.516$, $\alpha = 0.05$, (Table 4.2). The average NO_3^--N concentration in the samples collected from the potato sites was significantly higher compared to those collected from the grain and hay sites, $p < 0.001$, $\alpha = 0.05$.

The lack of a significant fertility treatment effect on the concentration of NO_3^--N in the collected water samples is consistent with the results of Chapter 3, and with the first year of study conducted by Cambouris et al. (2008). The lysimeters are too sensitive to the spatial variation within the field. Further work similar to Alberts et al. (1977), who reported high spatial variation in NO_3^--N concentrations of water samples collected using porous ceramic cup samplers, is needed to determine the number of samplers required to obtain the desired level of precision. The lack of significant difference between the treatments may also be a function of the selected growers and the relatively small difference between the CON and NMP treatments.

However, the difference in the NO_3^--N concentration of the samples collected from the potato sites compared to those collected from the grain and hay sites is not a surprising result based on the relatively large differences in fertility treatment among crops (Table

4.1), Bergström (1987) also noted a cropping system effect on NO_3^--N concentrations in water samples collected from tile drained plots and drainage lysimeters.

The number of samples collected from the lysimeters installed in the potato sites was considerably lower than the lysimeters in the grain sites and moderately lower than the hay sites (Table 4.3). It should be noted that even though the lysimeters in the potato sites collected a similar number of samples as those in the hay sites, the examination of the distribution of samples within the potato treatments reveals that 67% of the total number of samples and 92% of the volume collected from the potato sites came from 2 of the 8 sites, and 5 of the 8 sites did not have any samples collected at all and were dropped from analysis.

Table 4.2 Mean lysimeter water sample NO_3^--N concentration (mg N L^{-1}) from all years combined.

Crop Treatment	Fertility Treatment	Mean NO_3^--N (mg N L^{-1})
Potato	CON	30.65
	NMP	32.12
	Mean	**31.39a**[1]
Grain	CON	1.52
	NMP	2.16
	Mean	**1.84b**
Hay	CON	1.64
	NMP	4.67
	Mean	**3.16b**

[1]Values followed by the same letter are not significantly different at the 0.05 significance level.

The low number of collected samples in the commercial potato sites is not consistent with the results obtained in Chapter 3. The lysimeters at the Harrington site performed at approximately 70 - 80% efficiency; that is on the days that samples were collected, approximately 70 - 80% of the lysimeters had an adequate sample volume (greater than 5 mL). The source of this substantial difference in sample number collection between the commercial sites and the research plot could not be determined. One possible explanation is a layer of non-decomposed organic material that has been found in a number of commercial potato fields across Prince Edward Island at a depth of 25 - 30 cm, which was not found at the Harrington research site. This layer may act as a hydrological barrier disrupting the downward flow of water. A second possible explanation is the difference in the scale of the harvesting operation. Commercial potato producers use much larger harvesting equipment than the Harrington research farm, which may cause compacted soil layers to form, disrupting downward water movement. Neither of the two theories has been investigated, and future work is required to gain a better understanding as to why there is such a noticeable difference in sampling efficiency between a commercial potato site and a research potato plot. The failure to obtain samples from each lysimeter on each sampling occasion underscores a limitation to this method. It is not clear whether there was no water flowing in the system or whether the water was not effectively sampled by the lysimeter.

Table 4.3 Summary of the lysimeter water samples collected from 21 sites.

Site	Crop Treatment	# Samples Collected
1	Potato	10
2	Potato	23
5	Potato	0
7	Potato	16
10	Potato	0
12	Potato	0
14	Potato	0
20	Potato	0
Total		**49**
4	Grain	22
6	Grain	16
8	Grain	1
11	Grain	36
13	Grain	40
16	Grain	30
18	Grain	21
21	Grain	10
Total		**176**
3	Hay	3
9	Hay	1
15	Hay	33
17	Hay	17
19	Hay	3
Total		**57**

4.3.2 Soil Samples

The nutrient management fertility application treatment had no significant effect on the soil NO_3^--N content at any of the investigated depths. Soil NO_3^--N content was significantly higher following a potato crop than following a grain or hay crop at all depths of interest in September and October samples, and at all depths except the 0-15 cm depth in the November samples (Tables 4.4 - 4.7).

Table 4.4 Soil NO_3^--N concentrations (kg N ha^{-1}) at depth 0-15cm from 2006 and 2007 combined.

Crop Treatment	Fertility Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
Potato	CON	62.60	54.61	11.59
	NMP	44.78	43.89	10.08
	Mean	**53.69a[1]**	**49.25a**	**10.84a**
Grain	CON	7.79	4.83	10.91
	NMP	6.74	3.36	9.16
	Mean	**7.27b**	**4.10b**	**10.04a**
Hay	CON	8.10	9.33	15.59
	NMP	8.81	8.23	14.86
	Mean	**8.46b**	**8.78b**	**15.23a**

[1]Values followed by the same letter within each month are not significantly different at the 0.05 significance level.

Table 4.5 Soil NO_3^--N concentration (kg N ha^{-1}) at depth 15-30cm from 2006 and 2007 combined.

Crop Treatment	Fertility Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
Potato	CON	104.80	48.65	21.63
	NMP	75.23	46.25	35.50
	Mean	**90.01a[1]**	**47.45a**	**28.57a**
Grain	CON	8.02	6.72	10.62
	NMP	8.21	5.34	8.72
	Mean	**8.12b**	**6.03b**	**9.67b**
Hay	CON	6.40	7.01	10.08
	NMP	6.54	8.24	9.94
	Mean	**6.47b**	**7.63b**	**10.01b**

[1]Values followed by the same letter within each month are not significantly different at the 0.05 significance level.

Table 4.6 Soil NO_3^--N concentration (kg N ha^{-1}) at depth 30-45cm from 2006 and 2007 combined.

Crop Treatment	Fertility Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
Potato	CON	44.04	31.80	21.36
	NMP	36.81	33.39	35.12
	Mean	**40.43a[1]**	**32.60a**	**28.24a**
Grain	CON	5.01	8.02	4.99
	NMP	5.60	3.78	3.77
	Mean	**5.31b**	**5.90b**	**4.38b**
Hay	CON	3.69	2.13	6.77
	NMP	5.61	2.21	4.99
	Mean	**4.65b**	**2.17b**	**5.88b**

[1]Values followed by the same letter within each month are not significantly different at the 0.05 significance level.

Table 4.7 Soil NO_3^--N concentration (kg N ha^{-1}) at depth 0-45cm from 2006 and 2007 combined.

Crop Treatment	Fertility Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
Potato	CON	211.44	135.06	54.58
	NMP	156.82	123.53	80.71
	Mean	**184.13a[1]**	**129.30a**	**67.65a**
Grain	CON	20.82	19.56	26.52
	NMP	20.55	12.48	21.64
	Mean	**20.69b**	**16.02b**	**24.08b**
Hay	CON	18.19	18.47	32.44
	NMP	20.96	18.67	29.80
	Mean	**19.58b**	**18.57b**	**31.12b**

[1]Values followed by the same letter within each month are not significantly different at the 0.05 significance level.

Fall monitoring of soil NO_3^--N displayed the same trends as the lysimeter water samples. There was no significant fertility treatment effect on the amount of soil NO_3^--N for all crops at all depths of interest. The trend of higher levels of soil water NO_3^--N following a potato crop that was seen in the lysimeter water samples was also apparent in the soil samples. With the exception of the November soil samples collected at the 0 - 15 cm depth, the amount of soil NO_3^--N was significantly higher in the sites cropped to potato than in those cropped to grain and hay sites. This trend is not very surprising based on the substantial difference in N fertilizer application rate among crops (Table 4.1). Bélanger et al. (2003b) and Zebarth et al. (2003) both reported that residual soil NO_3^--N increased with increasing nitrogen fertilizer application.

The general decrease in the amount of soil NO_3^--N was consistent at all four depths at the potato sites (Tables 4.4 - 4.7). Over the course of the fall season the amount of soil NO_3^--N gradually decreased. In the top 15 cm, the amount of soil NO_3^--N actually decreased down to levels similar to those found in the grain and hay sites. It is not clear as to what the cause of this decrease in soil NO_3^--N was, either nitrate leaching or losses as a result of denitrification. Not being able to identify the losses of soil NO_3^--N is a major disadvantage of this monitoring method. Although the mechanism responsible for the NO_3^--N lost from the soil is not known, it is important to note that ~ 110 kg N ha^{-1} was lost from the top 45 cm of the soil profile throughout the course of the fall to the environment. This appears to be a major loss with the potential for damaging environmental effects.

The overall trend at the hay sites displayed an increase in soil NO_3^--N from September to November at all four depths. It is important to note that the only hay site that did not experience this trend was site #3, which displayed the opposite (Tables 4.8 - 4.10). Site #3 was plowed in late August 2006 and had a grain cover crop planted soon thereafter, the decrease in soil NO_3^--N in the top 15 cm can likely be explained by the plant NO_3^--N uptake over the course of the fall. The remaining four sites were ploughed either in October or in the following spring.

The trend in the grain was also fairly consistent at all four depths, with a decrease in soil NO_3^--N from September to October, with the exception of the 30-45 cm depth, followed by an increase from October to November. This trend could be attributed to NO_3^--N uptake from the under-seeded clover throughout September and October, then following a stop in nutrient uptake, resulting from frost, some NO_3^--N could then be mineralized from the clover residues.

Table 4.8 Fall soil NO_3^--N concentrations (kg N ha^{-1}) at depths 0-15, 15-30, 30-45 and 0-45 cm for 2006 sites.

Depth			0-15 cm		15-30 cm	
Site	Crop	Treatment	September NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})	September NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
1	Potato	CON	7.26	8.30	6.30	13.88
		NMP	69.80	5.58	18.54	15.15
2	Potato	CON	18.15	6.21	17.82	10.31
		NMP	25.91	10.94	86.04	57.62
3	Hay*	CON	23.58	9.90	20.28	10.34
		NMP	21.60	9.18	19.89	13.07
4	Grain	CON	6.12	6.66	3.32	10.34
		NMP	3.96	11.88	7.22	12.68
5	Potato	CON	10.23	4.83	16.92	9.74
		NMP	10.56	5.52	9.90	33.84
6	Grain	CON	9.36	9.90	9.56	13.85
		NMP	8.64	10.80	11.90	9.56
7	Potato	CON	44.06	11.55	159.12	22.46
		NMP	25.08	14.03	104.94	21.60
8	Grain	CON	12.42	7.38	17.75	8.78
		NMP	10.44	9.18	10.92	8.58
9	Hay**	CON	2.52	6.84	4.29	6.83
		NMP	8.64	11.88	6.24	7.61
10	Potato	CON	120.12	17.99	288.00	23.40
		NMP	39.93	9.08	77.94	11.70

* Indicates August ploughing followed by a barley cover crop. ...Continued
** Indicates mid October ploughing.

Table 4.8 Continued

Depth			30-45 cm		0-45 cm	
Site	Crop	Treatment	September NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})	September NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
1	Potato	CON	8.19	21.80	21.75	43.98
		NMP	19.89	33.89	108.23	54.62
2	Potato	CON	7.61	9.51	43.58	26.03
		NMP	52.07	19.47	164.01	88.03
3	Hay*	CON	7.14	9.45	51.00	29.69
		NMP	13.23	6.30	54.72	28.55
4	Grain	CON	6.51	6.09	15.95	23.09
		NMP	2.94	5.88	14.12	30.44
5	Potato	CON	27.89	10.42	55.04	24.99
		NMP	22.23	31.49	42.69	70.84
6	Grain	CON	4.20	6.51	23.12	30.26
		NMP	8.40	6.93	28.94	27.79
7	Potato	CON	32.76	18.14	235.94	56.15
		NMP	32.37	28.67	162.39	64.29
8	Grain	CON	7.56	4.83	37.73	20.99
		NMP	4.20	4.41	25.56	22.17
9	Hay**	CON	8.40	5.04	15.21	18.71
		NMP	5.67	5.46	20.55	24.95
10	Potato	CON	64.74	37.25	472.86	78.63
		NMP	26.52	11.70	144.39	32.48

* Indicates August ploughing followed by a barley cover crop.
** Indicates mid October ploughing.

Table 4.9 Fall soil NO_3^--N concentrations (kg N ha^{-1}) at depths 0-15 and 15-30 cm for 2007 sites.

Depth			0-15 cm		
Site	Crop	Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
11	Grain	CON	14.17	6.91	11.49
		NMP	8.45	1.93	9.95
12	Potato	CON	237.99	69.45	21.76
		NMP	111.39	50.12	9.93
13	Grain	CON	2.75	6.25	12.20
		NMP	4.51	5.27	1.61
14	Potato	CON	35.17	36.35	9.90
		NMP	21.58	40.95	10.73
15	Hay*	CON	6.86	13.38	25.57
		NMP	6.56	14.37	23.71
16	Grain	CON	4.69	4.16	21.56
		NMP	5.19	4.45	14.73
17	Hay*	CON	3.74	11.96	27.18
		NMP	3.16	6.95	17.66
18	Grain	CON	2.81	4.75	10.13
		NMP	4.04	2.66	11.15
19	Hay*	CON	3.82	2.65	8.44
		NMP	4.08	3.36	11.89
20	Potato	CON	27.84	58.04	12.14
		NMP	53.99	40.61	14.85
21	Grain	CON	10.00	2.06	7.97
		NMP	8.68	2.48	3.94

* Indicates fall glyphosate application and spring ploughing. ...Continued

Table 4.9 Continued

Depth			15-30 cm		
Site	Crop	Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
11	Grain	CON	7.00	20.01	6.58
		NMP	5.80	11.33	4.25
12	Potato	CON	149.61	66.99	47.13
		NMP	82.46	55.67	36.96
13	Grain	CON	2.53	6.25	10.10
		NMP	4.60	4.21	3.55
14	Potato	CON	110.07	27.31	23.47
		NMP	86.22	30.28	43.63
15	Hay*	CON	3.22	11.01	14.13
		NMP	2.54	16.14	17.24
16	Grain	CON	7.78	2.48	24.82
		NMP	7.39	3.70	15.09
17	Hay*	CON	2.44	8.07	15.46
		NMP	1.08	4.84	7.87
18	Grain	CON	4.74	3.89	6.17
		NMP	4.59	4.80	11.92
19	Hay*	CON	1.75	1.95	3.65
		NMP	2.95	3.73	3.94
20	Potato	CON	90.56	51.65	18.69
		NMP	135.85	52.79	63.53
21	Grain	CON	11.52	0.97	4.29
		NMP	12.26	2.66	4.10

* Indicates fall glyphosate application and spring ploughing.

Table 4.10 Fall soil NO_3^--N concentrations (kg N ha^{-1}) at depths 30-45 and 0-45 cm for 2007 sites.

Depth			30-45 cm		
Site	Crop	Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
11	Grain	CON	3.76	20.31	3.00
		NMP	5.07	12.06	2.33
12	Potato	CON	67.16	44.39	27.35
		NMP	33.46	42.26	59.03
13	Grain	CON	1.23	1.76	3.55
		NMP	2.30	3.49	1.85
14	Potato	CON	66.71	19.07	17.92
		NMP	60.16	21.22	13.29
15	Hay*	CON	1.11	2.82	13.61
		NMP	1.31	3.76	9.69
16	Grain	CON	5.10	2.85	12.31
		NMP	7.18	1.48	3.54
17	Hay*	CON	0.93	2.48	3.86
		NMP	0.49	1.33	2.69
18	Grain	CON	4.61	2.86	3.32
		NMP	2.41	1.12	3.83
19	Hay*	CON	0.87	1.08	1.88
		NMP	7.35	1.54	0.80
20	Potato	CON	77.27	31.39	28.51
		NMP	47.76	36.69	83.46
21	Grain	CON	7.09	12.32	0.32
		NMP	12.28	0.74	1.35

* Indicates fall glyphosate application and spring ploughing. ...Continued

Table 4.10 Continued

Depth			0-45 cm		
Site	Crop	Treatment	September NO_3^--N (kg N ha^{-1})	October NO_3^--N (kg N ha^{-1})	November NO_3^--N (kg N ha^{-1})
11	Grain	CON	24.92	47.22	21.07
		NMP	19.32	25.33	16.54
12	Potato	CON	454.77	180.83	96.24
		NMP	227.30	148.06	106.93
13	Grain	CON	6.52	14.25	25.85
		NMP	11.41	12.97	7.01
14	Potato	CON	211.86	82.73	51.29
		NMP	167.96	92.45	67.64
15	Hay*	CON	11.19	27.20	53.31
		NMP	10.41	34.27	50.64
16	Grain	CON	17.57	9.50	58.69
		NMP	19.76	9.63	33.36
17	Hay*	CON	7.11	22.51	46.51
		NMP	4.74	13.12	28.22
18	Grain	CON	12.16	11.49	19.62
		NMP	11.04	8.58	26.90
19	Hay*	CON	6.45	5.68	13.98
		NMP	14.37	8.63	16.62
20	Potato	CON	195.66	141.62	59.35
		NMP	237.60	130.09	161.84
21	Grain	CON	28.60	15.35	12.58
		NMP	34.23	5.87	9.39

* Indicates fall glyphosate application and spring ploughing.

4.3.3 Yield

The nutrient management fertility treatment did not have a significant effect on total yield ($p = 0.360$) or marketable yield in either year of the study ($p = 0.906$ for 2006 and $p = 0.493$ for 2007, $\alpha = 0.05$) (Figures 4.1 - 4.3).

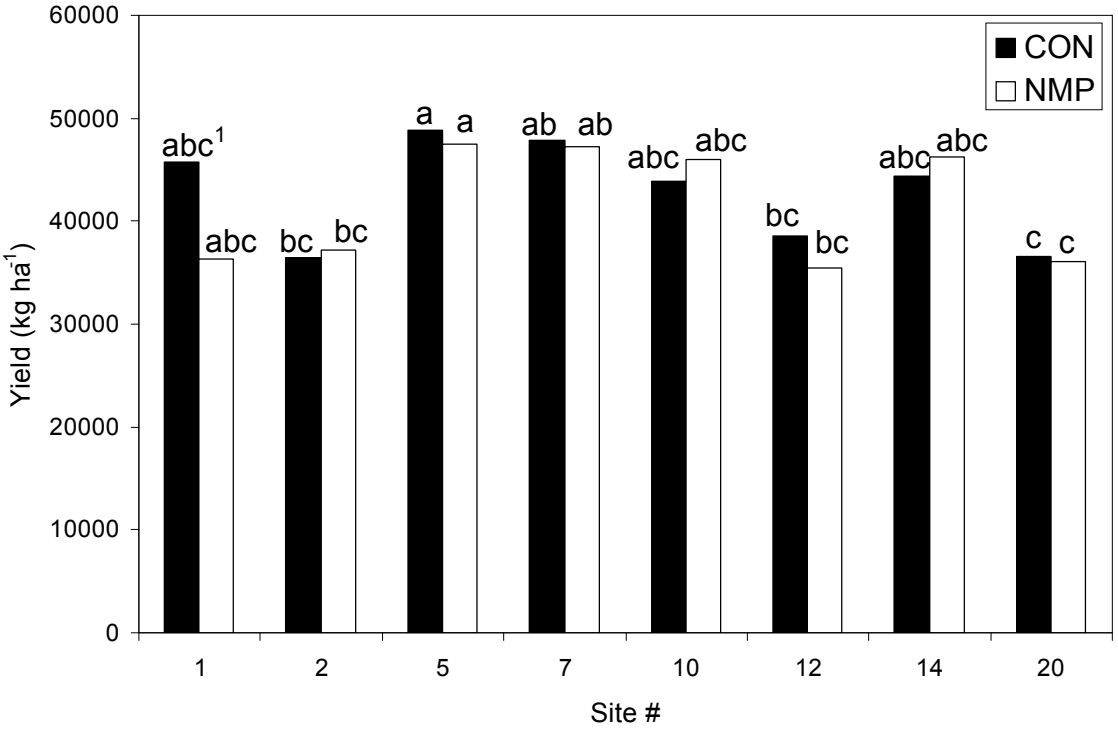

Figure 4.1 Effect of nutrient management fertility on total potato yield (kg ha^{-1}).
[1]Yields followed by the same letter are not statistically different at the 0.05 significance level.

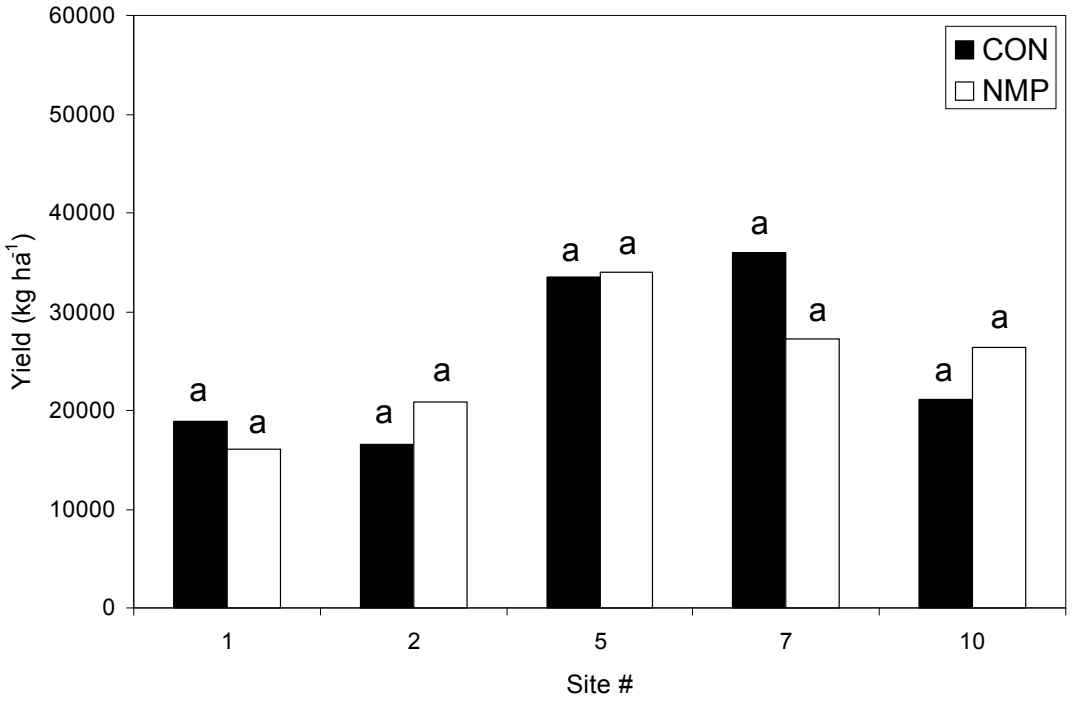

Figure 4.2 Effect of nutrient management fertility on 2006 marketable potato yields (kg ha^{-1}). [1]Yields followed by the same letter are not statistically different at the 0.05 significance level.

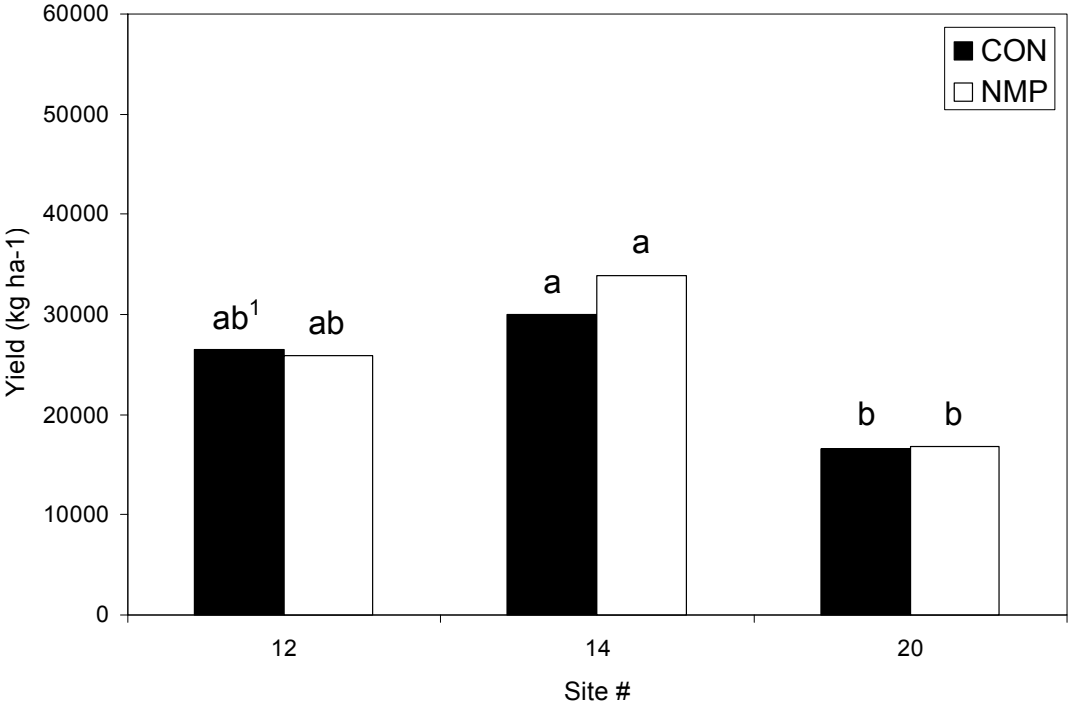

Figure 4.3 Effect of nutrient management fertility on 2007 marketable potato yields (kg ha^{-1}). [1]Yields followed by the same letter are not statistically different at the 0.05 significance level.

The lack of yield response can mainly be attributed to the relatively small difference between treatments in the amount of applied nitrogen (Table 4.1). The small difference between treatments in the amount of nitrogen applied is a result of the nature of the study and the grower's lack of confidence in the NMP recommendations. In an ideal situation, the NMP recommendations would reduce the amount of applied nitrogen by upwards of 100 kg ha^{-1} compared to what would be applied by the grower; however this was not the case. It is important to keep in mind that when it comes to working with commercial growers on full field scale trials, their income can be potentially reduced if the NMP recommendations do not produce comparable yields. Since the project cannot offer compensation for a dramatic loss in profit, the growers are hesitant to drastically reduce the amount of applied nitrogen. Fortunately for the participating growers in this study, there was no adverse impact on yield, and therefore income, as a result of the lower nitrogen application rate. The observed residual soil NO_3^--N at time of harvest in the top 45 cm of the soil profile was in excess of 100 kg N ha^{-1}. This is evidence of inefficient N management and, in a time of heightened public concern over the contamination of water by nutrients, threatens the long term sustainability of the potato industry. It is hopeful that the results of this study will allow growers to have the confidence required to continue to do further research in this area, and reduce nitrogen inputs even further in an attempt to develop further knowledge in the effectiveness of the NMP recommendations on Prince Edward Island.

4.5 Conclusion

To summarize the findings of this study, it was found that there was no fertility treatment effect on the concentration of NO_3^--N in the lysimeter water samples. The degree of spatial variation observed in the data was consistent with results reported in Chapter 3. The lysimeters experienced the same limitations as those used at the Harrington research site: high sensitivity to the spatial variation of the field, damage caused by wildlife and susceptibility to freezing in the winter months. The lysimeters used in this study also experienced a limitation that was not seen at the Harrington research site. The number of collected samples from the potato sites were much lower than what was expected based on the performance of the lysimeters at the Harrington research site and the lysimeters at the commercial grain and hay. The cause of this decreased number of samples was not fully explored and requires further investigation.

Fall soil samples also did not detect a fertility treatment effect on the potential for NO_3^--N leaching, however the sampling method was able to show that the potential for NO_3^--N leaching was much higher in the potato sites (> 100 kg N ha^{-1} lost from Sept. to Oct.) compared to the grain and hay site, which had similar soil NO_3^--N levels throughout the fall season. The soil data also revealed increasing soil NO_3^--N trends in the hay sites that were ploughed either late in the fall or early in the spring. This trend brings attention to the issues relating to fall cover crops that could lead to further research into this area. Overall it appears that the fall soil samples can provide a more reliable and cost effective means of estimating NO_3^--N losses from commercial potato rotation sites compared to the lysimeters.

The yield data indicated that there was no negative impact of the NMP on the total and marketable yield. The findings in this aspect of the study, in combination with the large amounts of surplus NO_3^- remaining in the soil in the fall, suggest that further work needs to be done to increase the producers' confidence in the nutrient management fertility recommendations. This will allow for a greater reduction in the amount of applied nitrogen in the NMP application compared to the CON application, to aid in refining the nutrient management recommendation process and reducing the potential for NO_3^- loss from potato production.

Chapter 5 - Conclusion

Water samples collected from tile-drained potato rotation research plots were used to evaluate the use of stainless steel zero tension lysimeters as a method for collecting soil water samples for NO_3^--N analysis. Fall soil sampling at various depths below the soil surface (0-15, 15-30 and 30-45 cm) were also evaluated as a practical method of determining the potential for nitrogen loss to the environment. These techniques were used as methods of evaluating the efficiency of nutrient management in reducing the potential for NO_3^--N leaching from commercial potato rotations. In addition to the effects of nutrient management on NO_3^--N leaching, the ability of nutrient management fertility recommendations to produce marketable potato yields in comparison with conventional fertility rates was assessed as part of a larger study on potato production.

Both of the soil water sampling systems experienced various degrees of success over the duration of the study, each encountering different problems. The lysimeters are susceptible to freezing and damage by wildlife. The automated samplers connected to the tile lines can potentially lose power and therefore miss collection dates. The soil samples, however, did not encounter any major set backs or problems throughout the duration of the study, and are considered to be the most reliable sampling method of the three discussed.

Neither the lysimeters nor the tile lines were able to detect a statistically significant treatment effect on the NO_3^--N concentration of collected water samples. The overall trends, however, in the mean concentrations of NO_3^--N conformed to expectation, with

the 300N treatment being numerically greater followed by similar values for the 200N and the MAN treatments and finally the CK treatment had the least in both sampling systems. The combination of the lysimeters' high sensitivity to the spatial variability of the plots and the small number of treatment replications limited the ability to separate the treatments statistically. The small number of treatment replications was also not sufficient to detect differences with the tile line sampling system given the high degree of variation between plots receiving the same treatment.

The advantages that were found to be associated with the tile line sampling system are:

- The greater area sampled by the tile drainage system (~ 1000 m^2) relative to the lysimeter (~ 1 m^2) makes this system less sensitive to within field variability,
- The combination of the known volume of water discharge and the average nitrate concentration allows for direct calculation of flow weighted average concentration,
- In addition to the flow weighted average concentration, the tile line system allows for an estimate of nitrate lost from the area of interest by integrating the flow weighted average concentration with annual infiltration. Lysimeters require indirect estimates of the volume of water draining from the profile to estimate the mass of NO_3^--N lost from the soil profile.
- The ability of the tile lines to draw water from the soil for a longer time frame allows for a prolonged sampling season which increases the ability to monitor the nitrate dynamics of a particular cropping system.

The major disadvantage associated with the tile drain is that the cost of installing a system such as the one used in this study in a commercially used field would be very great making this approach simply not practical based on the cost of installation and maintenance as well as the amount of soil disruption that would occur.

In terms of the lysimeters efficiency compared to the tile lines, they could prove to be a more cost effective method for sampling soil water for NO_3^--N analysis upon the establishment of the appropriate number of lysimeter samples required to achieve the desired level of precision of that of the tile lines.

There was no fertility treatment effect on the concentration of NO_3^--N in the lysimeter water samples in the commercial fields. The degree of spatial variation observed in the data was consistent with results reported at the Harrington research site. The lysimeters used in the commercial potato sites experienced a limitation that was not seen in the first study; that is the number of collected samples was much lower than what was expected based on the performance of the lysimeters at the Harrington research site and the lysimeters at the commercial grain and hay sites. The cause of this decreased number of samples was not fully explored and requires further investigation, but could be linked to two possible explanations: 1) A layer of non-decomposed organic material that has been found in a number of commercial potato fields across Prince Edward Island at a depth of 25 - 30 cm, which was not found at the Harrington research site. This layer may act as a hydrological barrier disrupting the downward flow of water. 2) The difference in the scale of the harvesting operation. Commercial potato producers use much larger

harvesting equipment than the Harrington research farm, which may cause compacted soil layers to form, disrupting downward water movement.

The soil sampling method proved to be more reliable and more sensitive than either the lysimeters or the tile lines, as it was possible to statistically separate the CK treatment from the other three treatments at the Harrington research site. Fall soil samples at the commercial sites did not detect a fertility treatment effect on the potential for NO_3^--N leaching which is largely attributed to the relatively small difference between conventional and nutrient management treatments. The sampling method was, however, able to show that the potential for NO_3^--N leaching was much higher in the potato sites (> 100 kg N ha^{-1} lost from Sept. to Oct.) compared to the grain and hay sites, which had similar soil NO_3^--N levels throughout the fall season. The ease of use, reliability and sensitivity of this sampling method may prove to be useful in acquiring an estimate of the potential for NO_3^--N loss when comparing treatments at a particular location. The disadvantage of this method is that it does not provide direct evidence of leaching. Losses could be due to leaching or denitrification.

There was no negative impact of the NMP on the total and marketable yield. The findings in this aspect of the study, in combination with the large amounts of surplus NO_3^- remaining in the soil in the fall, suggest that further work needs to be done to increase the producers' confidence in the nutrient management fertility recommendations. This will allow for a greater reduction in the amount of applied nitrogen in the NMP application compared to the CON application, to aid in refining the nutrient management

recommendation process and reducing the potential for NO_3^- loss from potato production systems.

The soil sampling method proved to be a more effective tool for determining the potential for NO_3^--N leaching than both the lysimeters and the tile line system.

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