The Effect of Liquid Hog Manure and Commercial Fertilizer on Nutrient Movement in a Sandy Soil

BY

JEFFREY MARK ENNS

A Thesis Submitted to the Faculty of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

Department of Soil Science
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

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A two-year field study was initiated in the spring of 2002 to investigate the effects of liquid hog manure and commercial fertilizer applications on the leaching losses of soil water and nutrient on a field site situated over the Assiniboine Delta Aquifer (ADA) at Carberry, MB. The study used two methods for determining soil water and NO_3-N leaching losses: traditional soil sampling and large intact soil core lysimeters. By the end of the two years, the highest rate of hog manure, cropped fertilizer and fertilizer fallow plots had 239, 253 and 227 kg NO_3-N ha^{-1}, respectively, within the root zone, which was significantly higher than the control, 2500 gal ac^{-1} and 5000 gal ac^{-1} plots (61, 107 and 123 kg NO_3-N ha^{-1}, respectively). The highest rate of manure and the two commercial fertilizer treatments had greater cumulative amounts of NO_3-N within the root zone than what Manitoba Agriculture guidelines considers excessive (i.e.168 kg NO_3-N ha^{-1}). Soil sampling showed leaching losses of nitrate-nitrogen from all treatments, however little movement of Mehlich-3 phosphorus was observed after two years of this study. There was a distinct rate effect as nitrate-nitrogen concentrations of 8, 11, 15 and 23 mg NO_3-N kg^{-1} were found in the control, 2500 gal ac^{-1}, 5000 gal ac^{-1} and 7500 gal ac^{-1} treatments at the 20-30 cm depth after two years, respectively. Nitrate-nitrogen concentration was increased by the application of commercial fertilizer (i.e. 12 mg kg^{-1}) above both the control (i.e. 2 mg kg^{-1}) and manure (ie. 6 mg kg^{-1}) plots at a depth of 75cm after two years. However below

75cm, the NO_3-N concentration was usually higher in the manure plot than the cropped fertilizer plot. Greater availability of nutrients from the commercial fertilizer compared to the hog manure resulted in higher crop yields, which limited soil water movement and the downward movement of nitrate-nitrogen. While leachate containing nitrate-nitrogen was expected from the fallow lysimeters, the amount of water (48 mm) and nitrate (18 kg ha^{-1}) leached from the control lysimeter shows that soil organic matter breakdown can result in loss of nitrate-nitrogen from these sandy soils without the additions of fertilizer or manure. Nitrate-nitrogen concentration in the leachate ranged from 10 mg NO_3-N L^{-1} to 122 mg NO_3-N L^{-1}. While the concentration of nitrate-nitrogen within the leachate was at a consistent level from May 2004 to November 2004, leachate amount showed a seasonal trend of higher volumes in spring and fall. After two years, this study shows that even under below normal precipitation levels nitrate-nitrogen will be lost from a dryland agricultural system subjected to various rates and sources of nitrogen application, however nitrate-nitrogen losses can be minimized through proper agricultural management.

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1. INTRODUCTION

Nitrate-nitrogen is one of the major sources of nitrogen required by plants. It has an important influence on agricultural production and can have a serious impact on environmental quality. Nitrate-nitrogen is soluble in water and consequently is very mobile in the soil (Havlin et al., 1999). Nitrate leaching is the downward movement of nitrate through the soil profile (Gardner, 1965), removing nitrate from the rooting zone.

Agricultural production is highly dependent on the addition of inorganic and organic forms of nitrogen to increase crop yields. Nitrogen is generally considered to be a limiting factor for crop production (Dodds et al., 1996). Crops exhibit positive yield responses to the addition of nitrogen, however there may be increased risk of leaching due to residual nitrogen left behind in the form of nitrate (Goulding, 2000). The amount of nitrate potentially available for plant uptake and leaching is dependent upon fertilizer additions and mineralization of organic nitrogen in the soil (Havlin et al., 1999). Nitrogen leached, as nitrate, is lost from the crop production system, and may result in an economic loss for producers.

Nitrate-nitrogen leaching also presents potential problems for human and animal health and environmental degradation. The population of North America relies heavily on groundwater as a source for domestic and industrial water use (Power and Schepers, 1989; Zebarth et al., 1999). Concentrations of nitrate in excess of

10 mg N L^{-1} in drinking water have been related to cases of methaemoglobinaemia, or blue baby syndrome (Hedlin, 1971; Water Quality Branch, 1995) and stomach cancer (Flynn, 1997). An additional environmental concern is the eutrophication of water bodies, where nitrate-nitrogen is an important factor limiting eutrophication, particularly in marine waters (Burton and Ryan, 2000).

A balance between environmental and economic priorities can be difficult to determine when considering acceptable NO_3-N levels in agricultural ecosystems (Younie et al., 1996). Agricultural practices can lead to increased levels of nitrate within the soil profile (Campbell et al., 1984) and the groundwater (Casey et al., 2002). As the intensity of cropping and animal management systems increases, a balance must be struck between supplying the crop with adequate nutrients and maintaining the integrity of natural systems, such as surface and groundwater.

The objectives of this research study are: 1) to quantify the leaching losses of nitrate-N as affected by liquid hog manure application rates; 2) to determine the effect of manure (organic) and commercial (inorganic) fertilizers on the magnitude of nutrient leaching; 3) to test the methodology of measuring nitrate leaching (i.e. traditional soil profile sampling vs. field core lysimeters).

2. LITERATURE REVIEW

2.1 The Assiniboine Delta Aquifer

The Assiniboine Delta Aquifer (ADA) is a large unconfined surface aquifer located east of Brandon, Manitoba. The aquifer covers approximately 388,500 hectares and is estimated to have an annual recharge capacity of 60,378 dam^3 (Render, 1987 as cited in Burton and Ryan, (2000)). The groundwater contained within the ADA is an important resource for communities located above the aquifer both for human consumption and for agricultural production. Kulshreshtha (1994) estimated the value of water within the ADA at approximately $219 million annually, in 1990 dollars, with the economic worth of the aquifer ranging from $57 million to $649 million, depending on the level of development.

Landuse over the ADA has steadily changed from grasslands to improved pastureland and cropland since the middle of the 1950s. Agricultural production in the area consists primarily of cereal crops with an increase in oilseeds and potato production in recent years. Potato production in Manitoba has increased from approximately 30,000 acres in the 1940s to 78,500 acres in 2001 (Manitoba Agriculture, 2002), with approximately 26, 300 hectares under irrigated production over the ADA (Kulshreshtha, 1994). The ADA is well suited for potato production due to the well-drained sandy soils, fairly level topography and close proximity to a water source for irrigation. These same characteristics contribute to the susceptibility of the ADA to nitrate leaching.

One of the main focuses of the livestock industry in Manitoba toward the end of the last century has been to increase swine production. By 2001, Manitoba was the third largest swine producing province behind only Quebec and Ontario (Beaulieu and Bédard, 2003). The land over the ADA has experienced average growth in swine production. The increase in swine and other livestock production has resulted in concerns over disposal and use of manure and the nutrients it contains. The result of livestock expansion is that a large enough landbase needs to be found so that appropriate amounts of manure can be applied (Ribaudo et al., 2003). The change in land use practices within a region may influence the potential for higher nitrate concentrations in groundwater (Zebarth et al., 1998). As the application of manure and commercial fertilizers can lead to increases in nitrate concentrations within the groundwater, suggestions have been made for further studies into nitrate leaching losses in order to better understand the impacts of activities occurring over the ADA (Burton and Ryan, 2000; The Assiniboine River Management Advisory Board, 1998).

2.2 Fates of Nitrogen in Soil

Whether the nitrogen originates from the addition of an inorganic or organic source, atmospheric deposition, or soil organic matter, plants require large amounts of nitrogen in the soil to grow. The greatest proportion of the nitrogen in soil is maintained within the soil organic matter, or the organic nitrogen pool. Organic nitrogen cannot be used by plants for growth; plants can only use inorganic forms of nitrogen. The two most common forms of inorganic nitrogen within the soil are NH_4-N and NO_3-N.

Nitrogen is continuously being exchanged between the organic and inorganic pools, within the soil profile. Mineralization occurs when soil organic nitrogen is converted to an inorganic form, while immobilization is the transformation of inorganic nitrogen into an organic form (Jansson and Persson, 1982). The balance between mineralization and immobilization can be influenced by the addition of various organic materials. Mineralization of nitrogen is favoured when materials rich in N (i.e. a narrow carbon (C) to N ratio) are added to the soil, such as animal manures, and green manure (i.e. legumes and forages). Immobilization is favoured when materials containing low N (i.e. wide C to N ratio) are added, such as cereal straw (Powlson, 1993; Mooleki et al., 2002). The result of mineralization is NH_4-N. NH_4-N is rapidly immobilized by microbes, nitrified into NO_3-N, assimilated by plants, or held by the soil particle exchange complex leaving only trace amounts of NH_4-N in the soil (Paul and Clark, 1996). Mineralization and immobilization are very difficult to control, resulting in spatial and temporal variability within the soil matrix. This variability can lead to accumulations of nitrate that are potentially available for transport.

The amount of NO_3-N in the soil depends on a number of processes. NO_3-N is added into the soil profile through mineralization of organic nitrogen, and the addition of inorganic and organic sources. Nitrates can accumulate in the soil due to mineralization of organic nitrogen occurring after plant uptake of nitrogen has ceased. The accumulated nitrate can be lost from the soil system through a number of processes: runoff, erosion, denitrification and leaching. The focus of this review will be on denitrification and leaching, as these processes are the most influential in the loss of nitrate to the groundwater.

2.2.1 Denitrification

Nitrate is lost from the soil system through the process of denitrification. Denitrification is the respiratory reduction of NO_3-N to gaseous NO, N_2O and N_2 by microbes (Firestone, 1982; Paul and Clark, 1996). Facultative anaerobes (i.e. bacteria that can use both oxygen and oxides of nitrogen as electron acceptors) are responsible for the denitrification of nitrate. The reduction pathway for NO_3-N is as follows:

$$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2NO \rightarrow N_2O \rightarrow N_2$$

This loss of vital plant nutrients has long been an economic concern, however, more recently environmental problems have arisen as a result of the release of nitrous oxide by denitrification. Denitrification can have a positive environmental effect because it decreases the amount of nitrate leaching to the groundwater. However, the negative effect is that the gaseous products of denitrification are greenhouse gases and may contribute to global warming (Paul and Zebarth, 1996). Nitrous oxide is a greenhouse gas, possibly contributing to increased warming of the Earth and the depletion of the ozone layer. Nitrous oxide molecules are 150 times more effective than carbon dioxide at causing warming of the Earth's atmosphere (Paul and Clark, 1996; Powlson, 1993). The amount of nitrogen lost from agricultural systems through denitrification is difficult to quantity. Studies indicate that the amount of nitrogen lost could range from 0 to 48 kg N ha^{-1} (Bhogal and Shepherd, 1997; Paul and Clark, 1996; Paul and Zebarth, 1997; Rochette et al., 2000). The loss of nitrogen by denitrification appears to depend upon site-specific conditions. Changes in agricultural practices designed to reduce nitrate leaching should not result in an increase in denitrification.

The difficulty with determining the pathway for the loss of nitrogen from an agricultural system is that many of the conditions favoring denitrification also favor nitrate leaching (Cavers, 1998). The general conditions required for denitrification to occur are: 1) reduced availability of O_2, or anaerobic conditions; 2) a sufficient supply of NO_3-N or other N oxides; 3) presence of denitrifying organisms; and 4) availability of suitable reductants (e.g., organic C) (Follett and Delgado, 2002; Paul and Clark, 1996).

Anaerobic conditions will be created if sufficient amounts of water enter the soil matrix, such as during spring snowmelt or heavy rainfall. Zero tillage systems can create anaerobic conditions due to slightly wetter conditions (Weed and Kanwar, 1996). Lund et al. (1974) determined that soil texture contributed to denitrification as soils with high clay content increased the opportunity for the creation of anaerobic conditions. In addition to creating an anaerobic environment for denitrification, excess water can also lead to leaching of nitrate

(Cambardella et al., 1999; Campbell et al., 1984; Stout et al., 1998; Toth and Fox, 1998).

The supply of nitrate-nitrogen and organic carbon can be increased through the application of manure. Denitrification rates are higher under manure treated soil than nonmanured soil due to favourable conditions for bacteria growth and the availability of nitrate and organic carbon (Paul and Clark, 1996; Rochette et al., 2000). Bhogal and Shepherd (1997) suggested that the reduction of nitrate at depth is the result of denitrification processes, which are fueled by organic carbon leaching from the application of poultry manure. Paul and Zebarth (1997) determined that denitrification accounted for 17% of the NO_3-N lost from the soil profile, indicating that NO_3-N disappearance from the soil profile was mainly from leaching losses.

2.2.2 Nitrate Leaching

The movement of water through the soil profile can carry NO_3-N. The solute transport processes of convection and diffusion are responsible for the movement of NO_3-N within the soil profile. Convective flow or mass flow of nitrate occurs when the soil solution itself moves and carries any dissolved nitrate with it (Gardner, 1965). The diffusion of nitrate-nitrogen can only occur within pore spaces that contain water. Due to uneven distribution of nitrate within the soil solution, concentration gradients exist, which lead to the movement of nitrate from areas of higher concentration to those of lower concentration

(Gardner, 1965). Convection and diffusion processes are generally described using the following convective-dispersive equation:

$$\frac{\sigma c}{\sigma t} = D \frac{-\sigma^2}{\sigma z^2} - v_0 \frac{\sigma c}{\sigma z}$$

where c = concentration of NO_3-N (mg L^{-1}),

D= apparent mean diffusion coefficient (cm^2 day^{-1}),

v = average pore velocity (cm day^{-1}),

z = linear distance in direction of flow (cm), and

t = time (days) (Paul and Clark, 1996).

This equation is valid for homogenous soil and steady-state soil water conditions. However, these conditions rarely exist within the soil profile. Instabilities that arise due to the velocity of liquid near the center of the pore being greater than near the edges, or changes in velocity due to dead ends and tortuous pore pathways result in the mixing of the soil solution (Gardner, 1965). This mixing of the solution is referred to as hydrodynamic dispersion and can potentially even out the concentration of NO_3-N in the flowing solution. When convective flow is rapid, hydrodynamic dispersion can greatly exceed, and overwhelm diffusion flow. In a soil solution at rest, hydrodynamic dispersion does not exist and the mixing of solutes only involves diffusive flows (Hillel, 1998).

Hillel (1998) describes nitrate flux as a combination of flux due to convective flow, flux due to diffusion, and flux due to hydrodynamic dispersion. The combined nitrate flux is the total mass of nitrate transferred through a unit cross-sectional area of soil within a unit of time in a steady state condition.

Of course, the prediction of nitrate movement in the soil is subject to many other causes or factors than the processes outlined above. Interference from such factors as micro- and macrobiological activities, the variability of weather, topography, and inherent heterogeneity of soil strata cause deviations in these calculations (Hillel, 1998). An example that defies easy explanation is nitrate movement through macropores. Macropores may provide a conduit for increasing or decreasing leaching losses depending on the availability of nitrates in the macropore. Experimental results show that the best explanation is that there is a heterogeneous moisture flow within the soil matrix, where a few pores contribute to the majority of soil water movement and a fraction remains immobile, especially in a clay soil (Maruyama et al., 2003; Yasuda et al., 1994).

2.3 Factors Influencing Nitrogen Leaching

There are two primary factors that influence the loss of nitrate through leaching: excess water and presence of available nitrate. In order for nitrate leaching losses to occur both of these factors must be present at the same time. Nitrate mobility depends on the amount of water present in the soil solution. In a dry year, nitrate is not lost by leaching, but accumulates within the soil profile (Weed and Kanwar, 1996). In the same way, excess moisture within the soil profile will percolate down through the rooting zone to the groundwater. However, if the soil does not contain available nitrate, then nitrate leaching losses will not occur. Excess moisture and the presence of available nitrate are the primary factors influencing leaching losses of nitrate. Secondary factors, influencing the loss of nitrate by leaching, are soil texture and agricultural management practices.

2.3.1 Excess Water

A primary influence on the movement of nitrate within the soil is the presence of excess water. Water can contribute to leaching losses in two ways: precipitation and soil moisture (Campbell et al., 1984). Precipitation can contribute to nitrate leaching and movement through the amount and timing of rainfall (Campbell et al., 1984; Cambardella et al., 1999; Toth and Fox, 1998). When precipitation exceeds evapotranspiration, the potential for downward movement of water and nitrate exists (Stout et al., 1998; Gardner, 1965). Younie et al. (1996) determined little downward movement of a chloride tracer during a normal growing season when evapotranspiration exceeded precipitation. During this period, the solute tended to disperse, decreasing the peak concentrations. However, the chloride tracer tended to move in a "pulse" manner during wet seasons or periods of maximum leaching.

In dryland agriculture (e.g. on the Canadian Prairies), precipitation generally only exceeds evapotranspiration in the spring during snowmelt. This movement of water results in a downward movement of available nitrate, possibly below the root zone (Campbell et al., 1984). Nitrate may also be leached below the root zone during the growing season by above-normal rainfall events (Campbell et al., 1984).

Soil moisture may induce net mineralization of organic nitrogen and potentially increase nitrate leaching losses (Campbell et al., 1993). The nitrate may then be leached during the growing season; however, most of the leaching generally occurs early in the growing season before the crop can utilize the applied and mineralized nitrate (Campbell et al., 1993). Dry soil and low precipitation during the fall season will decrease water movement, thus reducing nitrate leaching. However, the soil organic nitrogen continues to be mineralized throughout this period resulting in an accumulation of nitrate. When precipitation does exceed evapotranspiration, rapid infiltration and percolation of water can move available nitrate below the root zone (Cambardella et al., 1999; Chang and Entz, 1996).

Soil moisture can also influence the movement of nitrate within the soil matrix. The possibility of a precipitation event causing nitrate leaching depends upon the initial soil moisture. In a soil at field capacity, additions to the soil solution in the form of precipitation may cause a displacement of the existing soil solution. The result is that the excess moisture either runs off the field, possibly carrying nitrate within the runoff, or the existing soil solution (i.e. containing nitrate) moves down in the soil profile. Thus, nitrate leaching may result from "small" precipitation events, if the soil is near field capacity.

The standard allowable limit of nitrate in groundwater is 10 ppm NO_3-N or 10 mg NO_3-N L^- (Water Quality Branch, 1995), which is a concentration value. The amount of water moving through the soil must also be considered in order to calculate the amount of nitrate lost from a system. For example, Stout et al. (1998) determined that the concentration of nitrate leached from one experimental site (i.e. the Leck Kill site) was approximately 35% less than a different experimental site (i.e. the State College site). However, there was no significant difference between the two sites when the total load of nitrate losses was calculated. The leachate amount (i.e. percolating soil solution) must be considered when determining nitrate leaching loss. In this study, the greater leachate amount diluted the nitrate concentration at the Leck Kill site. If only the concentration of nitrate was considered, then the true nitrate leaching loss would be overlooked. Cambardella (1999) noted high nitrate losses coupled with low nitrate concentration. The high amounts of water percolating through soil may have contributed to reduced concentrations of nitrate.

2.3.2 Presence of Available Nitrate

The other primary reason for the occurrence of nitrate leaching losses is that an ecosystem contains more NO_3-N than it can use or immobilize. In order for the loss of nitrate to occur through leaching, nitrate must be available for transport.

For example, Izaurralde et al. (1995) found no indication of nitrate leaching under native vegetation of aspen, poplar, white birch, and spruce because nitrate did not occur in amounts over what the vegetation could utilize. The accumulation of nitrate within an ecosystem, for a variety of reasons, leads to the potential of nitrate leaching losses.

As a whole, an ecosystem may not contain excess nitrate, however spatial and temporal variability within the ecosystem may lead to localized leaching events. The variability within a natural system may be enough to produce nitrate losses via leaching. Younie et al. (1996) reported that the background NO_3-N levels can be close to drinking water standard of 10 mg NO_3-N/L, and that all treatments of commercial fertilizers and liquid cattle manure increased NO_3-N levels above this standard. Microtopographic features contributed to spatially sporadic increases in solute concentrations following recharge events (Schuh et al., 1997). These increases resulted in large, stable solute concentrations beneath the root zone. However, Evans (1994) found enough variability within the soil material and microtopography that topographic influences were minimal at best.

Temporal changes in nitrate concentration within the soil can lead to the potential for leaching losses. Nitrate can be available for leaching when applied at rates that exceed crop uptake within a given growing season. Residual soil nitrate after harvest and the mineralization of nitrate following harvest are important sources of available nitrate for leaching loss (Paul and Zebarth, 1997). Powlson

(1993) noted that mineralization "usually continues long after uptake by an arable crop has ceased, causing a considerable accumulation of nitrate during the late summer, autumn, and early winter."

2.3.3 Soil Texture

The texture of the soil affects the saturated hydraulic conductivity and the water holding capacity, influencing the amount of nitrate leaching. The hydraulic conductivity of the soil is a measure of the rate of water movement through the soil matrix, and is influenced by the texture of the soil. Stout et al. (1998) noted that soil texture could be a contributing factor to nitrate leaching when the textural differences are quite large (i.e. a sandy soil vs. a clay soil). Sandy soils allow rapid movement of soil water resulting in increased nitrate movement. Lund et al. (1974) reported that NO_3-N was distributed down the profile in sandy soils. As the clay content in the soil increase, nitrate concentrations below the rootzone decreased. Bergström and Johansson (1991) suggests that NO_3-N leaching through a sandy soil occurs uniformly and the addition of water dilutes the NO_3-N in the leachate, however the total load is more or less unaffected. Water movement through clay soil is slower, allowing crops time to take up available nitrate. NO_3-N is not protected in soil aggregates in a sandy soil like in a soil containing more clay.

Soil texture also influences the soil water holding capacity. The soil water holding capacity affects nitrate leaching losses through the moisture content of the soil (as discussed earlier), and through influencing the temporal distribution of nitrate leaching loss. Leaching under a high water-holding capacity soil, such as clay, mainly occurs during late winter and early spring. In contrast, soils with low water-holding capacity (i.e. sandy soils) have a more even distribution of nitrate leaching throughout the entire year (Stout et al., 1998). Pang et al. (1998) noted that leaching losses are lower when soils have a high water holding capacity. Hansen and Djurhuus (1996) determined that soils with a low field capacity results in rapid movement of nitrate through the root zone.

Soil texture can influence the structure of the soil. The structure of the soil may influence leaching by dictating the flow of water through the soil matrix. In a well structured soil, macropores may contribute to nitrate leaching losses through preferential flow of water (Feyen et al., 1998; Hillel, 1998). The transport of solute via macropores can lead to rapid movement through the soil profile and accelerate the transport of water and solutes at much faster rates than the often-assumed matrix flow (Haugen-Kozyra et al., 1993; Richards et al., 2003). Bergström and Johansson (1991) suggest that intense "watering" can wash NO_3-N through cracks, earthworm channels and other macro-fissures without allowing interaction with the soil aggregates, and thus leaching the NO_3-N.

Preferential flow of water through macropores may not always result in nitrate leaching losses. Cambardella et al. (1999) observed little change in the nitrate concentration when comparing individual storm events, and thus concluded that macropores were probably not a major mechanism of nitrate transport. Brown et al. (2000) found that bromide had greater leaching losses in a non-structured sandy soil compared to preferential flow conditions in a clay loam. The macropores and flow of water are not the only factors involved in this process; nitrate must be available for leaching to occur. The nitrate must be located on or near the surface of the soil or macropore in order for transport to occur. If nitrate diffuses into the bulk soil solution and is unavailable for transport, macropore flow may reduce the amount of leaching losses (Weed and Kanwar, 1996).

2.3.4 Soil Organic Matter

The organic matter content of a soil can be quite important in relation to nitrate leaching. Bergström and Johansson (1991) observed that sandy soil with low organic matter had nitrate leaching losses 4 times higher than a sandy soil with high organic matter. The sandy soil with high organic matter had less leaching losses than the loam and silty clay loam soils and similar losses as clay. The low amount of leaching, in the high organic matter sandy soil, resulted from vigorous crop growth with low amounts of NO_3-N left in the soil profile and small leachate volumes. The sandy soil with low organic matter had poor crop growth resulting in NO_3-N being left in the soil profile and lower soil moisture uptake to allow for higher drainage volumes.

2.3.5 Agricultural Management Practices

In order to combat nitrate leaching, agricultural production must consider management practices that reduce excess nitrate and water within the soil profile. Two of the main factors to consider are the source and rate of nitrogen.

2.3.5.1 Source of Nitrogen

In recent years, the interest in manure as fertilizers, as opposed to waste, has increased. The addition of manure not only increases the nitrogen content of the soil, it also adds organic carbon and other nutrients. Delgado and Follett (2002) suggest that agricultural practices contributing to increases in carbon content within the soil lead to improvements in water holding capacity, porosity and cation exchange capacity. The improvement of these characteristics lowers nutrient leaching losses by reducing water flow through the soil and by binding nutrients to soil particles.

It is generally assumed that approximately one-half of the applied organic nitrogen in the manure is rapidly mineralized to inorganic nitrogen (Angle et al., 1993; Chang and Janzen, 1996; Paul and Zebarth, 1997). The balance between immobilization and mineralization can be influenced by the addition of various organic materials. Mineralization of nitrogen and the subsequent nitrification of ammonium, is favoured when material rich in N (i.e. a narrow C to N ratio) are added to the soil, for example animal slurry (Mooleki et al., 2002; Powlson, 1993). The remaining portion of the manure is slowly released through mineralization processes throughout the growing season and into the fall, resulting in an accumulation of available nitrate within the soil during a time when plants are not growing (Angle et al., 1993). The mineralization of manure relies on many different soil, climatic and manure characteristics, factors that are difficult to predict making the amount of mineralizable nitrogen difficult to predict (Eghball et al., 2002).

While commercial fertilizers are manufactured to provide an even distribution of nutrient throughout the entire product, an even distribution of nutrient throughout the entire manure product, or in the application process is difficult (Ilsemann et al., 2001). Van Meirvenne et al. (2003) used 3-D mapping to show large variability of NO_3-N concentrations within a short distance. The variability in the distribution of NO_3-N was explained by the uneven application of liquid manure and/or variation in mineralization. Manure has been found to have residual effect for as much as 40 years after application (Foth, 1984 as referred to in Sommerfeldt et al., 1998) making determination of residual nitrogen difficult and compounding the problem of uneven manure application. Uneven distribution of nitrates will result in concentrated areas of nitrate that could potentially be leached down by above average rainfall.

Inorganic fertilizers may contribute to nitrate leaching losses when the form of nitrogen is already or is readily converted into a nitrate form. Portions of some inorganic fertilizers applied to the soil contain nitrogen in the form of nitrate, and the nitrogen is readily available for plant uptake or leaching loss (Flaten, 2001; Havlin, 1999). Olu Obi et al. (1986) found that different inorganic fertilizers behave differently in the soil. Calcium nitrate has greater uptake by crops than urea, resulting in urea having greater residual nitrogen in the soil. This suggests that using an ammonium-yielding fertilizer could lead to a build up of nitrogen within the soil profile and contribute to nitrate nitrogen being released into the soil at a later date. Field-Ridley (1975) determined that movement of nitrogen within the soil was greater under plots treated with $Ca(NO_3)_2$ than in plots treated with urea or $(NH_4)_2SO_4$. The movement of nitrogen depended on nitrification of ammonium nitrogen, which was slow in these fields. The result was that the nitrate from $Ca(NO_3)_2$ was subjected to a greater leaching period than the nitrate from the urea and $(NH_4)_2SO_4$.

2.3.5.2 Rate of Nitrogen

The rate of nitrogen, whether as inorganic fertilizer or organic materials, influences the amount of nitrate available for leaching loss. The ultimate goal of producers is to achieve maximum crop yield with minimal input costs. Although, extra nitrogen is often applied to ensure maximum yield is achieved, resulting in nitrate accumulation (Angle et al., 1993). Rates of application that exceed crop requirements potentially leave nitrates available for leaching (Peralta and Stockle, 2001). Leaching loss, as a percentage of application rate, increases with higher nitrogen application rates (Owens et al., 2000). Yanan et al. (1997) concluded that as the application rate increased the apparent N recovery decreased (recovery for 75 kg ha^{-1} and 120 kg ha^{-1} was 70.4 and 64.6 per cent of N added, respectively). However, Guo and Chorover (2003) found that nitrogen rate had no influence on N^{15} fertilizer or bromide movement. The rate of nutrient application has been shown to affect nitrate leaching losses, however the effect is also subject to spatial and temporal variability.

Agronomic management techniques attempt to determine the optimal rate of application to maximize yields and reduce losses (Goulding, 2000). Optimal rate determination can be a difficult process as sometimes even the economically optimal nitrogen rates result in fairly high losses of nitrate. For example, Owens et al. (2000) determined that at an optimal application rate, 24% to 55% of applied nitrogen was lost. Chichester (1977) concluded that the critical factor in quantifying NO_3-N leaching was the amount of nitrogen remaining in the soil after crop harvest. The fertilizer application rate and effectiveness of the crop in utilizing the fertilizer were the main influences in determining the excess of available N.

Campbell et al. (1984) examined another aspect of the rate of nutrient application: nutrient deficits. The amount of nitrate available for leaching largely depends upon the amount of plant uptake. By providing plants with the required amount of nutrients (i.e. nitrogen, as well as phosphorus), plant uptake of water was increased and the amount of water available for leaching was reduced. Poorly fertilized crops tended to have reduced rates of water uptake resulting in the potential for increased nitrate leaching losses. As a result, Campbell et al. (1993) concluded that nitrate leaching from crops that did not receive enough fertilizer could be as much of a problem as crops that received excess fertilizer.

Manure can be a valuable nitrogen source if applied at rates that do not exceed crop requirement. Mooleki et al. (2002) found the N use efficiency of low to medium (100-200 kg ha^{-1}) rates of liquid swine manure to be greater (50-60%) than high rates of liquid swine manure (10-30%). However, several studies found that predicting the optimal manure application rate is difficult with repeated manure applications due to the mineralization of organic N (Chang and Janzen, 1996; Ritter, 2001). Chang and Entz (1996) determined that manure applied at 1 to 3 times the recommended rate did not cause nitrate leaching losses under dryland agriculture, but resulted in nitrate accumulation within the soil profile. NO_3-N accumulation, due to over application of manure, may lead to nitrate leaching has been noted in numerous studies (Beckwith et al., 1998; Follett and Delgado, 2002; Hountin et al., 1997).

According to a number of studies (Chang and Entz, 1996; Guo and Chorover, 2003), the rate of nitrogen applied to a crop does not leading to losses of nitrate-nitrogen by leaching. The rate of nitrogen application does have an impact on the amount of nitrate-nitrogen remaining in the soil profile after the growing season. It is the nitrate-nitrogen remaining in the soil profile that influences the amount of nitrate-nitrogen lost from the agricultural system by leaching.

2.4 Determining Soil NO_3-N Distribution

2.4.1 Spatial and Temporal Variation in Nitrate Leaching

While the issue of nitrate leaching is a problem, determining the extent of nitrate leaching within an agricultural system can be difficult. The inherent variability within the soil profile, both spatially and temporally, creates difficulties for assessing nitrate distribution and fate. Within this framework, classifying variability can be difficult. Spatial variability can range from macropores and soil cracks (Iragavarapu et al., 1998; Van Meirvenne et al., 2003), to slight changes in soil properties (Feyen et al., 1998), to landscape positions (Strock et al., 2001; Cavers, 1998). Van Meirenne et al. (2003) observed large variability (0-15 mg NO_3-N kg^{-1}) within short distances (less than 10 cm), both horizontally and vertically. Cameron et al. (1979) reported that spatial variability resulted from soil physical properties and the distribution of infiltrating rainfall due to surface microrelief. Also, non-uniform fertilizer application accounted for 38% to 100% of the variability in samples taken immediately after fertilization. Lund (1982) noted that spatial variability resulting from soil properties was minor, while in most cases variations were related to factors other than soil and/or field characteristics.

Numerous researchers have studied the temporal variability of nitrogen within the soil profile. Many time dependent processes, such as rapid microbial processes (Paul and Clark, 1996; Rochette et al., 2000), precipitation events (Schuh et al., 1997), seasonal variation (Cameron et al., 1979) and even muti-year variability

(Chang and Entz, 1996; Sommerfeldt et al., 1988) can effect nitrate distribution. Lund (1982) suggests that temporal variability decreases as management practices achieve a steady-state management system. Methods for determining NO_3-N distribution and fate must take into account the various levels of variability within the soil profile and surrounding environment.

2.4.2 Soil Sampling

The traditional method for determining the distribution, or concentration of nutrients within a soil zone is to collect soil samples from the profile. For fertility determination, soil samples are gathered from depths of 0-30 and 30-60 cm. The number of soil samples obtained from a given field may vary depending on the detail required, or needed. Manitoba Agriculture (2001b) suggests collecting 15 to 20 soil samples in order to obtain a representative sample of the field before applying nutrients. However, temporal and spatial variability of nitrate concentration within the soil profile will decrease the accuracy of the test. In Germany, Ilsemann et al. (2001) found that following the established sampling guidelines resulted in a reasonable error range of 10 to 15 kg NO_3-N/ha for soil sampling. Sampling could, according to these guidelines, be adequate to achieve an accuracy of $\pm$ 10 kg NO_3-N/ha for some fields. However, the standardized sampling failed at some sites due to spatial variability of NO_3-N content. In order to improve the accuracy of soil sampling, information on field heterogeneity would be required prior to sampling.

While most leaching studies rely on some form of soil sampling, it can be difficult to evaluate and predict nitrate leaching strictly using soil sampling (Hansen and Djurhuus, 1996). This difficulty is related to the depth of sampling needed to capture all the nitrate information and the variability of nitrate concentrations within a small area. Van Meirenne et al. (2003) were able to demonstrate large variability within short distance through the use of 3-D mapping. The heterogenous nature of NO_3-N distribution was explained by uneven application of liquid manure or variation in mineralization. High NO_3-N concentrations could be found next to homogenous profiles with low NO_3-N concentrations. Borg et al. (1990) suggests that weaknesses in soil sampling are due to spatial and temporal variability. Measurements from soil sampling did not clearly reflect nitrogen dynamics caused by a major event, such as the application of nutrients or nutrients captured by plants. While collecting soil samples is useful to show actual nitrate concentration through the soil profile, we need to use the soil sampling method in conjunction with other nitrogen capturing methods to obtain the real picture of nitrogen dynamics.

2.4.3 NO_3-N Capture

In order to generate a better understanding of NO_3-N dynamics within the soil profile, two methods have been developed to capture NO_3-N in the soil water: lysimeters and suction samplers. In order to determine the amount of NO_3-N leaching from a system, an estimate of water flow volume is needed (Beckwith et al., 1998; Ridley et al., 2001). A lysimeter confines a desired section of the soil profile within a boundary, and provides a means to quantify total water flow and

N movement through soil (Owens et al., 2000). Lysimeters provide for a complete detection of solutes that reach the sampling depth and are well-suited for examining leaching behaviour of solutes (Jene et al., 1999).

Some of the problems that traditionally affect soil sampling, such as lateral and preferential flows, are not an issue with lysimeters. Due to the physical boundaries confining the soil profile, lateral flow is restricted. In order to deal with preferential flows and a capillary fringe caused by the zero-tension conditions at the lower boundary within the lysimeter, different lysimeter designs have been developed. Zhu et al. (2003) compared two types of lysimeters, zero-tension pan and passive capillary wick lysimeters. The wick lysimeter collected significantly more percolate than the pan lysimeter. The resulting collection efficiency of percolation water was found to be near 100% for the wick lysimeter, and only 40% for the pan lysimeter. The wick lysimeter was not affected by macropore flow and exhibited a better representation of field conditions. Pakrou and Dillon (2000) determined that repacked lysimeters had higher drainage (by 78% to 33%) volumes and N fluxes (3 to 5 times higher) than monolith (soil core) lysimeters, which can lead to some distortion of nitrate dynamics. Pakrou and Dillon (2000) concluded that shorter term studies and use of shallow or repacked lysimeter can distort conclusions. Stout et al. (1998) noted that soil core lysimeter without suction applied to the bottom of the lysimeter may have lower leachate volumes and denitrification rates could be higher than an intact soil column. A large draw back of the lysimeter sampling method is the commitment of both time and money. Lysimeters can be expensive to make and require specialized equipment.

Another method of sampling soil nitrate is through the use of suction samplers. A suction sampler consists of a container with a porous surface, usually ceramic or Teflon, under a slight vacuum used to mimic soil conditions. Suction samplers are relatively small, somewhat inexpensive (compared to lysimeters) and can easily be placed at any depth within the soil profile. Suction cups avoid the capillary fringe problem, and lateral flow of water and solute within the soil matrix are possible, however the volume of soil sampled is difficult to determine (Jensen et al., 2000). Djurhuus and Jacobsen (1995) concluded that a comparison of ceramic suction cups and soil sampling yielded similar results on sandy soil and on sandy loam soil. The results only differed significantly in one of four comparisons. However, concentrations collected by the suction cup isolates differed slightly from the volume-averaged concentrations obtained from soil samples. Shepherd and Bhogal (1998) found that suction samplers measured higher concentrations of nitrate in soil than the lysimeter. A possible reason for lower nitrate concentration using lysimeters is denitrification at depth due to slower drainage and wetter conditions towards the base of the lysimeter. Ridley et al. (2001) found that discrepancies may occur with suction cup measurement of NO_3-N concentration due to spatial and temporal variation of point measurements. The suction cups do not measure a true flux-averaged concentration rather they are measuring a fraction of 'immobile' soil solution.

Williams and Lord (1997) determined that the type of measurement method is important, as the agreement between ceramic suction cups and soil sampling analysis was poor. Discrepancies between the two methods were observed, at depth, due to preferential flow within the lower part of the soil profile. However, Shepherd and Bhogal (1998) found good agreement between Teflon water samplers, ceramic water samplers and monolith lysimeters.

The soil provides a dynamic and ever changing environment for solutes and the people trying to measure them. Heuvelman and McInnes (1997) suggested that soil characteristics should be taken into account when sampling soil or soil water, and the sample volume or area should be large relative to structure dimensions. The greater the number of samples collected using different methods, the better the understanding of solute distribution within the soil.

2.4.4 Tracers

Another method for determining the distribution and leaching losses of nitrate within the soil profile is the use of tracers, or an anion that behaves similar to nitrate in soil water but is not reactive with organic or inorganic fractions of the soil. Many studies have used chloride (Dyck et al., 2003b; Shuford et al., 1977) and bromide (Guo and Chorover, 2003; Iragavarapu et al., 1998; Jene et al., 1999; Ottman et al., 2000) to mimic the transport of NO_3-N within the soil profile and to indicate the maximum depth of movement for solute or the leaching potential of NO_3-N. However, bromide overestimated NO_3-N movement due to plant uptake and immobilization of N in the soil surface. NO_3-N and bromide peaks usually occur at different depths within the soil profile. Jene et al. (1999) found that bromide outflow had a relatively high correlation (r=0.94) to leachate amount. Using a bromide tracer, Gasser et al. (2002) were able to determine the amount of drainage water (190 mm) required to displace 50% of solute mass to a 1 m soil depth during the spring season. In a field study in Quebec, they determined that the average accumulated drainage water was less than 150 mm during this period, thus less than one half of the nitrate will leach if applied in a soluble form in spring.

Tracers can also be used to determine the fates of nitrogen in an agricultural system. Shuford et al. (1977) used a chloride tracer to account for losses and/or gains of NO_3-N through denitrification, fixation, and nitrification pathways. By using a bromide tracer in combination with a N^{15} leaching study Ottman et al. (2000) found that the probable amount of N lost to the system due to leaching was 32%. Tracer measurements can be quite important as they provide more information on the movement of soil water, and thus a better understanding of the dynamics within the soil matrix.

3. MATERIALS AND METHODS

3.1 Description of Site and Soil

This field study was conducted on a typical agriculture soil overlying the Assiniboine Delta Aquifer. The site was located northwest of the town of Carberry (legal location: SW-19-11-15W). The experiment was carried out on a Orthic Black Fairland series (loamy sand). The upper 75 to 90 cm is classified as loamy sand with the underlying material being sandy loam to loam. The depth to groundwater was 5-6 m.

The physical and chemical properties of the soil are given in Table 3.1. Physical and chemical properties were determined on background soil samples that were taken on April 30, 2002, before any amendments were added. Soil texture was determined using the pipette method as outlined by Gee and Bauer (1986). Bulk density and field capacity were measured in October 2001 using the procedure described by Shaykewich et al. (1998). Both pH and electric conductivity (EC) were measured using a 1:1 mixture of soil and water, which was stirred periodically over 30 minutes and then left to stand for one hour (McKeague, 1976). A Fisher Accumet AR50 Dual Channel pH/ion/conductivity meter equipped with a glass electrode was used to measure the pH and an Orion conductivity electrode was used to measure EC.

Table 3.1: Characteristics of the Fairland Loamy Sand Soil

Depth	Sand	Silt	Clay	pH	EC	Carbon	Bulk Density	Field Capacity	Volumetric MC	NO_3-N	Mehlich-III P
cm	-------------	%-------------			dS m^{-1}	%	g cm^{-3}	%	%	mg/kg	mg/kg
0-10	77.9	10.2	11.8	6.37	0.32	2.27	1.31	28	20	5.70	15.36
10-20	72.8	13.5	13.7	6.61	0.30	1.91	1.42	28	23	5.99	4.18
20-30	69.8	17.9	12.3	7.01	0.28	1.35	1.45	26	21	5.76	3.63
30-60	74.0	13.3	12.7	7.71	0.31	0.80	1.51	23	14	1.88	3.97
60-90	65.6	20.2	14.7	8.29	0.33	1.42	1.49	25	16	1.14	2.76
90-120	48.6	31.6	19.8	8.33	0.34	1.64	1.50	34	22	1.17	2.23

3.2 Lysimeter Design and Installation

In conjunction with the field study, large intact soil core lysimeters were installed to determine amounts of soil water and NO_3-N lost below the root zone. The lysimeters were installed within 2 m of the southern boundary of each plot, approximately in the middle of the plot (Figure 3.1). The lysimeters were designed and installed to make use of undisturbed or intact soil columns. Undisturbed soil columns were believed to provide best representation of natural soil and water interactions (Pakrou and Dillon, 2000). The following is a complete description of the design and installation procedure for each lysimeter. The large intact soil core lysimeters used at this site consist of three main parts: the main column, a circular perforated plate and a collection cap. We designed this lysimeter as a modification of the prototype recommended to us by Dr. W. Stout (personal communication).

The main column of the lysimeter was constructed using Schedule 80 (3.3 cm thick) PVC pipe with a diameter of 54.2 cm. The main column was 106.7 cm in length, representing the possible extent of a cereal crop rooting zone.

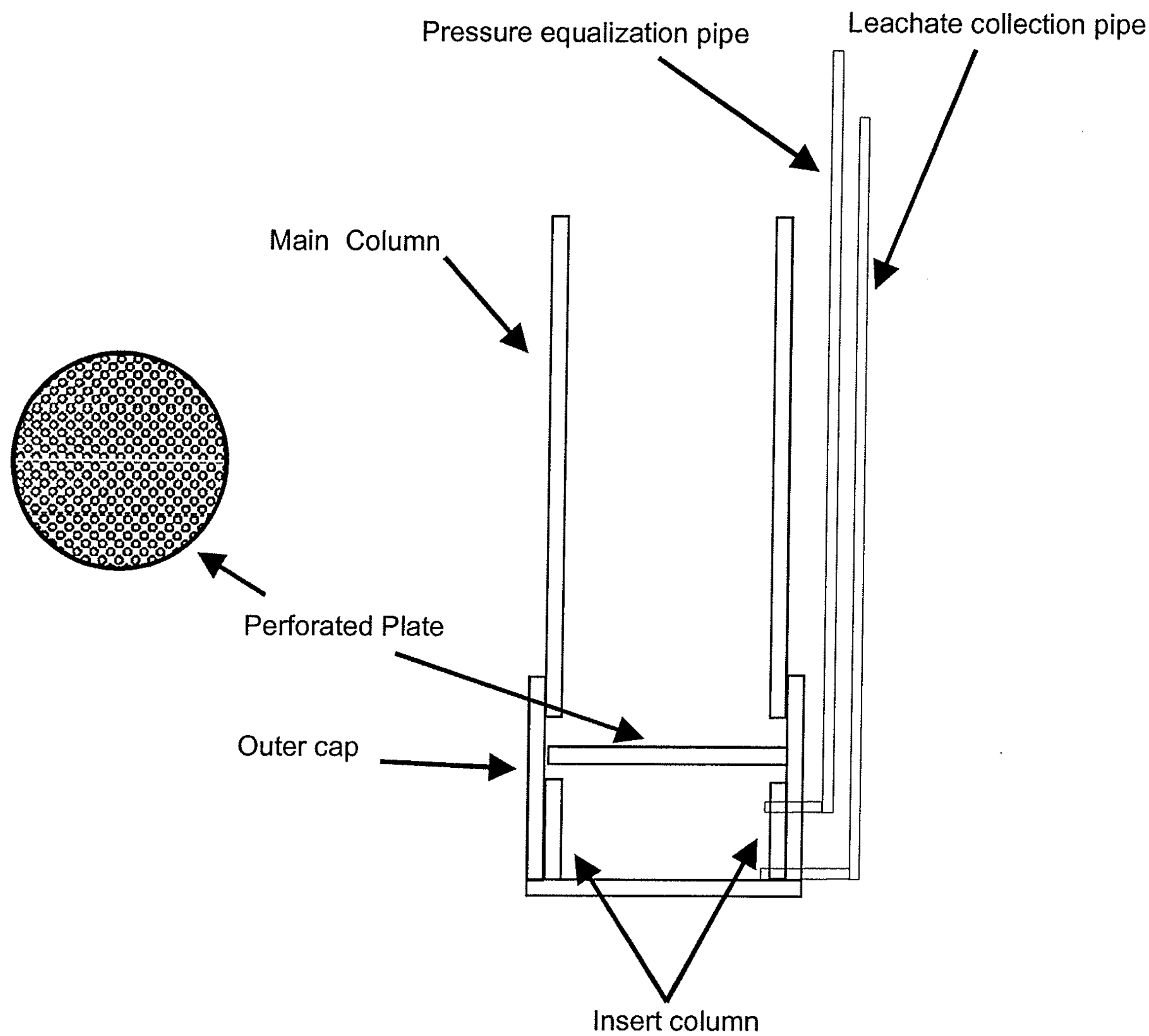


Figure 3.1: Illustration of an Intact Large Soil Core Lysimeter

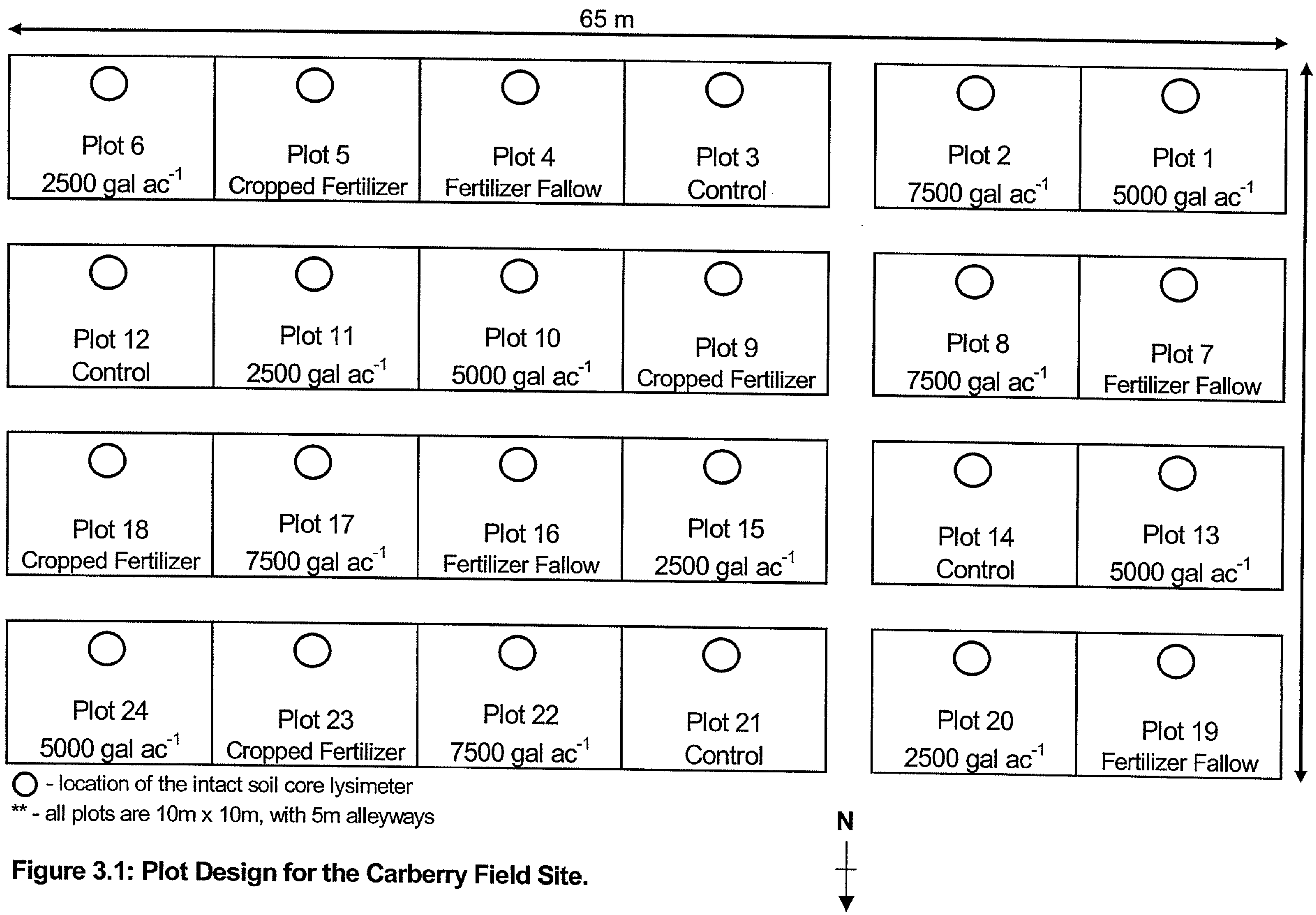


Figure 3.1: Plot Design for the Carberry Field Site.

This depth is an acceptable estimate of the root zone within the lysimeters, as the traditional estimate of the root zone for annual crops is 120 cm (Campbell et al., 1987; Dyck et al., 2003a) The PVC material was chosen so that the collection of nitrogen, carbon, and phosphorous could be made simultaneously using one device. The thickness of the PVC pipe was required to provide strength during the installation process. Two holes, 25 mm in diameter, were drilled 38.1 mm from the top of each main column and 180^0 from each other, to facilitate lifting. The base consists of two parts: a circular perforated plate and the collection cap. The plate is a 12 mm PVC sheet cut to a 60.9 cm diameter. Holes, approximately 3 mm in diameter, were drilled into the plate. The holes were placed approximately 25 mm apart. The holes allow for drainage into the collection cap. The collection cap consists of two parts: the outer cap and the insert column. The outer cap has a diameter of 67.4 cm and a depth of 28.7 cm (on the inside). The insert column is a piece of PVC with the same diameter as the main column and a height of 13 cm. The insert column was permanently fixed on the inside of the cap, at its base. The circular plate was placed on the top of the inset column, in this way a "catch basin" was created between the plate and the bottom of the cap.

The lysimeter collection system consists of space between the circular perforated plate and the bottom of the cap ($\approx$ 13 cm). The leachate is accessed via a hole drilled on the side of the cap at the most bottom part of the cap. A 90^0 PVC elbow was inserted into the tapped hole, and a ½" PVC pipe (i.e. the extraction pipe) runs from the bottom to the top of the lysimeter extending 15 cm above the soil surface. A second hole was drilled just below the resting place of the plate. A 90^0 PVC elbow and ½" pipe run to soil surface, and a PVC cap with a small hole was permanently fixed on its top. The second pipe was required for pressure equalization during leachate extraction, because the soil moisture was not to be suctioned from the soil. To extract the leachate from the "catch basin", a small hose is inserted into the extraction pipe and the leachate is suctioned out using a vacuum pump.

A special device, a drop hammer, was brought from State College, Pennsylvania, United States, to insert the lysimeter to the desired depth. The installation was performed with the drop hammer to reduce the disruption to the soil profile. The drop hammer consisted of a trailer with a collapsible tower attached onto the rear deck and a large winch on the front of the deck. The tower and the winch hoisted a 3 x 3 x1 foot piece of steel (i.e. the hammer) into the air. The hammer was dropped through the tower, landing on the top edge of the main column of the lysimeter, driving it into the soil. The procedure was repeated until the main column was driven down to the desired depth.

The installation procedure was conducted over three days, May 12 to 14, 2002. Driving the trailer over the designated location, and placing the lysimeter under the center of the hammer initiated the installation procedure. With the lysimeter in the ground, a hole was dug beside it with a backhoe. In order to lift the lysimeter, a chain was attached to the lysimeter using clevises and the two 1" predrilled holes. Before lifting the lysimeter, the main column was pulled sideways to break the soil column loose. The main column was then lifted out of the hole and placed on its side on the soil surface. The main column was then turned upside down using a backhoe prior to attaching the bottom cap. Where the soil was lost from the bottom of the column during the lift up, the void was filled with the appropriate soil from the existing hole. With the main column in the upside down position, geotextile material was cut to cover the entire soil surface and was placed over the soil to prevent soil from collecting in the "catch basin". The circular perforated plate was placed on top of the geotextile material. The inside of the cap and the outside of the bottom end of the main column were then covered with primer and then lots of glue. The glue provided a slick surface for the placement of the cap, if the cap did not slide into place a sledge hammer was used.

After the installation of the cap, the lysimeter was turned upright, and the 90^0 elbows were installed into the tapped holes in the cap. Teflon tape was wrapped around the male end of the 90^0 elbows to ensure a good fit. The ½ " PVC access pipes were glued into the 90^0 elbows, and a small block of wood secured between the pipes and the lysimeter and held together with duct tape to stabilize the pipes. The lysimeter were then pressurized using an air pump and inspected for leaks using water. A continuous bead of glue at the junction of the cap and the main column was necessary for a complete seal. Each lysimeter was inspected and any visible gaps or cracks in the glue between the main column and the cap were filled with glue. The glue was forced down into the gaps to ensure a good seal. Following the curing of the glue, the lysimeters were then pressure tested again using a vacuum pump. The top of the lysimeter was sealed with a circular wood plate and duct tape, and the lifting holes were sealed with rubber stoppers. A slight vacuum (2 inches) was obtained and held for a short time and slowly decreased.

3.3 Plot Design

In the spring of 2002, a field trial was established near Carberry, MB. The field experiment is a randomized complete block design with 6 treatments and 4 replicates for a total of 24 experimental units, each of which measured 10 m x 10 m (Figure 3.1). The treatments were randomized within the blocks. Treatments included: a control (no nutrients added), 3 rates of hog manure (≈ 2500, 5000, 7500 gallons per acre), the fifth treatment received N and P fertilizers at rates that matched the total nitrogen and total phosphorus content of the intermediate rate of hog manure, and sixth treatment was the same as the fifth treatment (ie. received N and P fertilizer) except that it was left as fallow. The commercial fertilizer nitrogen and phosphorous sources were a combination of urea and monoammonium phosphate (MAP).

3.4 Agronomic Description

3.4.1 Manure Application

Field plots were cultivated, to a depth of 6 to 7 cm, one or two days prior to the application of hog manure. The applications of hog manure were performed on May 18, 2002, and May 13, 2003, utilizing the Aerway system. The Aerway system consists of a liquid manure holding tank, a gang of spiked wheels, and a dribble bar. As the spiked wheels penetrate the soil surface (approximately 6 cm), manure is applied by dribbling onto the surface of the disturbed soil. The desired rates for manure application were 2500, 5000, and 7500 gal ac^{-1} (23,400, 46,800 and 70,200 L ha^{-1}), although the actual rates were slightly less at 2350, 4600 and 7350 gal ac^{-1} (22,000, 43,000 and 68,800 L ha^{-1}). One pass of the Aerway manure applicator over the plot yielded 2500 gal ac^{-1}. In order to achieve 5000 and 7500 gal ac^{-1} of manure, the plot received two and three passes of the manure applicator, respectively. The results of the liquid hog manure analysis revealed that the manure contained 10.5 kg total N 1000 $gallons^{-1}$ and 1.6 kg total P 1000 $gallons^{-1}$ (40 g total N L^{-1} and 6 g total P L^{-1}). The application of manure was based on the total N within the manure.

Due to the limited maneuverability of the Aerway applicator, a portion of the plot did not receive the manure treatment. The Aerway applicator is approximately 4.6 m (15 ft) wide, in essence leaving a gap of 0.8 m (2.6 ft). This gap of nonmanured soil is located in center of the plot in line with the lysimeter.

Manure from the same tanker truck as for the Aerway applicator, was sampled and hand applied to each lysimeter. The manure was applied at rates of 0.6, 1.2, and 1.8 L, representing rates of 2500, 5000, and 7500 gal ac^{-1}, respectively.

3.4.2 Inorganic Fertilizer and Seed Application

Seeding and fertilizer applications were done on May 28, 2002, and May 20, 2003, three-point hitch Allis Chalmers press drill planter. Urea was hand broadcast on to the appropriate plots, while P, added as MAP, was banded with the wheat seed. Inorganic fertilizer was applied at rates that matched the total N and P content of the intermediate manure rate (medium rate – 5000 gal ac^{-1}) (Table 3.2). Within the lysimeters, the wheat seed and MAP were placed in shallow rows and packed to simulate seeding similar to the press drill. Urea was broadcast over the appropriate lysimeters to ensure similar treatment to the plots.

In 2002, the lysimeter were reseeded on June 14th, due to the condition of the topsoil the wheat seed had poor germination. In order to place the plywood on top of the lysimeter main column during installation, a small amount of topsoil was removed resulting in a surface soil that was slightly compacted. The topsoil was turned in order to reduce the compaction of the soil, and wheat seed was planted according to the procedure above.

Table 3.2: Field Treatment Rates

Treatment	Fertilizer Source	N Rate (kg/ha)	P Rate (kg/ha)
M2500	Liquid Hog Manure	64	10
M5000	Liquid Hog Manure	129	19
M7500	Liquid Hog Manure	195	29
Ferilizer	Urea + MAP	129	19
Fertilizer Fallow	Urea + MAP	129	19
Control	none	-	-

3.4.3 Soil Sampling

Soil sampling was conducted five times each year, throughout the summer and fall of 2002 and 2003. A Giddings soil sampler was used for sampling soil in the spring and fall, and dutch augers were used for all soil samples taken during the growing season. Background physical and chemical soil properties were determined from the April 30th, 2002 soil samples. The April 30th sampling was performed on one-half of the field plots (3 plots within each block) at intervals of 0-10, 10-20, 20-30, 30-60, 60-90, and 90-120 cm. For the remaining sampling dates (June 25, July 23 and September 23, 2002), samples were obtained from all plots at intervals of 0-10, 10-20, 20-30, 30-45, 45-60, 60-90, and 90-120cm, except on October 9, 2002, when the 60-90 cm interval was split into 60-75 and 75-90 cm. All soil sampling in 2003 (May 9, June 19, July 18, August 19, and October 10) was conducted using intervals of 10 cm for the first 30 cm and 15 cm segments thereafter to 120 cm.

Within each plot, samples were obtained from two core holes. The core holes were located in the northern half of the plot not containing the lysimeter. The two sample cores were composited and a subsample was taken in order to determine gravimetric moisture content. Soil, with a similar soil texture as the original soil layer, was used to fill the sampling holes. All soil samples were sealed in plastic bags and placed in coolers with ice packs for transport. Soil samples were immediately air-dried and ground to pass through a 2 mm sieve.

3.5 Laboratory Analyses of Manure, Soil and Leachate Samples

3.5.1 Manure Analysis

Manure samples were analyzed for total N and P using a modification of the wet oxidation method (Akinremi et al., 2003). 40 mL of liquid manure ($\approx$ 1% solid) was utilized for the digestion, in order to obtain $\approx$0.4 g of solid material. The manure was combined with 2.2 mL of digestion solution (H_2O_2, Se, Li_2SO_4 and H_2SO_4), and maintained at 100^0C until the solution was reduced to less than 5 mL ($\approx$ 26 hours). Another 2.2 mL of digestion solution was added, and the solution was digested for 3 hours at a temperature of 350^0C. The digest was quantitatively transferred into a 50 mL volumetric flask and made to volume with deionized water. This sample was analyzed for NH_4-N, after appropriate dilution, using a Technicon auto analyzer (Maynard and Kalra, 1993). From the 100 mL volumetric flask solution, 5 mL was placed in a 25 mL volumetric flask along with 4 mL of color solution, and made to volume. Total P was determined colormetrically using the molybate-blue method (Murphy and Riley, 1962), on an Ultrospec 3100 *pro* UV/Visible Spectrophotometer (Biochrom Ltd Cambridge, England) at a wavelength of 882 nm.

3.5.2 Soil Analysis

All soil samples were analyzed for NO_3-N, NH_4-N, and Mehlich-3 P (M-III P). Inorganic nitrogen (NO_3-N and NH_4-N) was extracted using 2N KCl at a soil:extractant ratio of 1:5 (i.e. 5g soil: 25mL of extractant) (Maynard and Kalra, 1993). The soil, after shaking in a reciprocating shaker for 30 minutes at 80 epm (excursions per minute), was filtered through Whatman 40 Ashless filter paper. The filtrate was analyzed for NO_3-N and NH_4-N by the cadmium reduction procedure, using a Technicon AutoAnalyzer II (Maynard and Kalra, 1993). For M-III P, the soi was extracted using a Mehlich solution at a soil:extractant ratio of 1:10 (i.e. 2.5g soil: 25mL extractant) (Mehlich, 1984). Concentrations of P were determined colormetrically using the molybate-blue method as described above (Murphy and Riley, 1962). Every twenty-fifth soil sample was analyzed twice and two standard soils were analyzed every 100th sample with each batch of extractions as a measure of quality control-quality assurance.

The upper two soil samples, in 2002, (0-10 and 10-20 cm) in each plot were analyzed for Olsen P, and were extracted using a soil:extractant ratio of 1:20 (i.e. 1g soil: 20mL extractant) (Olsen et al., 1954). Concentrations of Olsen P were determined using a spectrophotometer and the molybate blue method (Murphy and Riley, 1962).

Background soil samples (April 30, 2002) were also analyzed for Total P using the Wet oxidation method (Parkinson and Allen, 1975). Total carbon and nitrogen was determined on finely ground soil (<1.0mm) using an automated elemental analyzer (Carlo Erba, Milan, Italy).

3.5.3 Plant Analysis

Biomass samples were taken on July 23, 2002 and July 18, 2003 (partial heading) and final harvest was on September 10, 2002 and August 19, 2003. Plant samples taken at partial heading were analyzed as the whole plant biomass, while plant samples taken at harvest were separated into straw and grain. All plant samples were taken from the plots in two 1m x 1m subplots, except for the 2002 biomass sampling where only one 1m x 1m subplot was used.

Plant analysis was conducted using the Wet Oxidation method (Parkinson and Allen, 1975). The digestion of a 0.4g sample of ground plant material resulted in a solution that was diluted and analyzed for total N by the cadmium reduction procedure, using a Technicon AutoAnalyzer II (Maynard and Kalra, 1993) and total P was determined using a spectrophotometer and the molybate blue method (Murphy and Riley, 1962)

Wheat N uptake was calculated using the following equation (Garand, 1999; Mooleki et al., 2002):

$$N_{up} = \frac{\%N_{st} \times DMY_{st}}{100} + \frac{\%N_{g} \times DMY_{g}}{100}$$

N_{up} = total N uptake by plant (kg N ha^{-1}),
$\%N_{st}$ = concentration of total N in wheat straw,
DMY_{st} = dry matter yield of wheat straw (kg ha^{-1}),
$\%N_{g}$ = concentration of total N in wheat grain,
DMY_{g} = dry matter yield of wheat grain (kg ha^{-1}).

The apparent N recovery or N use efficiency of the wheat was calculated using the following calculation (Garand, 1999; Mooleki et al., 2002):

$$\%N_{rec} = \frac{\left({}^{trmt}N_{up} - {}^{ctl}N_{up}\right)}{{}^{trmt}N_{ap}} \times 100$$

$\%N_{rec}$ = apparent N recovery of inorganic or organic N source expressed as percent,
${}^{trmt}N_{up}$ = total N uptake by wheat (kg N ha^{-1}) for a given treatment,
${}^{ctl}N_{up}$ = total N uptake by wheat (kg N ha^{-1}) for the unfertilized control,
${}^{trmt}N_{ap}$ = total N applied (kg N ha^{-1}) as inorganic or organic N source.

3.5.4 Leachate Collection and Analysis

Leachate collection from the lysimeters was performed using a vacuum pump and a 500 mL Erlenmeyer flask. Leachate samples were transferred to plastic containers and stored in a cooler with ice packs for transport. The leachate samples were weighed and then placed in a refrigerator at a temperature of 4°C until they could be analyzed (less than one week). Leachate collection carried out approximately a month after lysimeter installation and during the 2002 growing season yielded trace amount of leachate. In 2003, leachate collection commenced on May 8th and occurred approximately every two weeks until early July. Leachate was also collected in early November to empty the collection basins prior to freeze up for the following spring leachate.

Leachate analysis was performed on a subsample of the original leachate, after a thorough shaking. The procedure for determining the amount of for NO_3-N, NH_4-N and dissolved P are as outlined for the soil samples. Dissolved organic carbon analysis was carried out on a subsample of the leachate by colorimetrically using a Technicon AutoAnalyzer II (Technicon Industrial Systems, 1978).

3.5.5 Statistical Analysis

Analysis of variance (ANOVA) was performed on nitrogen, phosphorus and soil moisture data for all soil samples using SAS version 8 software (SAS Institute Inc., 1999). Concentration of NO_3-N, M-III P and volumetric water content in soil samples were analyzed as a split-split plot, with treatment as main plot, depth as subplot, and time as sub-subplot. Wherever a significant Treatment x Depth and Treatment x Depth x Time interaction occurred, LSD values were calculated to show the differences. Due to the nonhomogenous of variance within the soil profile, the NO_3-N concentration values were $\log_{10}$ transformed to ensure normality of the data for statistical analysis. Statistical analysis was performed on log-transformed NO_3-N concentration data.

Treatment and time effects within the soil profile were determined by adding the amount of NO_3-N, M-III P, and soil water in the soil profile to a depth of 120 cm. Calculations were performed to determine kg ha^{-1} of NO_3-N and M-III P and cm of soil water using individual sample soil bulk densities. Plant data was analyzed using Fisher's LSD test.

4. RESULTS AND DISCUSSION

4.1 Field Study

4.1.1 Precipitation

Precipitation amounts in 2002 and 2003 are shown in Figure 4.1. The weather station at the field plot was established in August 2002, so precipitation data for 2002 was obtained from the Environment Canada weather station located 11 km away at the Manitoba Crop Diversification Centre (MCDC). The normal precipitation data is 30 year averaged data (1961 to 1990) from the Environment Canada Carberry station. In 2002, Environment Canada data indicated that precipitation before June and after August was generally below normal. During June, July and August 2002, precipitation was close to normal for the area, except in August, which was above normal. Early in the growing season, the wheat crop was visibly affected by low amounts of precipitation in 2002, but managed to recover by harvest. Precipitation data for 2003 is from the weather station located on the field site.

In 2003, precipitation levels in March, April and May were at normal levels, however during the growing season precipitation was well below normal. Upon a site visit in mid-June, it was noticed that a herd of cattle had been grazing within the field site and subsequently damaged the rain gauge on the weather station. The weather station data was compared with Environment Canada's data to determine if precipitation was missed due to this disruption. The wheat crop in

2003 suffered under such low precipitation amounts as is evident by the lower yield compared with 2002 data.

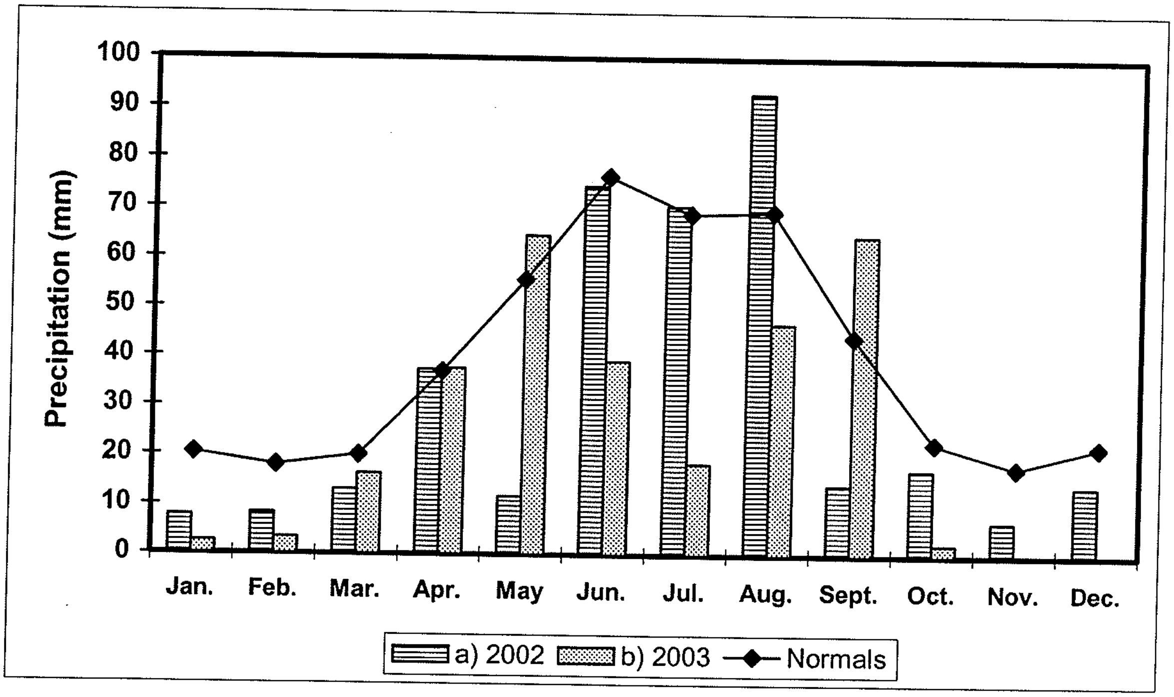


Figure 4.1: Precipitation data recorded by: a) Environment Canada weather station in 2002 and b) Field site weather station in 2003.

4.1.2 Changes in Total Soil Water in 2002 and 2003

As the amount of water within, or entering the soil matrix directly affects the movement of NO_3-N within the soil, soil samples were measured for gravimetric soil moisture content. As a soil layer approaches field capacity, soil water will move to the adjoining soil layer carrying with it solutes obtained from the soil matrix. Soil moisture was compared between treatments and expressed as the total volume of water in the 120 cm soil profile (Table 4.1). The volumetric moisture content of the soil profiles are also shown in Figures 4.2 to 4.5.

Table 4.1: Total Volume of Soil Water (cm) within the root zone (120 cm)

	25-Jun-02	23-Jul-02	10-Sep-02	9-Oct-02	9-May-03	19-Jun-03	18-Jul-03	19-Aug-03	8-Oct-03
Manure 2500 gal	20	15b*	20b	16	22	21bc	15b	12b	20
Manure 5000 gal	23	17b	21b	17	22	20c	17b	12b	19
Manure 7500 gal	19	18b	22ab	17	24	24ab	18ab	14ab	20
Fertilizer (wheat)	23	16b	18b	21	26	20bc	16b	12b	18
Fertilizer (fallow)	23	22a	26a	20	27	26a	25a	17a	22
Control	24	17b	21b	17	25	22abc	16b	13b	20

* - Means followed by different letters (a,b,c...) within a column differ significantly ($P<0.05$ Fisher's LSD means comparison)
** - Values are the means of four replicates.

The application of liquid hog manure on May 18th, 2002, did not significantly affect the amount of water within the soil profile as shown by the amount of water in the soil profile on June 25, 2002 (Table 4.1). As expected during the growing season (June to July), the soil moisture content in the fallow plot decreased only slightly, while the soil moisture contents in all seeded plots decreased more substantially. Fuentes et al. (2003) noted that fallow plots stored higher amounts of water than cropped plots. The decrease in soil water in the fallow plot during the growing season was mainly due to evaporation and drainage, while the soil moisture decrease in the cropped plots resulted from evapotranspiration and drainage.

Precipitation amounts in August, 2002 (Figure 4.1) increased moisture content within the soil profile in September (Table 4.1). However, a dry fall resulted in a decrease of soil water within the profile by October. During this period, the soil water within the fallow plots showed a greater decrease than the soil water within other treated plots. This decrease could be due to evaporation and loss of soil water by leaching.

Between the fall of 2002 and the spring of 2003, snowmelt and spring precipitation increased the soil water within the profile of all treatments by 5 to 7 cm (Table 4.1). In 2003, soil water content under each treatment followed a similar trend as in the previous year. Soil water under the fallow treatment showed little change between May 9th and July 18th, only decreasing by 2 cm. The cropped treatments experienced soil water decreases ranging from 5 cm (M5000) to 10 cm (Fertilizer) during a similar period (May 9th to July 18th). Due to the cropped fertilizer plot having a greater wheat yield than the M5000 plot (Table 4.4), a greater reduction in soil water occurred in the cropped fertilizer plot than the M5000 plot (Table 4.1). The more vigourous crop growth in the cropped fertilizer plot resulted in a greater uptake of water than in the M5000 plot.

Below normal levels of precipitation, during June, July, and August 2003 (Figure 4.1) contributed to dramatic decreases in soil water. August 2003 was the only sampling event that recorded soil water below 20 cm in the fallow plots (Table 4.1). Contributions from September precipitation increased soil water levels within the soil profile by October.

Figures 4.2 through 4.5 show the distribution of the volumetric water content within the soil profile as affected by the different treatments. The average field capacity of the Fairland Loamy Sand soil ranges from 27% in the upper 20 cm and decreases to 21% within the 45-60 cm section of soil. The 90-120 cm section of soil has a maximum field capacity of 35% (Figure 4.2). The fluctuations in field capacity reflect the amount of clay contained within the different soil layers.

The application of manure did not result in significant treatment differences within the top 90cm of the soil profile in June 2002, as the distribution of soil water was similar among the various manure plots (Figure 2a). Crop uptake of water decreased soil moisture levels within all treatments by July (Figure 4.2b). Water uptake by the crop did not create significant treatment differences in the total volume of soil water in the soil profile between manure rates due to small crop yield differences between manure rates (Table 4.4). Above normal precipitation in August 2002 resulted in soil moisture levels that were close to field capacity in the upper 45cm of the soil profile by September 2002 (Figure 4.2c). Due to below normal precipitation in September and October 2002, little water was added to the soil, consequently soil water content decreased, especially in the upper 45 cm of the soil profile (Figure 4.2d). This decrease of soil water was the result of evaporation from the soil surface and some downward movement of soil water.

Figure 4.3 shows the volumetric water content of the plots treated with different rates of hog manure. The soil moisture patterns in 2003 were similar to 2002, however, a lack of precipitation in July and August 2003 resulted in low soil moisture levels (less than 10% in the upper 60 cm of the soil profile) (Figure 4.3d).

Soil moisture distribution was similar for plots treated with commercial fertilizer and manure (Figure 4.4 and 4.5). Changes in soil moisture levels throughout the year were similar for the cropped fertilizer plot and the manured plot. The high soil water content in the cropped fertilizer plot (Figure 4.4d) was not expected as soil water content in all the other plots decreased during this period. This difference in soil water content could be due to spatial variability or experimental error. The fallow fertilizer plot contained higher levels of soil moisture than the cropped fertilizer and manured plots, especially during periods when crop uptake affected soil moisture levels (Figure 4.4b and 4.5c). A significant yield difference between the cropped fertilizer and manured plots in 2003 (Table 4.4) resulted in a lower soil moisture levels in the cropped fertilizer plot than in the manure plot (Figure 4.4c). The more vigorous crop growth in the cropped fertilizer decreased soil moisture levels below levels in the manure plot, especially at depth (Figure 4.5 c through e).

The two years of this study experienced below normal levels of precipitation during the growing season (May to August). While normal levels of precipitation are 270mm, the study area received only 250mm in 2002 and 169mm in 2003.

Low levels of precipitation during the growing season resulted in low crop yields and limited differences in soil moisture between treatments.

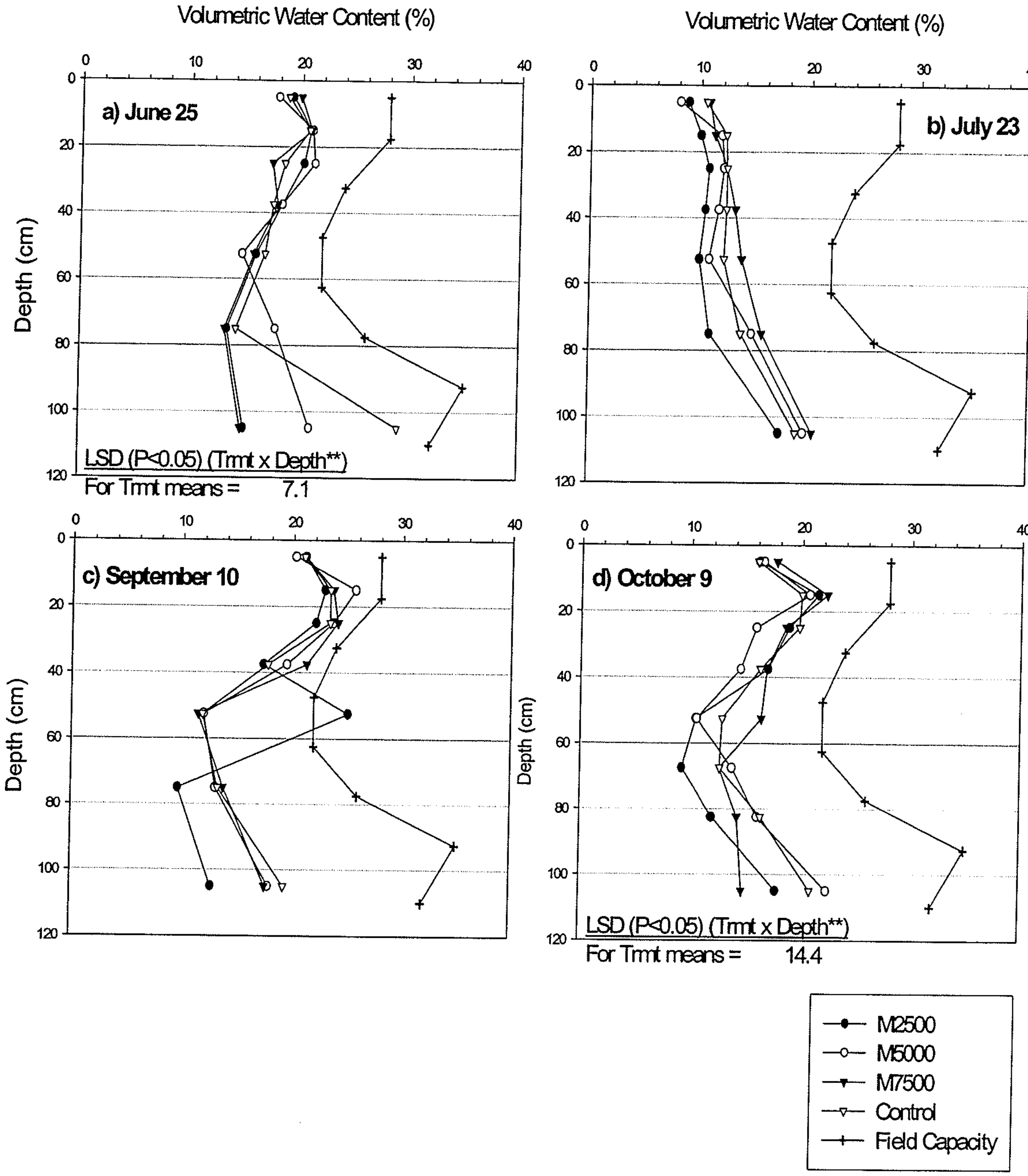


Figure 4.2: Comparison of soil water distribution in plots treated with different rates of liquid hog manure at various dates in 2002.

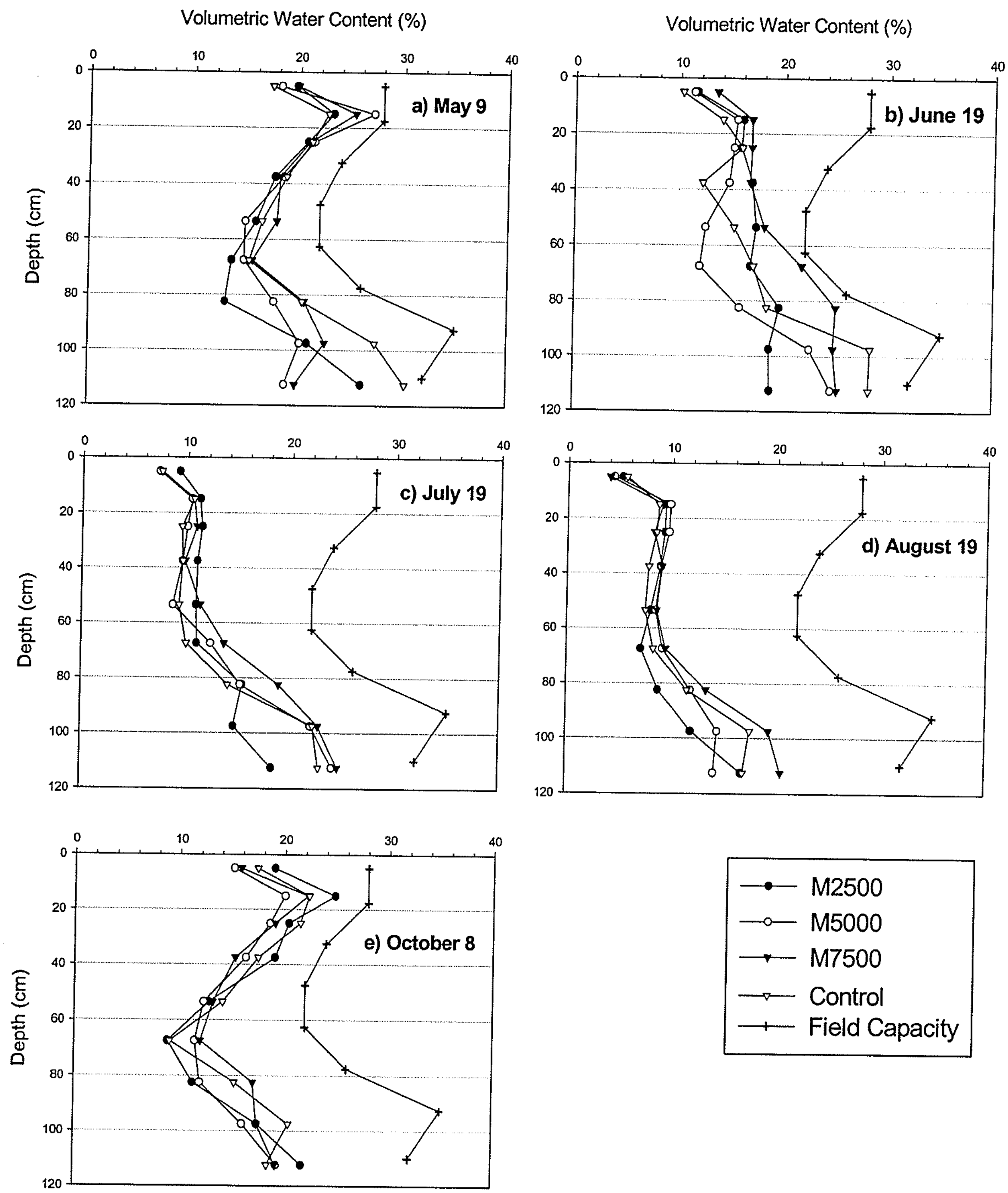


Figure 4.3: Comparison of soil water distribution in plots treated with different rates of liquid hog manure on various dates in 2003.

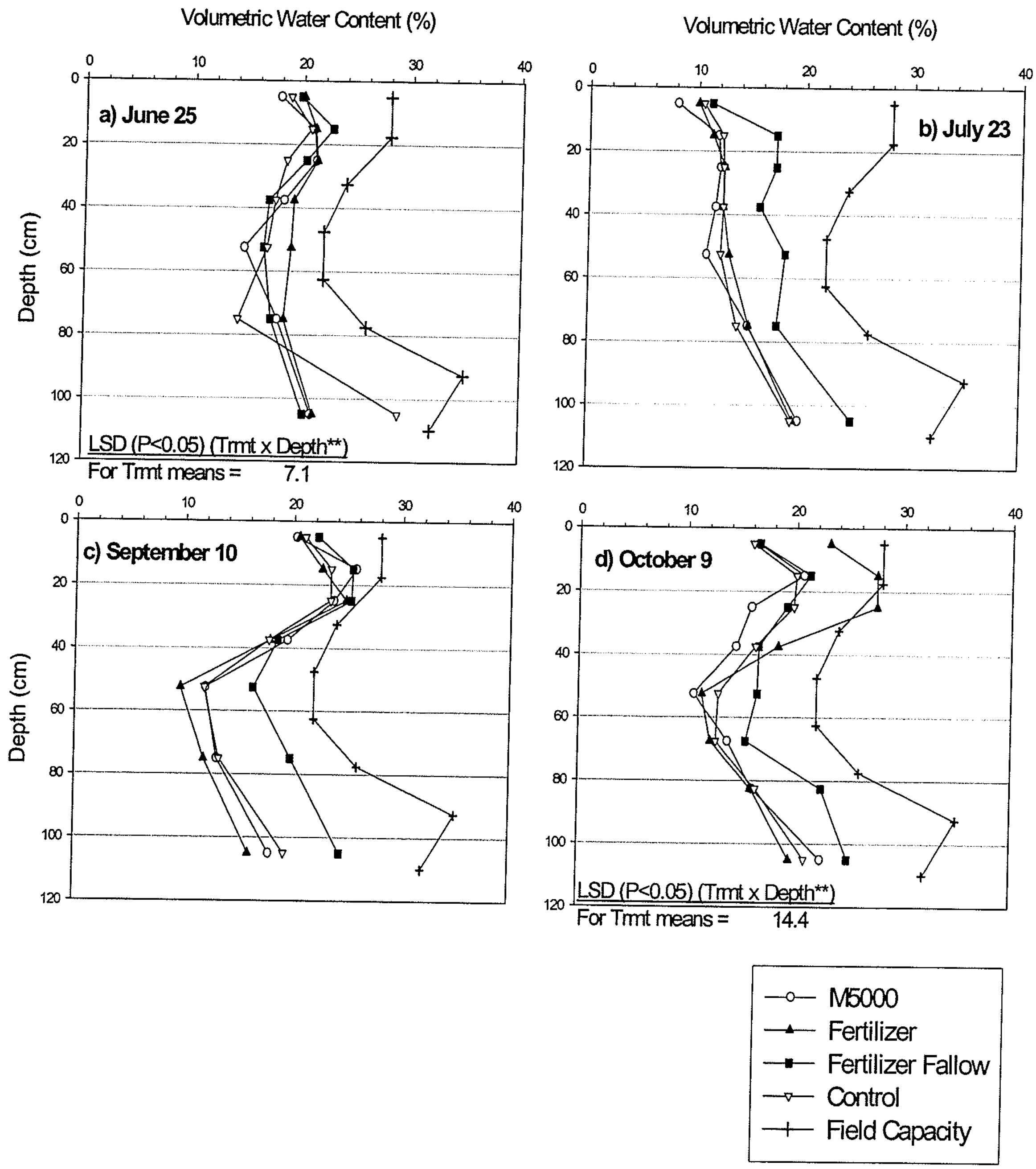


Figure 4.4: Comparison of soil water distribution in plots treated with liquid hog manure and commercial fertilizer on various dates in 2002.

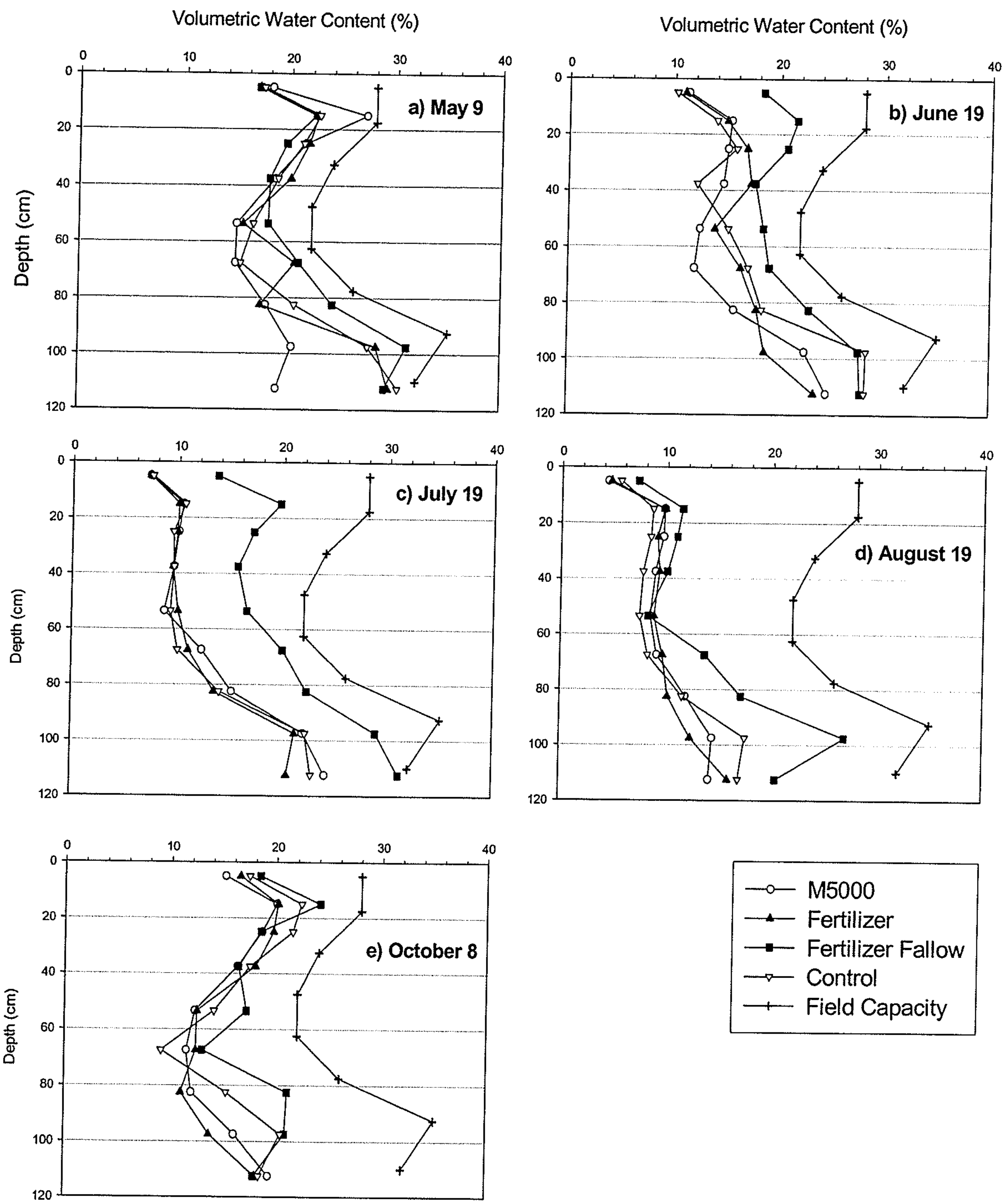


Figure 4.5: Comparison of soil water distribution in plots treated with liquid hog manure and commercial fertilizer on various dates in 2003.

4.1.3 NO_3-N Distribution

4.1.3.1 Changes in Cumulative Soil NO_3-N in 2002 and 2003

Table 4.2 shows the cumulative NO_3-N content within the root zone (120 cm) as affected by treatment and time. Table 4.2a is a summary of the cumulative NO_3-N content means for each treatment at various times during 2002 and 2003. Table 4.2b shows the cumulative NO_3-N content in each replicate for each treatment at various times during 2002 and 2003. Table 4.2b has been included to show the variability in NO_3-N content within treatment measurements. The background soil, sampled on April 30th, 2002, contained 43 kg ha^{-1} of NO_3-N, averaged across the entire site. Between April and June 2002, mineralization of soil organic N and nitrification of ammonium contributed to the increase in soil NO_3-N, as indicated by an increase from 43 to 58 kg NO_3-N ha^{-1} in the control plot.

Table 4.2a: Cumulative NO_3-N (kg ha^{-1}) within the root zone (120cm) at various times during 2002 and 2003.

	25-Jun-02	23-Jul-02	10-Sep-02	9-Oct-02	9-May-03	19-Jun-03	18-Jul-03	19-Aug-03	8-Oct-03
Manure 2500 gal	133bcd*	46cd**	114bc	85cd	125bc	141cd	65cd	154bc	107b
Manure 5000 gal	102cd	76c	94bc	94bcd	98bc	214bc	146bc	211 ab	123b
Manure 7500 gal	187abc	118b	136b	121bc	111bc	266b	185b	306a	239a
Fertilizer (wheat)	239a	77c	109bc	149b	163b	253b	167b	205ab	253a
Fertilizer (fallow)	218ab	309a	275a	243a	309a	319a	370a	288a	227a
Control	58d	31d	54c	61d	78c	72c	34d	66c	61b

* - Means followed by different letters (a,b,c...) within a column differ significantly (P<0.05 Fisher's LSD means comparison)
** - Values are the means of four replicates.

Table 4.2b: Cumulative NO_3-N (kg ha^{-1}) within the root zone (120 cm) at various times during 2002 and 2003

		25-Jun-02	23-Jul-02	10-Sep-02	9-Oct-02	9-May-03	19-Jun-03	18-Jul-03	19-Aug-03	8-Oct-03
Manure 2500 gal	Block 1	79	29	176	78	81	182	86	175	151
	Block 2	92	56	76	87	142	100	65	187	75
	Block 3	206	52	114	86	203	103	58	90	98
	Block 4	153	46	88	87	72	179	53	165	105
	Mean	**133bcd***	**46cd**	**114bc**	**85cd**	**125bc**	**141cd**	**65cd**	**154bc**	**107b**
	Std Error	29	6	22	2	30	23	7	22	16
Manure 5000 gal	Block 1	137	83	53	83	73	317	130	269	100
	Block 2	135	104	62	114	62	132	123	202	122
	Block 3	79	49	90	98	127	210	123	216	137
	Block 4	59	69	172	82	130	196	208	156	132
	Mean	**102cd**	**76c**	**94bc**	**94bcd**	**98bc**	**214bc**	**146bc**	**211 ab**	**123b**
	Std Error	20	12	27	8	18	38	21	23	8
Manure 7500 gal	Block 1	220	158	106	120	102	270	198	354	310
	Block 2	214	137	144	155	115	258	249	211	190
	Block 3	233	87	174	107	114	268	147	330	229
	Block 4	80	92	119	101	114	268	147	330	229
	Mean	**187abc**	**118b**	**136b**	**121bc**	**111bc**	**266b**	**185b**	**306a**	**239a**
	Std Error	36	17	15	12	3	3	24	32	25
Fertilizer (wheat)	Block 1	133	43	92	249	103	298	126	165	262
	Block 2	337	83	94	195	261	205	208	250	276
	Block 3	316	87	92	59	138	314	277	215	262
	Block 4	168	96	160	94	149	195	55	188	211
	Mean	**239a**	**77c**	**109bc**	**149b**	**163b**	**253b**	**167b**	**205ab**	**253a**
	Std Error	51	12	17	44	34	31	48	18	14
Fertilizer (fallow)	Block 1	252	322	222	203	378	262	429	176	124
	Block 2	252	322	222	258	228	254	248	208	155
	Block 3	129	317	293	253	280	332	486	443	273
	Block 4	240	276	364	259	349	428	318	326	358
	Mean	**218ab**	**309a**	**275a**	**243a**	**309a**	**319a**	**370a**	**288a**	**227a**
	Std Error	30	11	34	13	34	40	54	61	54
Control	Block 1	68	32	48	65	65	71	31	67	54
	Block 2	61	32	81	58	79	86	28	87	75
	Block 3	39	26	41	59	90	59	35	53	63
	Block 4	64	33	45	61	79	70	40	58	53
	Mean	**58d**	**31d**	**54c**	**61d**	**78c**	**72c**	**34d**	**66c**	**61b**
	Std Error	7	1	9	2	5	6	3	7	5

* - Means followed by different letters (a,b,c...) within a column differ significantly ($P<0.05$ Fisher's LSD means comparison)
** - Means followed by different letters (v, w, x...) within a row differ significantly ($P<0.05$ Fisher's LSD means comparison)

The application of manure (May 18, 2002) and fertilizer (May 28, 2002) increased NO_3-N content within the soil profile. The NO_3-N content was significantly increased in the highest manure treatment (M7500) and the two fertilizer treatments above the control treatment. The cropped fertilizer treatment had significantly higher NO_3-N content (239 kg ha^{-1}) than the M5000 treatments (102 kg ha^{-1}) (Table 4.2a). These differences could be attributed to nitrogen sources (manure vs. commercial fertilizer) as only 30 to 90% of hog manure applied is expected to be available in the year of application (Angle et al., 1993; Chang and Janzen, 1996; Mikkelsen, 1997; Paul and Zebarth, 1997). After the application of treatments, the ranking for the amount of NO_3-N in the soil profile was Control < M5000 < M2500 < M7500 < Fertilizer Fallow $\approx$Cropped Fertilizer, which was expected, except in the case of the M5000 treatment which had less NO_3-N than the M2500 treatment. This result was not expected and may be due to the variability with the manure application (Ilsemann et al., 2001) or within the soil (Van Meirvenne et al., 2003).

By July 23, 2002, the NO_3-N content had decreased in all the cropped plots, mainly due to the uptake of NO_3-N by the crop (Table 4.2a). The cumulative amount of NO_3-N in the control (31 kg NO_3-N ha^{-1}) was lower than the M2500 (46 kg NO_3-N ha^{-1}) plot and significantly lower than the M5000 (76 kg NO_3-N ha^{-1}) plot (Table 4.2a). The M7500 (118 kg NO_3-N ha^{-1}) plot did have a significantly greater amount of NO_3-N than the control, M2500 and M5000 plots within the root zone. There was no significant difference in the amount of NO_3-N between the M5000 (76 kg NO_3-N ha^{-1}) and the cropped fertilizer plots (77 kg NO_3-N ha^{-1}).

NO_3-N uptake by the crop did not account for the entire decline in NO_3-N content within the soil profile in every treatment. Crop uptake, from June until September 2002, ranged from 41 to 63 kg N ha^{-1} (Table 4.4) in the control through the cropped fertilizer treatments, respectively. The decrease in NO_3-N content in the cropped fertilizer plot from 239 to 77 kg NO_3-N ha^{-1} and in the M2500 plot from 133 to 46 kg NO_3-N ha^{-1} treatments exceeded crop uptake. The decline in NO_3-N could be a reflection of the spatial variability within the soil or application of treatments, as little denitrification is expected and the lysimeters did not produce any leachate.

Denitrification is not considered a major loss pathway at this site, as the sandy soil at this site has a low water-holding capacity and good aeration, two factors limiting denitrification (Mooleki et al., 2002). Flynn (1997) found that some denitrification occurred in sandy soils, however only at high soil temperature and extremely high moisture content.

The significantly higher NO_3-N content in the fallow plots versus the cropped plots indicates the amount of NO_3-N uptake by the wheat crop (Table 4.2a). While the NO_3-N content in the cropped plots decreased due to uptake by the wheat crop, the NO_3-N content in the fertilizer fallow plot increased. This increase in NO_3-N shows the possible amount of nitrogen mineralization and nitrification within this soil. Grift (2001) also noted an increase in NO_3-N levels throughout the growing season under a fallow treatment and attributed this to mineralization and nitrification of soil organic nitrogen. If the amount of NO_3-N in Block 3 of the fertilizer fallow treatment could be ignored (Table 4.2b), the mean value for June 2002 would be 248 kg NO_3-N ha^{-1}. An increase from 248 to 309 (July 2002, Table 4.2b) would suggest mineralization of approximately 60 kg NO_3-N ha^{-1}. This amount of mineralization and nitrification appears high, as Watson and Mills (1998) found gross nitrification to be 44 kg N ha^{-1} in soil with high soil organic matter (i.e. 11%) receiving consecutive application of 100 kg N ha^{-1} of NH_4NO_3.

In September and October 2002, the amount of cumulative NO_3-N in the root zone was not significantly different between the various manure rates, although the M7500 treatment always had the highest amount of NO_3-N (Table 4.2a). As well, the M7500 treatment had significantly higher NO_3-N levels than the control during this period. Mooleki et al. (2002) observed low levels of available N in the soil after harvest, except at the highest rate of manure application (400 kg N ha^{-1}). Between July and October 2002, the soil NO_3-N content was not significantly different between the M5000 and fertilizer treatments (Table 4.2), however the cropped fertilizer plot consistently had a higher amount of NO_3-N within the soil profile.

The trends in the fluctuations of soil NO_3-N content in 2002 were evident in the samples obtained in 2003. The application of treatments increased the soil NO_3-N content in June 2003 and nitrogen uptake by the crop decreased the soil NO_3-N content at a greater rate than mineralization and nitrification in July 2003. Due to the residual of NO_3-N from treatments of the previous year, the soil NO_3-N content in 2003 started off at higher levels than in 2002. As a result of this residual NO_3-N effect, levels of soil NO_3-N throughout the summer and fall in the treated plots were higher in 2003, than in 2002.

The control plot maintained a soil NO_3-N content at a somewhat constant level of approximately 55 kg ha^{-1} (range of 31 to 78 kg ha^{-1}) throughout both years, with some fluctuation due to increased mineralization in the spring and N uptake by crops during the growing season (Table 4.2a). By the end of the two years, the M7500, cropped fertilizer and fertilizer fallow plots had 239, 253 and 227 kg NO_3-N ha^{-1}, respectively, within root zone, which was significantly higher than the NO_3-N content within the root zone of the control, M2500 and M5000 plots (61, 107, and 123 kg NO_3-N ha^{-1}, respectively). This difference indicates that N application rate exceeds the requirements of the crop and resulted in NO_3-N accumulation (Chang and Entz, 1996; Hountin et al., 1997; Mooleki et al., 2002). The dry conditions during the two years of this study, reduced the uptake of NO_3-N by the crop (Cowell and Doyle, 1993) and increased the accumulation of NO_3-N within the soil profile (Deutsch and Lee, 1994; Morecroft et al., 2000). Manitoba Agriculture (2001a) guidelines state that a NO_3-N content of greater than 168 kg ha^{-1} within the top four feet of soil is considered to be in excess. After two years of this field study, the highest rate of manure (M7500) and the two fertilizer treatments were above this threshold.

4.1.3.2 Effects of Manure Rate on NO_3-N Distribution

Figure 4.6 illustrates the distribution of NO_3-N within the soil profile of the manured and control plots throughout summer and fall of 2002. The data points on all concentration distribution figures have been placed in the middle of the sampling zone range, for example the data point for the sampling zone 30-45 cm was placed at 37.5 cm. The LSD values relate to the log NO_3-N scale on the bottom x-axis. Actual NO_3-N concentration values have been included on the upper x-axis for ease of interpretation.

The application of different rates of liquid hog manure significantly increased the NO_3-N concentration in the top 20 cm of the soil above the control plot (Figure 4.6a). Following the application of hog manure, NO_3-N concentration was significantly increased above the control treatment (4 mg NO_3-N kg^{-1}) near the soil surface (0-10cm) in the M2500 (30 mg NO_3-N kg^{-1}), M5000 (24 mg NO_3-N kg^{-1}) and the M7500 (50 mg NO_3-N kg^{-1}) treatments. The manured plots showed a distinct rate effect on the NO_3-N distribution within the soil profile, although the M5000 plot was expected to have higher NO_3-N concentrations than the M2500 plot. This difference may be due to a sampling error because in July 2002, the M5000 plot had higher NO_3-N concentration than the 2500 plot (Figure 4.6c).

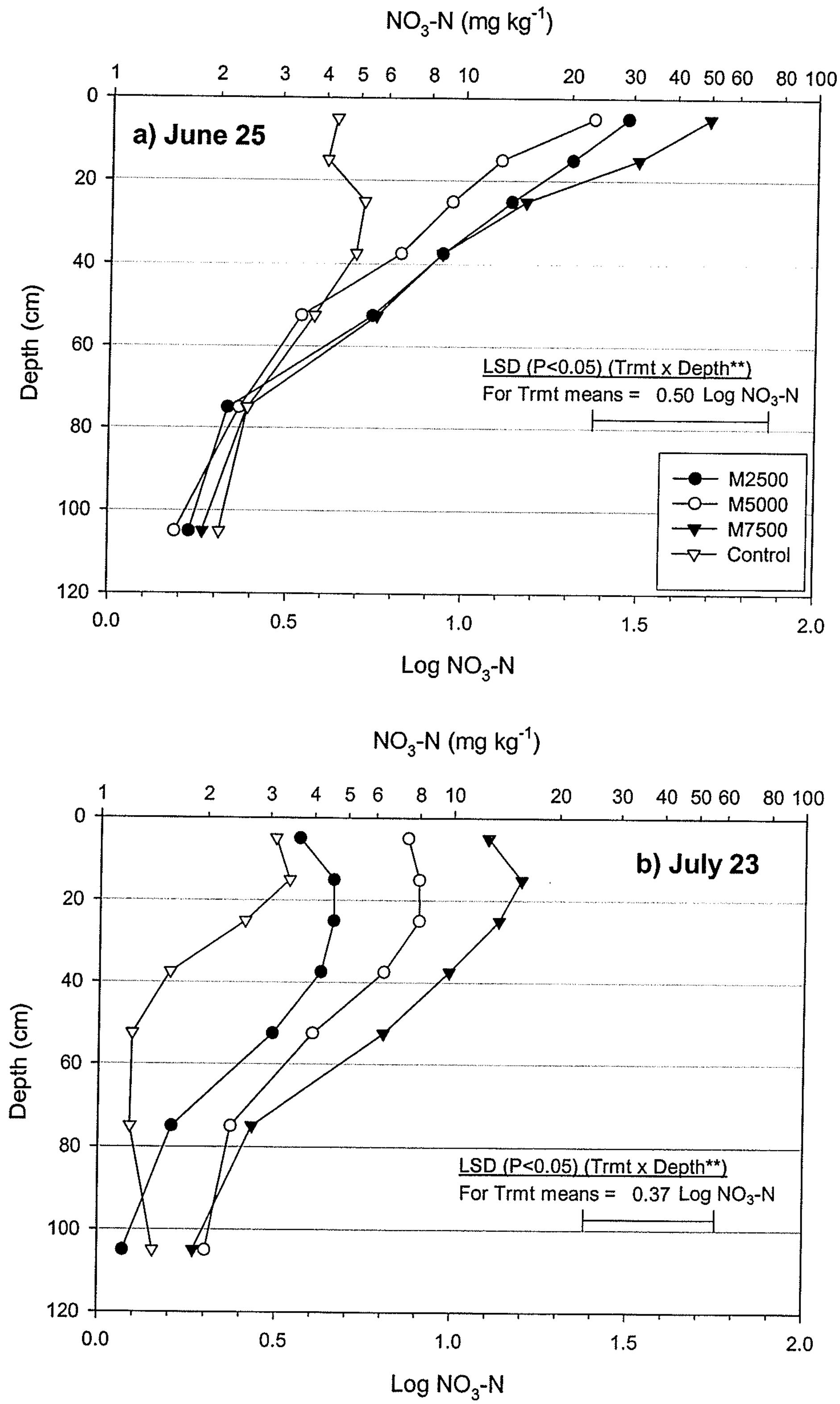


Figure 4.6: Comparison of NO_3-N distribution in 2002 between soils receiving different rates of liquid hog manure.

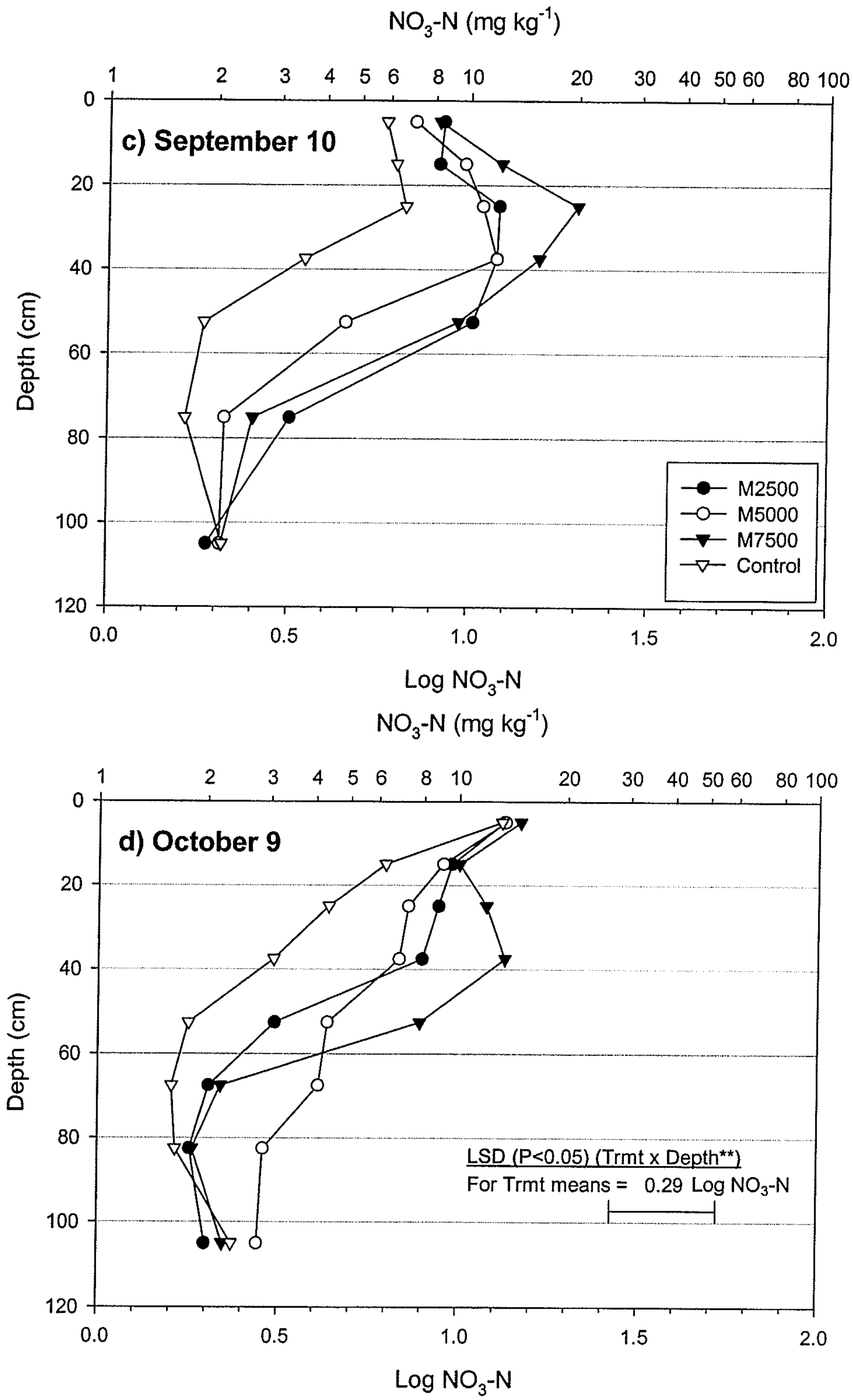


Figure 4.6: Comparison of NO_3-N distribution in 2002 between soils receiving different rates of liquid hog manure.

By July 2002, crop uptake and the downward movement of NO_3-N decreased NO_3-N concentrations within the 0-30cm section of the soil profile (Figure 4.6b). Below 30cm, NO_3-N concentrations increased above June levels in the M5000 and M7500 treatments indicating downward movement of NO_3-N. The M5000 and M7500 treatments had significantly higher NO_3-N concentration than the control treatment in the upper 60cm of the soil profile, while the M2500 treatment was only significantly higher than the control in the 30-60cm section of the soil profile (Figure 4.6b). The M7500 treatment was also significantly higher than the M2500 treatment near the soil surface (0-20cm).

Above normal precipitation in August (Figure 4.1), increased soil water content in September resulting in the downward movement of NO_3-N (Figure 4.6c). The decrease in NO_3-N concentration above the 20cm depth and an increase in NO_3-N concentration below 20cm in all plots is evidence of the downward movement of NO_3-N between the July and September sampling dates. The NO_3-N concentration in M7500 treatment plot is higher than the control throughout the soil profile, and higher than M2500 and M5000 plots in upper 45cm of the soil profile, although none of the differences are significant.

During the growing season (i.e. July), NO_3-N uptake by crop was greater than mineralization of soil organic N resulting in a reduction of NO_3-N levels in the soil, especially close to the soil surface. However, in the fall the trend was reversed, as NO_3-N levels were greater in all rates of hog manure, in the top 10 cm, in

October than July and September (compare Figure 4.6d to Figure 4.6b and c). This increase in NO_3-N levels could have been the result of mineralization due to damp, warm fall conditions, or the evaporation and upward movement of soil moisture may have carried NO_3-N into the upper soil layers. Dyck et al. (2003a) reported that extraction of soil water by plants caused some Cl^- tracer to move upward within the rooting zone. Campbell et al. (1987) showed upward movement of NO_3-N into the root zone of a wheat crop in southern Saskatchewan.

By October 9, 2002, the M5000 and M7500 treatments had NO_3-N concentrations that were significantly higher than the control treatment to depths of 75 and 60 cm, respectively. The depth of significant change in NO_3-N concentration indicates the maximum penetration of NO_3-N from the treatments, which would be approximately 60 to 75 cm in 2002.

The same treatments were sampled in May 2003, before the application of manure (Figure 4.7a). The results showed a decline in the high concentrations of NO_3-N going from the fall of 2002 to the spring of 2003, especially in the M7500 treatment (compare Figure 4.6d and 4.7a). Increases in NO_3-N concentration at depth were not sufficient to account for the decline in NO_3-N between the fall of 2002 and the spring of 2003. However, the loss of these high levels of NO_3-N could be due to the downward movement of NO_3-N following spring snowmelt, resulting in NO_3-N leaching losses from the soil profile.

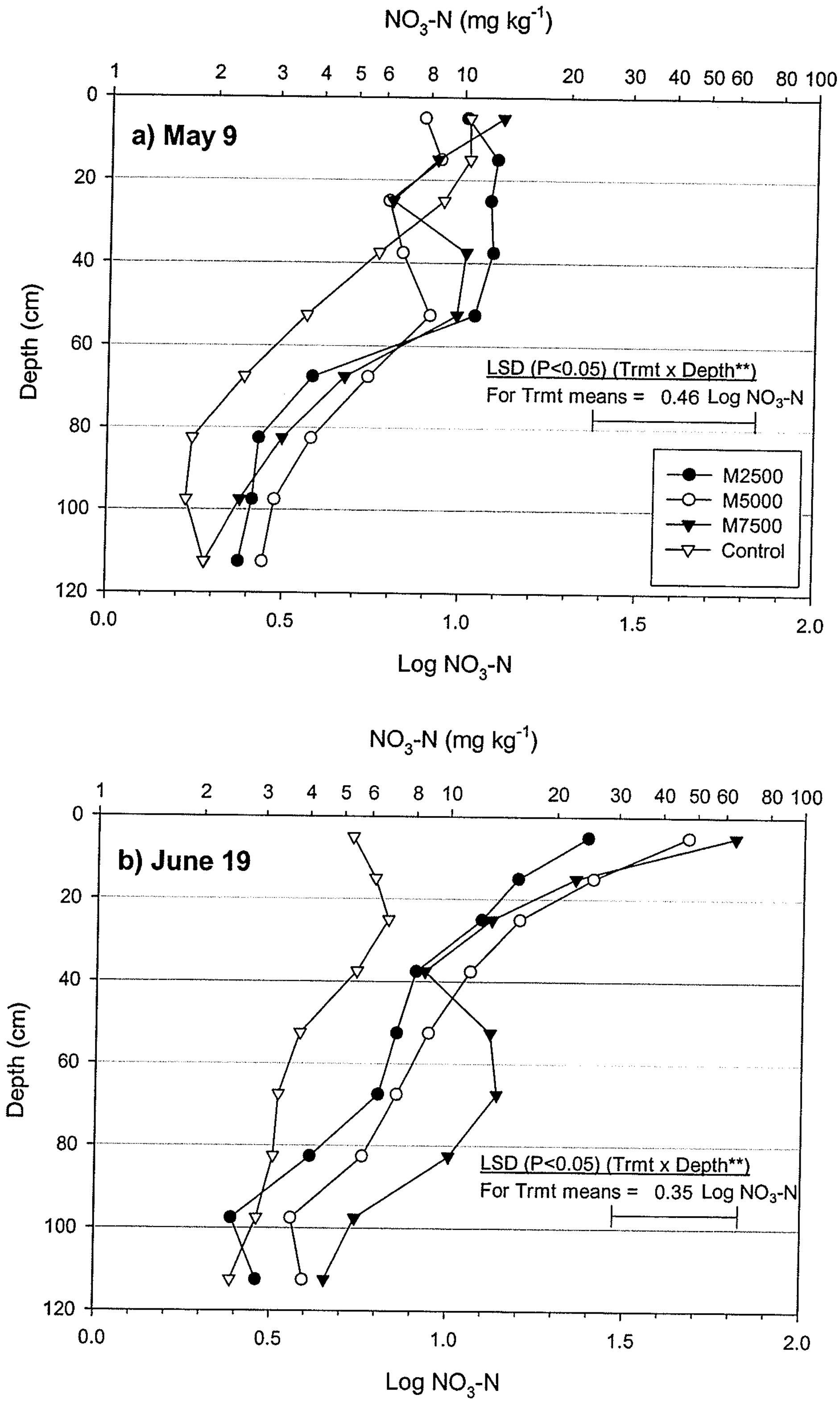


Figure 4.7: Comparison of NO_3-N distribution in 2003 between soils receiving different rates of liquid hog manure.

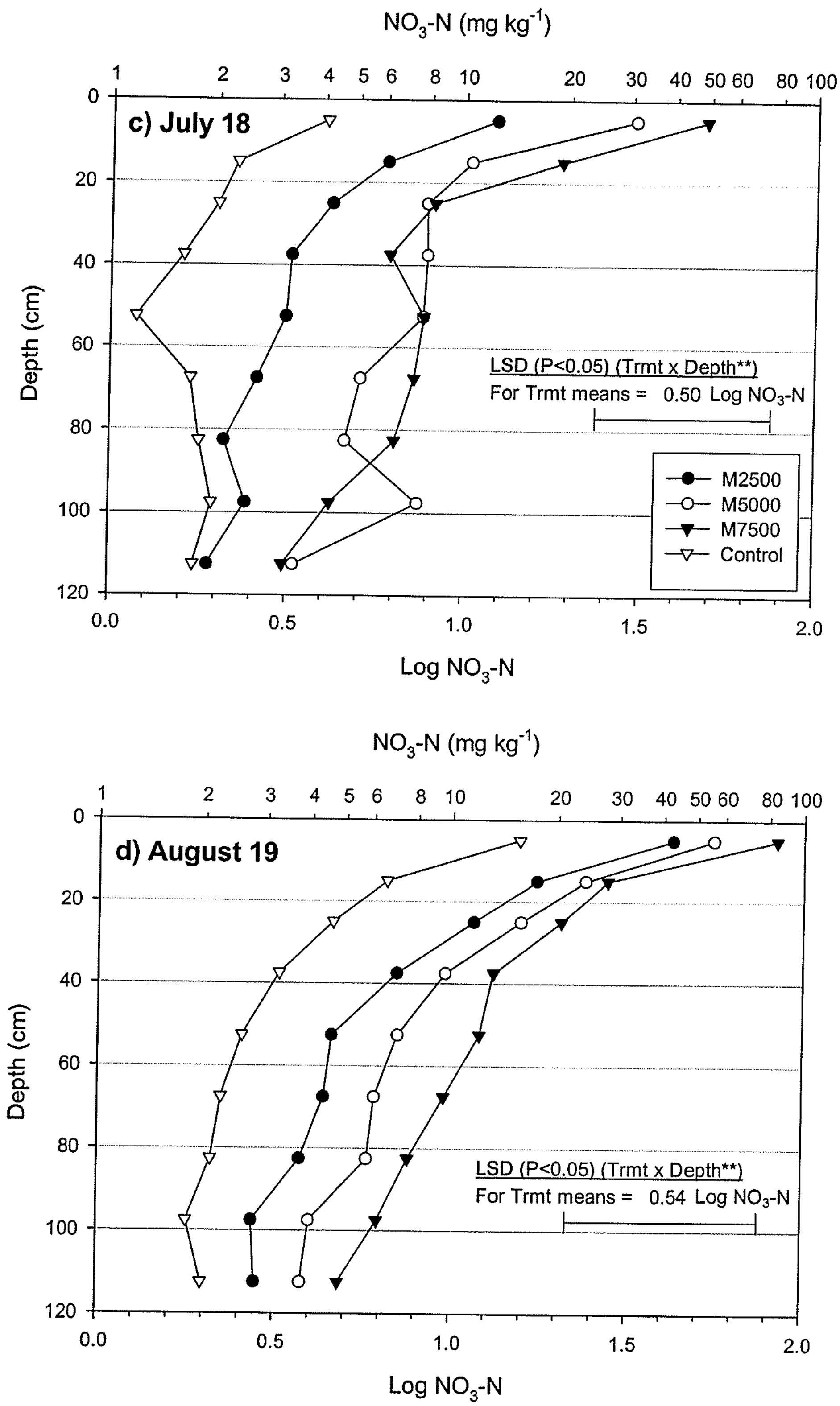


Figure 4.7: Comparison of NO_3-N distribution in 2003 between soils receiving different rates of liquid hog manure.

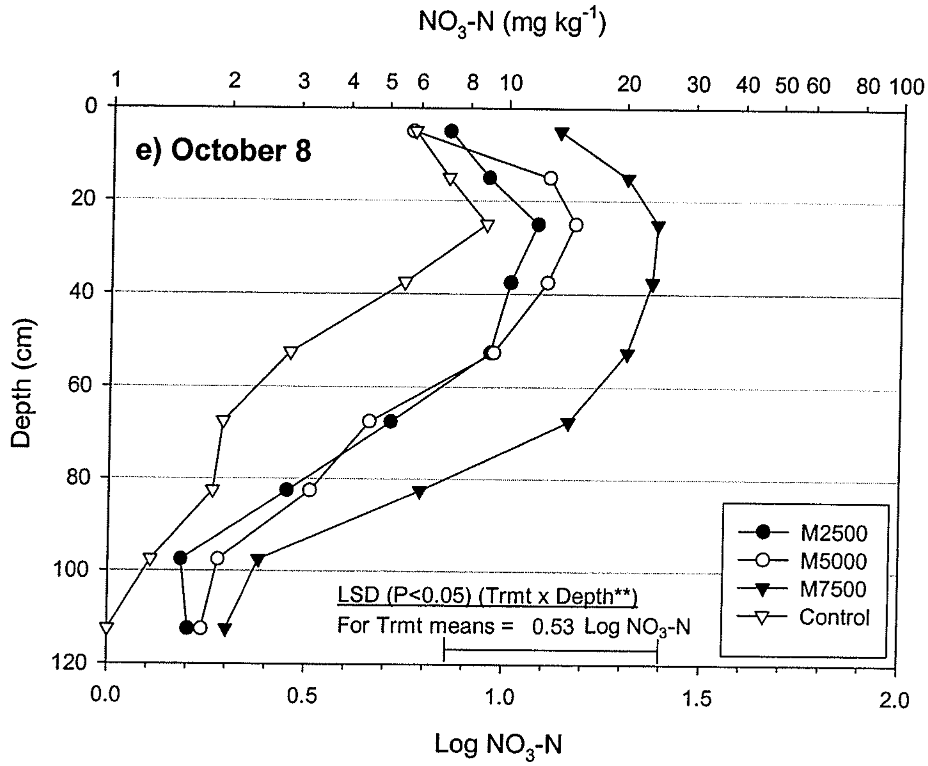


Figure 4.7: Comparison of NO_3-N distribution in 2003 between soils receiving different rates of liquid hog manure.

Manure application in May 2003 had a similar effect on the soil surface NO_3-N concentration measured in June 2003, as was the case in June 2002 (Figure 4.7b). All manure treatments significantly increased the NO_3-N concentration above the control near the soil surface (0-20cm). The NO_3-N concentration was significantly higher in the M2500 (25 mg NO_3-N kg^{-1}), M5000 (49 mg NO_3-N kg^{-1}) and the M7500 (64 mg NO_3-N kg^{-1}) plots than the control (5 mg NO_3-N kg^{-1}) plot by June 2003 (Figure 4.7b). Significantly higher NO_3-N concentrations under the M7500 treatment than the control were also evident between the depths of 60 to 90 cm. This bulge may be the result of the downward movement of residual NO_3-N from the previous year (compare Figure 4.6d and 4.7b). This shows that in approximately one year, an application of 7500 gal ac^{-1} of liquid hog manure ($\approx$

180 kg N ha^{-1}) significantly increased the soil NO_3-N concentration to a depth of 90 cm, even in dryland agricultural conditions.

The high levels of NO_3-N resulting from manure application declined by July 2003 due mainly to NO_3-N uptake by the crop, as NO_3-N concentrations changed little at depth (Figure 4.7c). The M7500 plot had NO_3-N concentrations significantly higher than the control to a depth of 90cm and was significantly higher (49 mg NO_3-N kg^{-1}) than the M2500 plot (12 mg NO_3-N kg^{-1}) at the soil surface (0-10cm) (Figure 4.7c). NO_3-N concentrations were significantly higher in the M5000 plot than the control in the 0-60cm portion of the soil profile as well as in the 90-105cm portion of the soil profile.

In spite of the crop uptake, NO_3-N concentrations near the soil surface (0-30cm) of all treatments were higher in August 2003 than June 2003 (compare Figures 4.7d to 4.7b). Evaporation and upward movement of soil moisture may have contributed to the increase in NO_3-N levels within the upper soil layers. However, the upward movement of soil moisture would only contribute a small amount of NO_3-N as declines in NO_3-N concentration were not observed at lower depths to account for an upward movement of NO_3-N. The most probable explanation for the increase in NO_3-N concentration is mineralization of organic nitrogen from the soil organic matter and hog manure. Borg et al. (1990) observed that nitrate content within the soil profile increased at the end of growing season when root-uptake became less than mineralization. The accumulation of hog manure in the soil surface has resulted in higher levels of mineralization in the second year of application when compared to the first study year (compare Figures 4.6c and d to Figures 4.7c and d).

For example in September 2002, NO_3-N concentrations were 8, 6 and 8 at the soil surface (0-10cm) in the M2500, M5000, and M7500 plots, respectively (Figure 4.6c). By October 2002, NO_3-N concentrations had increased to 14, 14 and 16 mg NO_3-N kg^{-1} in the M2500, M5000, and M7500 plots, respectively (Figure 4.6d). In 2003, the NO_3-N concentrations in the 0-10 cm soil section increased from 13 to 42 mg NO_3-N kg^{-1} in the M2500 treatment, 31 to 55 in the M5000 treatment and 49 to 84 in the M7500 treatment between July and August 2003. Ndayegamieye and Cote (1989) noted that the application of pig slurry increased the levels of potentially mineralizable nitrogen in the soil.

In August 2003, NO_3-N concentrations decreased from the soil surface to depth in all treatments (Figure 4.7d). The M7500 plot had the highest NO_3-N concentrations throughout the entire root zone, followed by the M5000, M2500 and the control plots. The concentration of NO_3-N was significantly higher in the M7500 plot than the control in the upper 90cm of the soil profile.

The difference in NO_3-N concentration between the manure rates was carried over from August into October (Figure 4.7e), with the highest NO_3-N concentrations in the M7500 plot than M5000, M2500 and the lowest NO_3-N concentrations in the control. All the manure treatments had higher NO_3-N concentrations than the control throughout the root zone. The M7500 plot (23, 20 and 18 mg NO_3-N kg at 45, 60 and 75 cm soil depths, respectively) had significantly higher NO_3-N concentrations than the control (6, 3 and 2 mg NO_3-N kg at 45, 60 and 75 cm soil depths, respectively) in the 45-75cm section of the soil profile.

Above normal precipitation in September, increased the soil moisture levels (Table 4.1), thus transporting NO_3-N downward within the soil profile (Figure 4.7e). NO_3-N concentrations increased to a depth of 90cm under all manure treatments. In October, NO_3-N concentrations decreased from NO_3-N levels in August 2003 in the 105-120cm section of the soil profile in all treatments (Compare Figures 4.7d and e). This decrease is the result of NO_3-N leaching below the root zone due to fall precipitation.

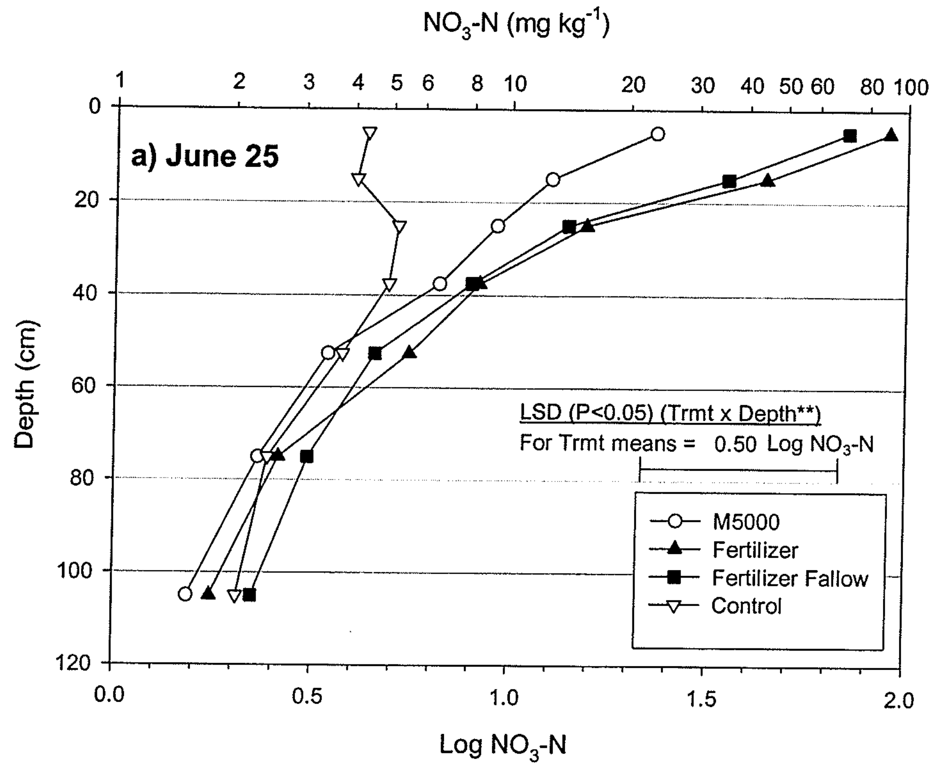
The application of different rates of manure has resulted in the accumulation of NO_3-N within the rootzone after two years of dryland wheat production. The application of the lowest (2500 gal ac^{-1}) and intermediate (5000 gal ac^{-1}) rates of liquid hog manure resulted in similar NO_3-N distributions throughout the soil profile, and increased the NO_3-N concentration above the control to a depth of 90 cm. The highest rate of liquid hog manure (7500 gal ac^{-1}) increased soil NO_3-N concentration above the lower and intermediate rates of hog manure and significantly increased soil NO_3-N concentration above the control to a depth of

90 cm. The application of M7500 is not recommend under these low moisture conditions due to the significantly higher NO_3-N concentrations in the M7500 treatment than the control, indicating that excessive amounts of hog manure have been applied to the soil surface (Chang and Entz, 1996). Because all treatments appeared to have NO_3-N leaching losses after two years, the M2500 rate of hog manure would be recommended so as to reduce the amount of NO_3-N lost.

4.1.3.3 Effects of N Source on NO_3-N Distribution

Figure 4.8 shows the distribution of NO_3-N concentration with plots receiving equivalent rates of Total nitrogen ($\approx$130 kg Total N ha^{-1}) as liquid hog manure (5000 gal ac^{-1}) or as commercial fertilizer (i.e. urea). The commercial fertilizer was applied to two different cropping regimes: the plot that was cropped to wheat; and the plot that was left fallow. These fertilized plots will be referred to as cropped fertilizer, for the plot that was planted to wheat, and fertilizer fallow for plot left as fallow.

The application of manure and fertilizer significantly increased NO_3-N concentrations above that measured in the control plot near the soil surface (0-20cm). At this early part of the growing season, there were no significant treatment differences in NO_3-N concentration below the 20cm depth (Figure 4.8a). Also, there was a significant N source effect as the cropped fertilizer plot had significantly higher NO_3-N levels in the upper 20 cm than the manured plots.



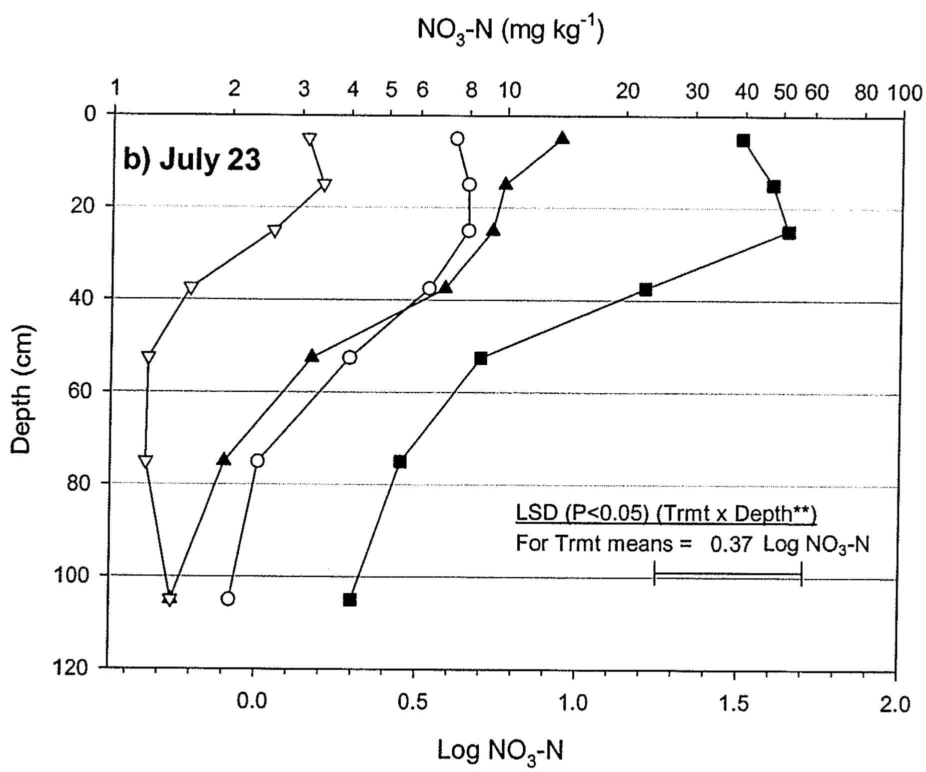


Figure 4.8: Comparison of NO_3-N distribution in plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios in 2002.

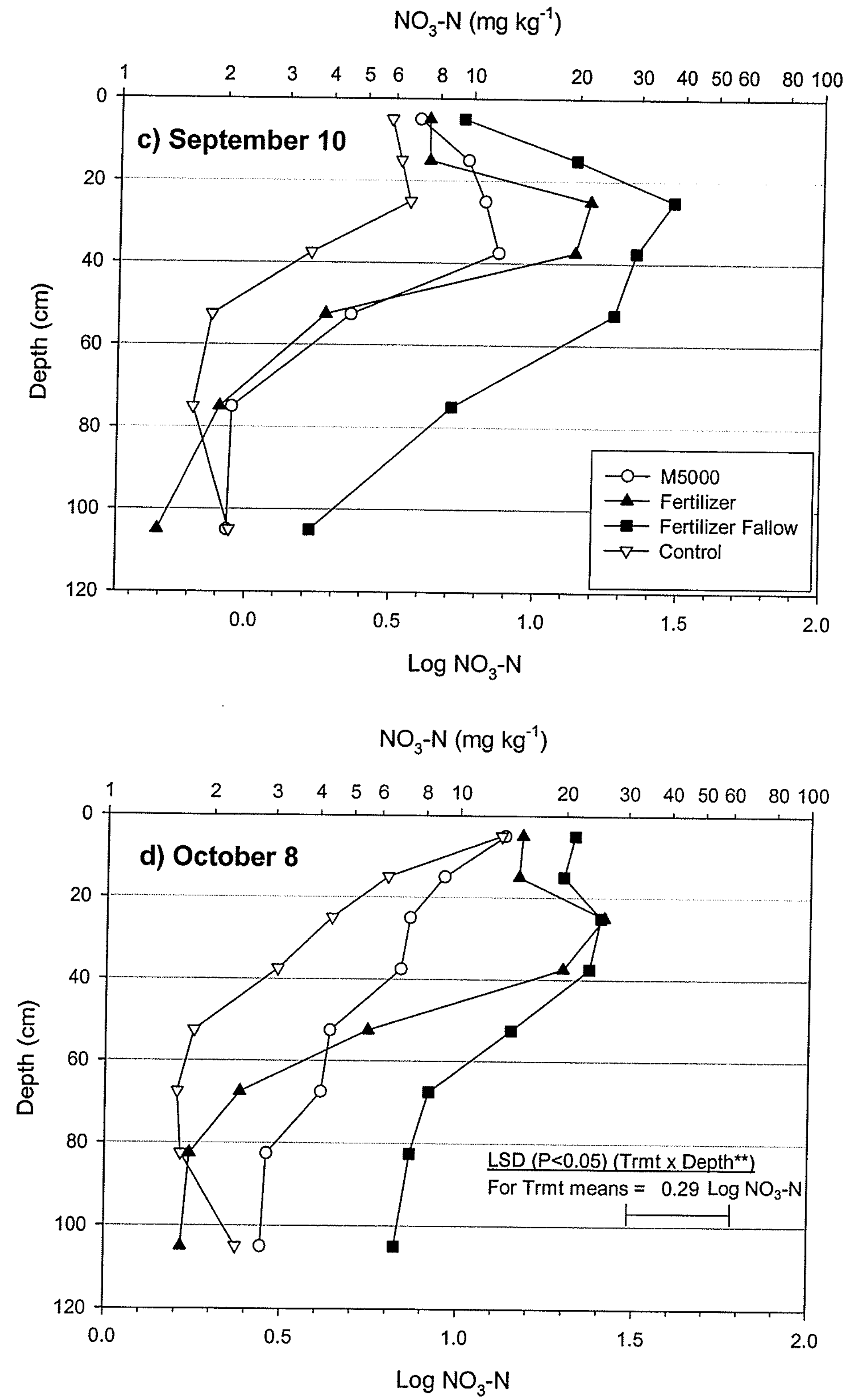


Figure 4.8: Comparison of NO_3-N distribution in plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios in 2002.

The NO_3-N concentrations in the 0-20 cm soil section were 23 and 13 mg NO_3-N kg^{-1} in the manure plots, and 90 and 44 mg NO_3-N kg^{-1} in the cropped fertilizer plot (Figure 4.8a). These differences can be attributed to the difference in the availability of the nitrogen sources (manure vs. commercial fertilizer) (Angle et al., 1993; Chang and Janzen, 1996; Mikkelsen, 1997; Paul and Zebarth, 1997).

By July 2002, there were no significant treatment differences in NO_3-N concentration between the manure and cropped fertilizer plots (Figure 4.8b). Although, both the manure and cropped fertilizer plots had significantly higher NO_3-N concentration than the control in the 0-60cm portion of the soil profile. While the difference was not significant, above 45cm the NO_3-N concentration in the cropped fertilizer plot was higher than the manure plot, however below 45cm NO_3-N concentration was higher in the manure plot than the cropped fertilizer plot (Figure 4.8b).

Figure 4.8 (b) shows a large divergence in the NO_3-N distribution between the cropped fertilizer and fertilizer fallow plots. In the upper 45 cm of the soil profile, the NO_3-N concentrations in the fertilizer fallow plots were significantly greater than the cropped fertilizer plots. This difference in NO_3-N concentration of the two fertilizer plots demonstrates the ability of wheat to reduce NO_3-N concentrations within the soil profile, although the differences between these two treatments cannot be accounted for by crop uptake alone. For example, the amount of NO_3-N near the soil surface (0-10cm) in the cropped fertilizer plot, in

June 2002, was 109 kg ha^{-1}, declining to 17 kg ha^{-1} by July 2002 with a total crop uptake for the entire growing season of 63 kg N ha^{-1}. An N balance would result in approximately 30 kg ha^{-1} of NO_3-N being left unaccounted for near the soil surface between June and July 2002. Of course, wheat does not only take up nitrogen from near the soil surface, indicating that the decrease in NO_3-N between June and July 2002 in the 0-30cm section of the soil profile is probably greater that 30 kg ha^{-1}. A possible reason for the dramatic decrease in NO_3-N concentration could be spatial variability, resulting in some discrepancies in the sampling results (Ilsemann et al., 2001).

By July 2002, the fertilizer fallow plots showed increased NO_3-N levels at all sampling points below 20 cm and a decline in NO_3-N concentration above 20 cm, indicating the downward movement of NO_3-N due to precipitation (Figure 4.8b). The higher levels of soil moisture within the fertilizer fallow plot (Figures 4.4 and 4.5) translate into greater NO_3-N movement than in the cropped fertilizer plot. The downward movement of soil water under the fallow treatment is only limited by evaporation from the soil surface, while the uptake of water and NO_3-N from the soil by crops reduces their availability for leaching.

By September, all treatments exhibited increases in NO_3-N concentration at depth due to precipitation (Figure 4.8c). The manured and cropped fertilizer plots exhibited similar patterns of NO_3-N distribution as the fallow fertilizer plots, except that their NO_3-N concentrations were lower. All treatments exhibited an increase in NO_3-N concentration between 30-45 cm with maximum concentrations of 10, 20 and 38 mg kg^{-1} in the M5000, cropped fertilizer and fallow fertilizer plots, respectively. The fertilizer fallow treatment showed possible NO_3-N leaching by September 2002 as NO_3-N levels at the 120 cm depth declined from 4.2 mg NO_3-N kg^{-1} in July 2002 to 3.5 mg NO_3-N kg^{-1} in September 2002. As in July 2002, the cropped fertilizer plot had higher NO_3-N concentrations than the manure in the upper 45cm of the soil profile, while the manure plot had higher NO_3-N concentrations than the cropped fertilizer plot below 45 cm. The more vigorous crop growth in the cropped fertilizer plot than the manure plot reduced the amount of soil moisture within the soil profile, thus reducing the downward movement of NO_3-N.

In October 2002, mineralization of soil organic N increased NO_3-N levels near the soil surface (0-20cm) in all treatments as a result of a warm and moist fall conditions (Campbell et al., 1984) (Figure 4.8d). The cropped fertilizer plot had significantly higher NO_3-N concentration than the control plot within the 20-60cm portion of the soil profile. As well, the cropped fertilizer plot has higher NO_3-N concentrations than the manure in the upper 60cm of the soil profile, with the NO_3-N concentration being significantly higher than the manure plot at the 30cm depth (Figure 4.8d). The manure plot had significantly higher NO_3-N concentrations than the control between 60-75cm.

Similar to July and September, the NO_3-N concentration in the cropped fertilizer plot was lower than the manure plot at depth (below 60cm) (Figure 4.8d). Campbell (1993) concluded that inadequately fertilized crops could lead to greater NO_3-N leaching than adequately fertilized crops. The NO_3-N leaching from inadequately fertilized crops is due to poor crop growth resulting in lower uptake of soil water and NO_3-N than the adequately fertilized crop. The manure treatment did result in lower uptake of soil water (Table 4.1) and NO_3-N (Table 4.4), than the cropped fertilizer plot. The manure treatment may not have supplied the wheat crop with adequate nutrient compared to the commercial fertilizer, resulting in greater movement of NO_3-N at depth in the manure treatment.

By October 2002, the manured and cropped fertilizer plots have NO_3-N movement to depths of 75 and 60 cm, respectively, while NO_3-N has moved to a depth of 120 cm in the fallow fertilizer plots (Figure 4.8d). The lack of water and nutrient uptake by wheat in the fallow plot allowed NO_3-N to reach the limit of the rooting zone (120 cm) even in the dry growing season of 2002. Other studies have concluded that the use of fallow in agricultural production favours NO_3-N leaching (Campbell et al., 1994; Izaurralde et al., 1995).

Figure 4.9 shows the NO_3-N distribution with the soil profile at sampling dates in 2003. Snowmelt and spring precipitation in May 2003 (Figure 4.1) resulted in downward movement of NO_3-N, increasing NO_3-N concentrations to a depth of

75 cm in the M5000 and fertilizer treatments, and throughout the entire profile in the fallow treatments (Figure 4.9a). The concentration of NO_3-N in the cropped fertilizer plot was greater than the manure plot within the 30-60 cm section of the soil profile, and significant higher than the manure in the 45-60 cm soil section. After one year, the fertilizer plot had a NO_3-N concentration of 26 mg kg^{-1} at a depth of 60 cm and the equivalent rate of liquid hog manure had a NO_3-N concentration of 8 mg kg^{-1} at the same depth (Figure 4.9a). However, the manure plot had significantly higher NO_3-N concentrations than the cropped fertilizer in the 90-105cm portion of the soil profile. This difference in NO_3-N concentration at depth between the two N sources was carried over from the previous fall (compare Figure 4.8d and 4.9a), and was possibly the result of poor crop growth. The poor crop growth can leave greater amounts soil water and NO_3-N in the soil profile than average crop growth, resulting in greater potential for the downward movement of NO_3-N (Campbell et al., 1984).

The application of fertilizer and manure in May 2003 significantly increased NO_3-N concentration in the M5000 and cropped fertilizer plots above the control plot near the soil surface (0-30 cm soil section) similar to 2002 (Figure 4.9b). The NO_3-N concentration in the cropped fertilizer plot remained significantly higher than the control in 45-60cm soil section from May 2003 into June 2003 (Figure 4.9a and b). The cropped fertilizer plot contained higher NO_3-N concentrations than the manure plot between the 10-75cm soil section, although the difference was not significant.

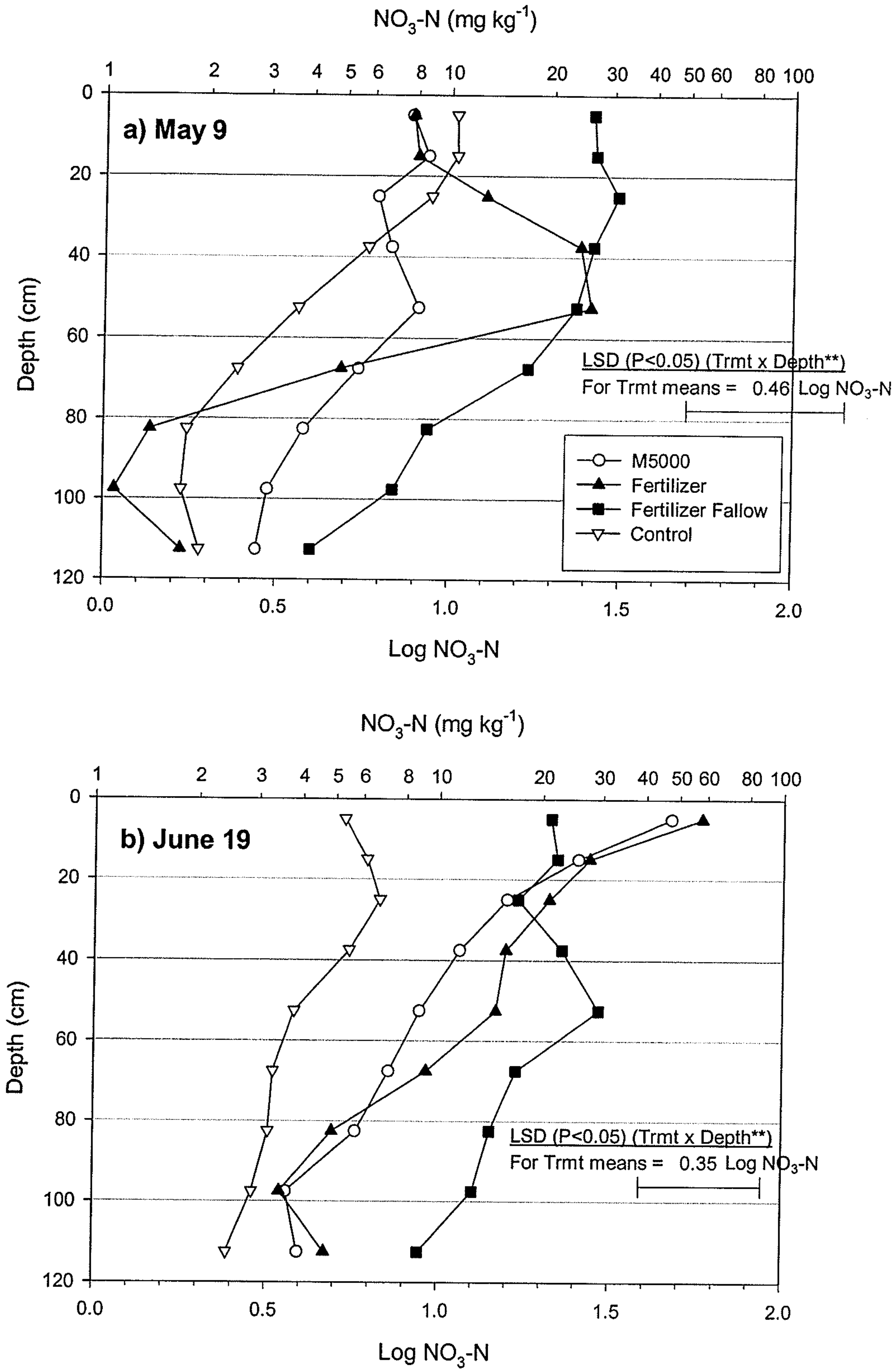


Figure 4.9: Comparison of NO_3-N distribution in plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios in 2003.

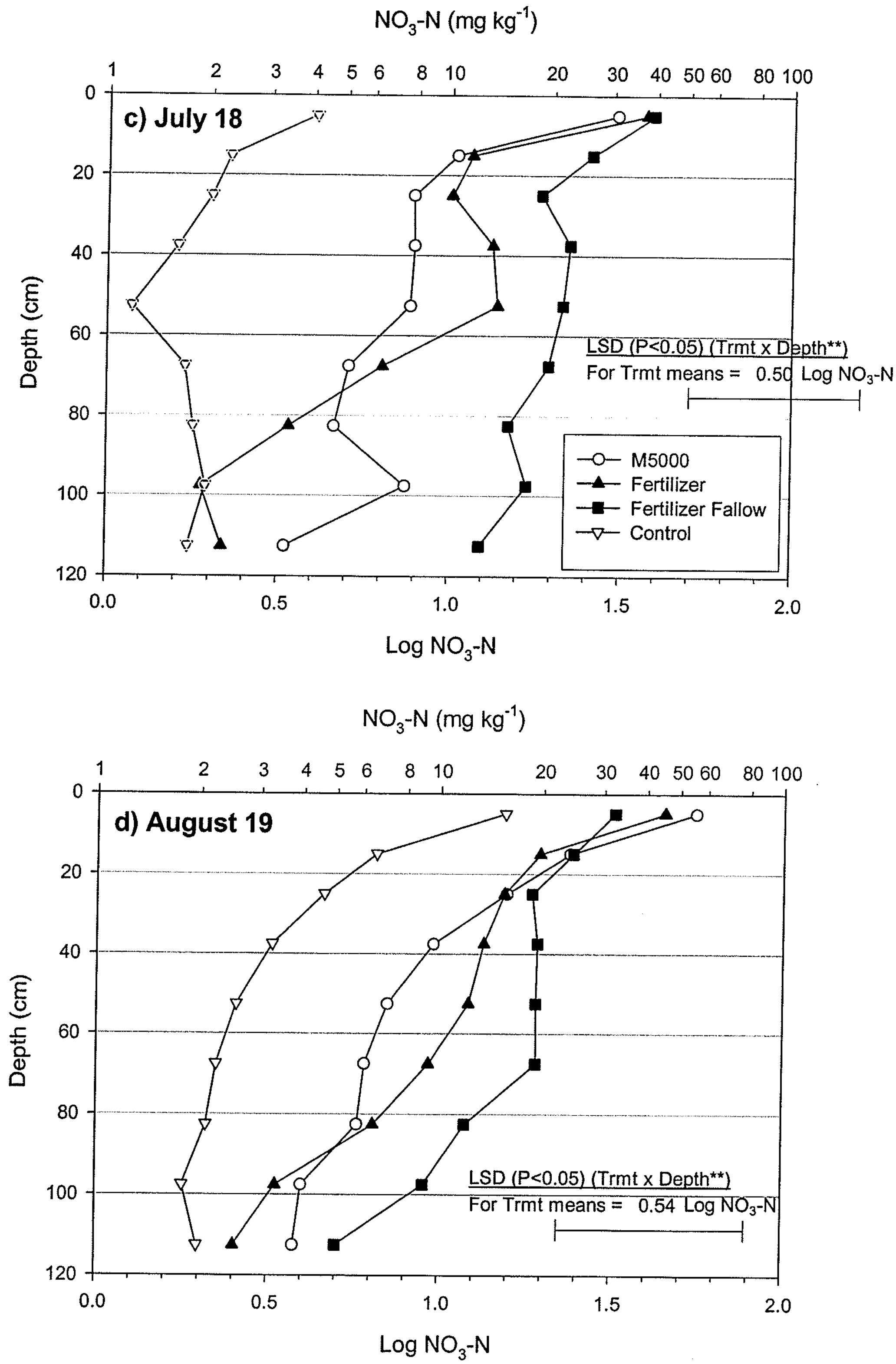


Figure 4.9: Comparison of NO_3-N distribution in plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios in 2003.

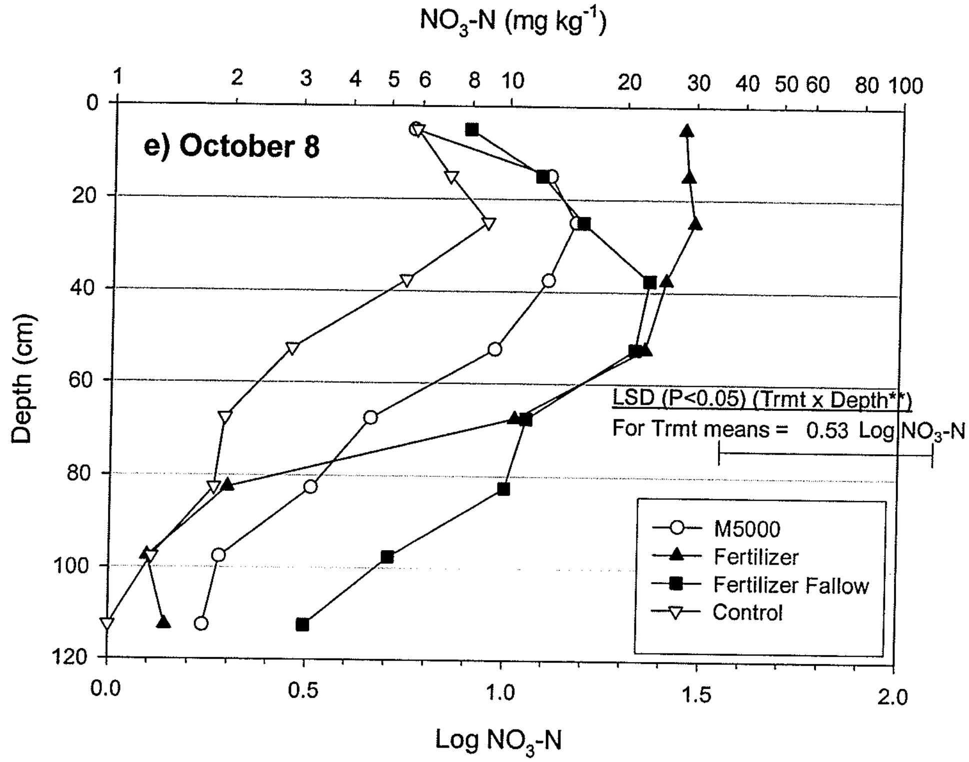


Figure 4.9: Comparison of NO_3-N distribution in plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios in 2003.

NO_3-N concentrations were similar for the manure and cropped fertilizer plots below 90cm (Figure 4.9b). The fertilizer fallow plot contained significantly higher NO_3-N concentrations than the control throughout the soil profile. NO_3-N concentration increased in the 120cm soil layer in the fertilizer fallow plot from May to June 2003 indicating the downward movement of NO_3-N (Figure 4.9a and b). The NO_3-N distribution in July 2003 for the manure and cropped fertilizer plots was similar to July 2002. The control, M5000 and cropped fertilizer plots experienced a decrease in NO_3-N concentration within the upper 60cm of the soil profile due to NO_3-N uptake by the crop (Figure 4.9c). The concentration of NO_3-N was significantly higher in the manure and cropped fertilizer plots than the control plot in the upper 75cm of the soil profile (Figure 4.9c). In July, the NO_3-N concentration remained higher in the cropped fertilizer than the manure plot in the upper 75cm, and was lower in the cropped fertilizer than the manure plot below 75cm. The manure plot had a significantly higher NO_3-N concentration at a depth of 105cm than the cropped fertilizer plot (Figure 4.9c).

By August, the mineralization of organic N had increased the NO_3-N concentration within the upper 45cm of the soil profile in each treatment (Figure 4.9d). The manure plot (45 mg NO_3-N kg^{-1}) had NO_3-N concentrations significantly higher than the control (17 mg NO_3-N kg^{-1}) near the soil surface (0-20cm). The cropped fertilizer plot had lower NO_3-N concentrations than the manure plot in the upper 20 cm of the soil profile and in the 105-120cm soil section. However, NO_3-N concentrations were higher in the cropped fertilizer plot than manure plot within the 30-90cm section of the soil profile (Figure 4.9d). The fertilizer fallow plot contained NO_3-N concentrations significantly higher than the control in the 30-105cm section of the soil profile. A decline in the NO_3-N concentration at depth (105-120cm) indicates loss of NO_3-N by leaching from the fertilizer fallow plot.

Above normal precipitation in September 2003 (Figure 4.1) resulted in the movement of NO_3-N from the 0-20 cm depth down to the 30 to 60 cm region in all treatments (Figure 4.9d and e). Between August and October 2003, NO_3-N levels at the 0-10cm depth decreased from 55 to 6 mg kg^{-1} in the M5000 plot, from 45 to 28 mg kg^{-1} in the cropped fertilizer plot, and from 16 to 6 mg kg^{-1} in the control plot. The NO_3-N concentration declined in all treatment plots at depth (105-120cm) indicating a loss of NO_3-N by leaching.

The high NO_3-N concentration (28 mg kg^{-1}) in the upper 30cm of the soil profile in the cropper fertilizer plot was not expected (Figure 4.9e). The NO_3-N distribution for the cropped fertilizer plot was expected to decline near the soil surface, similar to the other treatment. The high NO_3-N concentrations of these points may be due to an experimental error or spatial variability within the soil.

In October, the concentration of NO_3-N was significantly higher in the cropped fertilizer plot than the control in the upper 75cm (Figure 4.9e). The cropped fertilizer plot also had higher NO_3-N concentrations than the manure plot in the upper 75cm, although the difference was not significant. The manure plot did have higher NO_3-N concentrations than the cropped fertilizer plot below 75cm.

The application of different nitrogen sources, namely liquid hog manure and commercial fertilizer at an equivalent rate of total N, resulted in the accumulation of NO_3-N within the soil profile. While the distribution of NO_3-N was similar between the manure and cropped fertilizer plots, the concentration of NO_3-N within the soil profile was higher in the cropped fertilizer plot than the manure plot in the upper 75cm of the soil profile. The NO_3-N concentration was increased by the application of commercial fertilizer (i.e. 12 mg kg^{-1}) above both the control (ie.

2 mg kg^{-1}) and manure (ie. 6 mg kg^{-1}) plots at a depth of 75cm after two years. However below 75cm, the NO_3-N concentration was usually higher in the manure plot than the cropped fertilizer plot. The manure plot may not have supplied the crop with adequate nutrients resulting in reduce vigor and yield in wheat crop. This reduction in vigor and yield of the wheat could have resulted in less uptake of water and NO_3-N in the manure plot, thus allowing greater downward movement of water and NO_3-N. Although, nitrate-nitrogen leaching may have been as high or higher from the inorganic nitrogen source plot due to a higher accumulation of nitrate-nitrogen being leached during wet periods. The results indicate that the amount of inorganic nitrogen applied to a crop should be lower than an organic source of nitrogen due to higher available of inorganic nitrogen source

4.1.3.4 Changes in NO_3-N concentration over time

Figures 4.10 through 4.12 depict the changes in NO_3-N concentration that occurred in the control, M5000 and cropped fertilizer plots over the two years of this study. Figure 4.10 shows the changes that have occurred with the control plot. At the beginning of summer, NO_3-N concentrations ranged from 4 mg kg^{-1} at the soil surface to 2 mg kg^{-1} at depth (Figure 4.10a). The relatively low concentrations of NO_3-N in spring within the soil profile indicate the poor fertility of the Fairland Loamy Sand soil.

By July, the amount of NO_3-N in the soil profile decreased dramatically, in part due to uptake of NO_3-N by the crop. A significant decline in NO_3-N concentration from 5 to less than 2 mg kg^{-1} occurred within the 45-60cm section of the soil profile. However, the changes in NO_3-N concentration were not limited to the extent of the wheat roots (probably about 75cm in depth at this time in the growing season) as NO_3-N levels declined below the root zone. This decrease in NO_3-N concentration at depth from June to July could be due leaching. However, the dryness of the growth season and the vigorous use of water by wheat at this growth stage may not be conducive to nitrate leaching at depth.

By September and into October, NO_3-N levels through the soil profile increased, with greater increases occurring near the soil surface (0-30cm) than at depth. The increase in NO_3-N from the mineralization of soil organic N was due to the wetting/drying soil moisture cycles within the soil profile (Campbell et al., 1984). The greater increases in NO_3-N concentration were due to higher levels of soil organic matter near the soil surface, which contains the soil organic N.

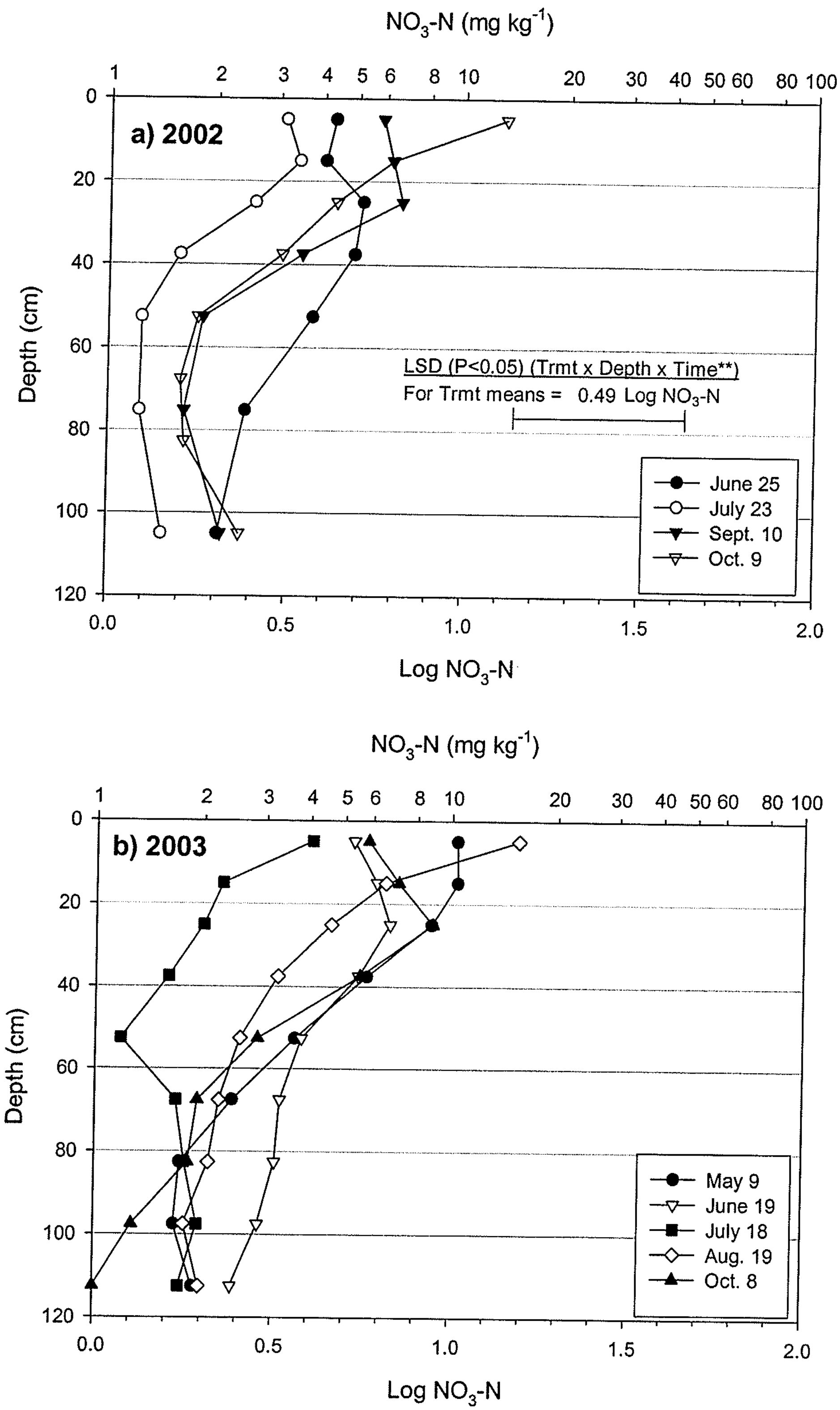


Figure 4.10: Comparison of NO_3-N distribution in the Control plot over time.

The lack of soil water uptake by crop could have led to downward movement of NO_3-N to lower depths. In October, NO_3-N concentration increased slight at the soil surface (0-10cm) and decreased in the soil sections just below the soil surface (Figure 4.10a). This change in NO_3-N concentration could be the result of soil water evaporation moving NO_3-N upward in the soil profile (Campbell et al., 1987).

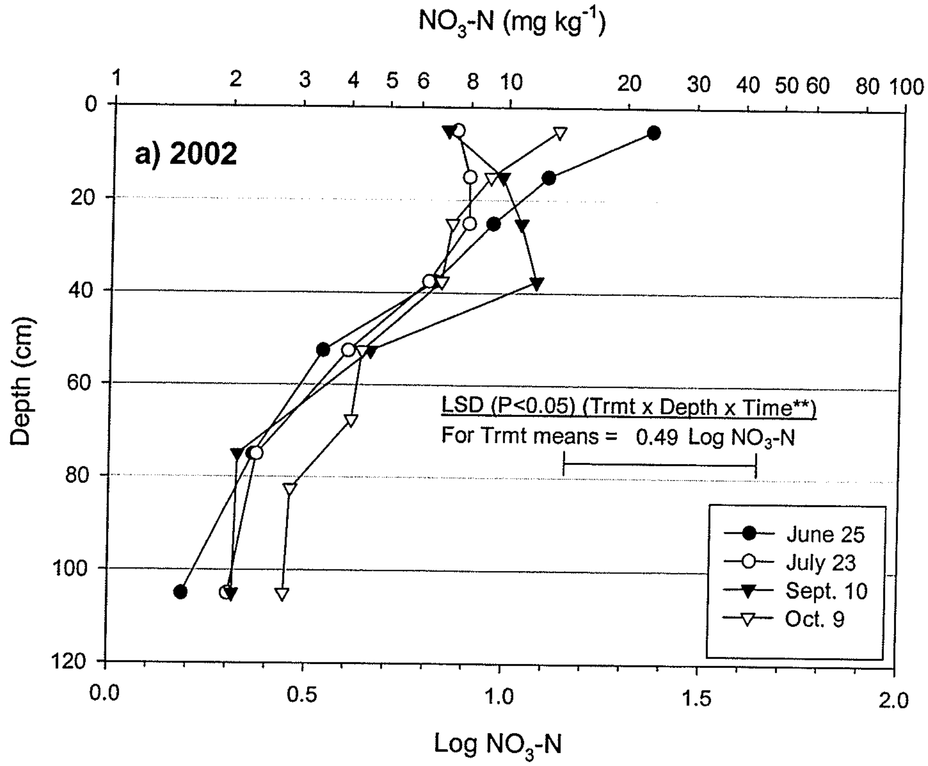
In May 2003, the mineralization of soil organic N and its subsequent downward movement due to snowmelt and spring precipitation, increased NO_3-N concentrations at depth (Figure 4.10b). NO_3-N concentrations ranged from 10 mg kg^{-1} at the soil surface to a low of 2 mg kg^{-1} at depth. The water additions in spring transported NO_3-N downward in the soil profile, however little if any NO_3-N was leached at this time since NO_3-N concentrations do not appear to have changed much at depth from October 2002 to May 2003. This result was confirmed by the lysimeter where no leachate was collected under the control plots before the May 9th sampling date (Figure 4.18).

The patterns of NO3-N distribution in the control plot were similar in 2003 to 2002. By June, NO_3-N concentrations declined in the upper portion of the soil profile (0-60cm) and increased at depth due to the downward movement of soil water carrying the NO_3-N. This increase of NO_3-N at depth could lead to a loss of NO_3-N by leaching. The lysimeters confirmed that leaching losses occurred between May 9th and June 19th.

In July 2003, NO_3-N concentration declined throughout the entire root zone. In the upper 75cm, this decline was the result of NO_3-N uptake by the crop, however below 75cm, this decline was due to NO_3-N leaching. Mineralization in the upper 75cm increased NO_3-N concentrations by August, with little effect on NO_3-N concentration at lower depths. Above normal precipitation in September, transported NO_3-N downward, increasing NO_3-N concentrations in the upper 75cm, and reducing NO_3-N concentration below 75cm by leaching.

Figures 4.11 and 4.12 depict the changes in NO_3-N concentration in the intermediate rate of hog manure (M5000) and the cropped fertilizer plots, respectively. The changes in NO_3-N distribution for the M5000 and cropped fertilizer treatments were similar to the control plot, except the concentrations of NO_3-N are greater due to the treatment application.

In June 2002, the application of manure (M5000) resulted in high NO_3-N concentration near the soil surface decreasing with depth (Figure 4.11a). The concentration of NO_3-N ranged from 22 mg NO_3-N kg^{-1} near the soil surface to less than 2 mg NO_3-N kg^{-1} at depth (Figure 4.11a). By July 23rd, crop uptake of NO_3-N significantly reduced NO_3-N concentrations near the soil surface (0-10cm), and to a depth of 45cm. Unlike the control plot, NO_3-N concentrations did not decline at depth in the M5000 plot, possibly due to greater downward movement of NO_3-N.



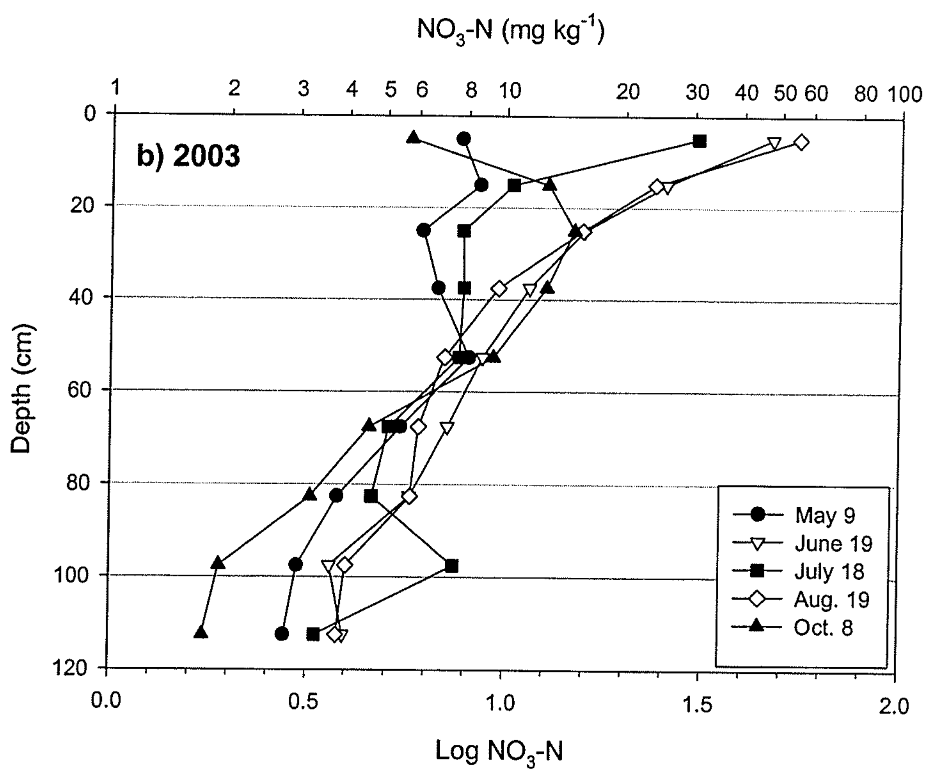


Figure 4.11: Comparison of NO_3-N distribution in the M5000 plot over time.

By September, mineralization had increased NO_3-N concentration in the upper soil layer (0-45cm), with little change in NO_3-N concentrations at depth. NO_3-N concentrations increased at depth by October due the downward movement of NO_3-N, from the upper portion of the soil profile, possibly leading to some losses of NO_3-N by leaching.

Between October 2002 and May 2003, NO_3-N concentration decreased in the upper 45cm of the soil profile leading to an increase in NO_3-N concentration below 45cm (Figure 4.11b). The application of manure in May dramatically increased the NO_3-N concentration throughout the soil profile, especially within the upper 45cm. After the application of manure, NO_3-N concentrations ranged from 48 mg NO_3-N kg^{-1} at the soil surface to 4 mg NO_3-N kg^{-1} at depth. These NO_3-N concentrations are higher than the NO_3-N concentrations after the manure application in 2002, indicating the accumulation of NO_3-N within the soil profile from this treatment.

By July 2003, NO_3-N concentrations were reduced by crop uptake of NO_3-N in upper 60cm of the soil profile, while NO_3-N concentration increased at depth, similar to 2002 (Figure 4.11b). NO_3-N concentrations were increased by mineralization in the upper 45cm by August 2003, however the increase in NO_3-N was more considerable than in 2002. Consecutive applications of manure increase the amount of mineralizable nitrogen within the soil profile (Ndayegamiye and Côté, 1989).

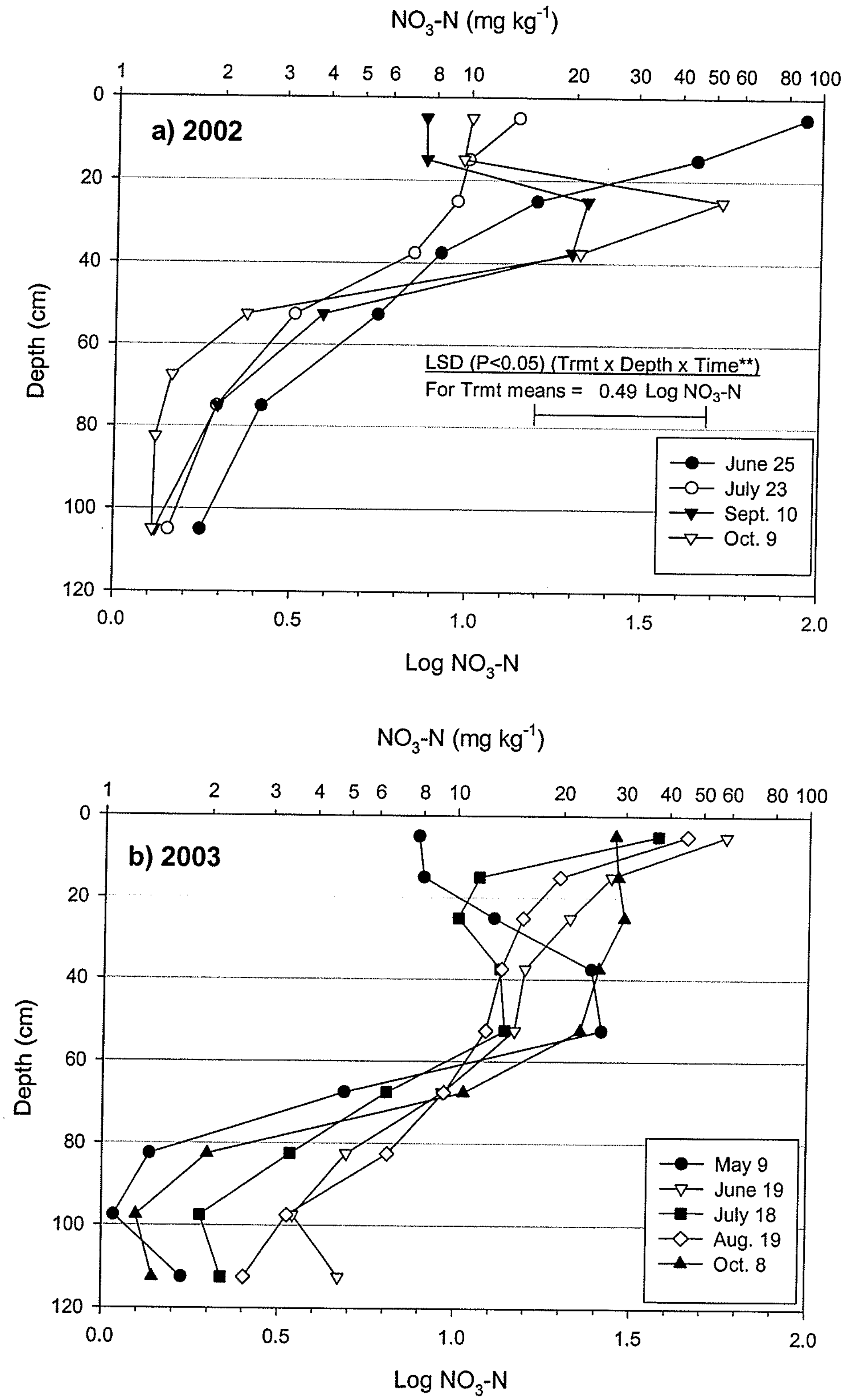


Figure 4.12: Comparison of NO$_3$-N distribution in the Cropped Fertilizer plot over time.

The above normal rainfall in September affected the NO_3-N distribution in the M5000 treatment in much the same way as the control treatment (Figure 4.11b). NO_3-N concentrations were reduced near the soil surface, by the downward movement of soil water. NO_3-N concentrations were also reduced at depth, indicating the leaching loss of NO_3-N from the soil profile.

The patterns of NO_3-N distribution in the cropped fertilizer plot during the two years of this study were similar to those in the control and M5000 plots. The concentration of NO_3-N in the cropped fertilizer plot was often higher than NO_3-N concentrations in the control and M5000 plot, especially in the upper 60cm of the soil profile (Figure 4.12). The cropped fertilizer plot had concentrations of NO_3-N ranging from 90 mg NO_3-N kg^{-1} near the soil surface to less than 2 mg NO_3-N kg^{-1} at depth in June 2002 (Figure 4.12a).

By July 2002, crop uptake of NO_3-N had significantly decreased NO_3-N concentrations near the soil surface (0-10cm) from 90 mg NO_3-N kg^{-1} to 14 mg NO_3-N kg^{-1} (Figure 4.12a). NO_3-N concentrations declined throughout the entire soil profile however declines at depth may not be the result of leaching, because of dry conditions and water use by the crop. Precipitation in August resulted in the downward movement of NO_3-N in the soil profile to a depth of 90 cm by September. The increase in NO_3-N concentrations in the upper 30cm of the soil profile may be due to mineralization (Campbell et al., 1984) or evaporation of the soil moisture carrying NO_3-N upward (Campbell et al., 1987).

Between October 2002 and May 2003, NO_3-N moved downward from near the soil surface to accumulate between 45-60cm in the soil profile, as well NO_3-N concentrations decreased at depth due to leaching losses (Figure 4.12b). The NO_3-N concentration in the cropped fertilizer plot ranged from 8 mg NO_3-N kg^{-1} at the soil surface to 1 mg NO_3-N kg^{-1} at depth, with a maximum concentration of NO_3-N (28mg NO_3-N kg^{-1}) within the 45-60cm soil section. The application of fertilizer in May increased NO_3-N concentrations near the soil surface by June 2003, while soil water transported the accumulated NO_3-N to depth, increasing the NO_3-N concentration and possibly removed some NO_3-N from the root zone. Weed and Kanwar (1996) found that a dry year may not result in the loss of nitrate-nitrogen, only the accumulation. The accumulation of solute in the soil profile leads to leaching losses during periods of high moisture, such as wet seasons or years (Younie et al., 1996).

Crop uptake of NO_3-N reduces NO_3-N concentrations within the upper 60cm of the soil profile, while NO_3-N concentrations decreased at depth due to leaching (Figure 4.12b). NO_3-N concentrations increased throughout the soil profile between July and August 2003. This increase was due to soil organic nitrogen mineralization in upper 45cm of the soil profile and the downward movement of NO_3-N below 45 cm. By October, high concentrations of NO_3-N ($\approx$25 mg NO_3-N kg^{-1}) had accumulated in the upper 60cm of the soil profile, while September precipitation reduced NO_3-N concentration at depth through leaching.

After two years of this study, the resulting NO_3-N levels within the control plot were similar to NO_3-N levels at the beginning (Figure 4.10). The maximum concentration of NO_3-N for all plots occurred in the 20-30 cm soil section at concentrations of 9, 15 and 30 mg NO_3-N kg^{-1} for the control, M5000 and cropped fertilizer treatments, respectively. Treatments of hog manure and commercial fertilizer resulted in increased NO_3-N levels throughout the soil profile, especially in the upper 75 cm (Figure 4.11b and 4.12b). All treatments showed similar patterns of NO_3-N distribution in the soil profile due to crop uptake of NO_3-N, mineralization of soil organic nitrogen and soil water movement. The result was that each treatment showed signs of NO_3-N leaching losses.

4.1.4 Mehlich-3 P Distribution

4.1.4.1 Changes in Cumulative Soil M-3 P in 2002 and 2003

Table 4.3 shows the Mehlich-3 extractable phosphorus (M3P) content within the 120 cm soil profile at various sampling dates during the two years of this study. The cumulative amount of M3P within the 120 cm before treatments were imposed was 72 kg ha^{-1}. The application of manure and fertilizer in May 2002 resulted in a significant treatment effect by the end of June, however the control is not significantly different than any of the other treatments. In fact even after the application of treatments, some of the plots (i.e. M2500, M5000 and cropped fertilizer) contained less M3P within the rootzone than the control plot. The highly variable nature of P within the soil may account for most of the differences between treatments on different sampling dates. Gerritse (1981) stated that P variability within the soil may be due to mineralization, which can vary considerably.

The amount of P applied to the plots was low relative (i.e 10, 19 and 29 kg ha^{-1}) to the amount of M3P originally in the soil. The application of hog manure will supply little mineralizable P as only 1-2% of the liquid hog manure was solid, and P is mainly contained within the solid portion of the manure. Generally the M3P content within the treatments tends to mimic the control plot, in that for the most part there is very little treatment effect.

Table 4.3: Cumulative Mehlich-III P within the root zone (120 cm)

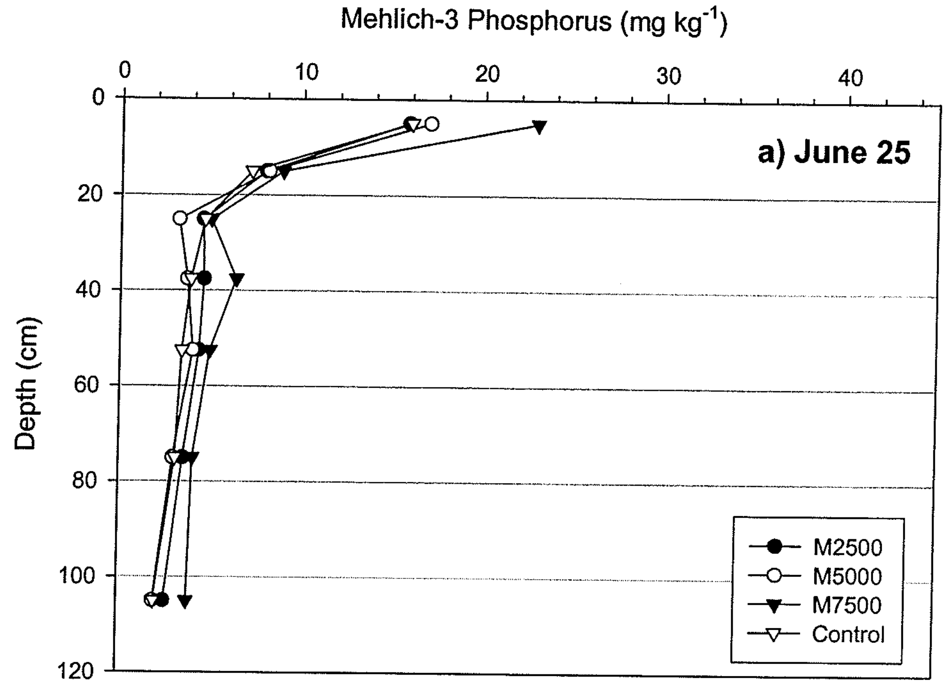
	25-Jun-02	23-Jul-02	10-Sep-02	9-Oct-02	9-May-03	19-Jun-03	18-Jul-03	19-Aug-03	8-Oct-03
Manure 2500 gal	88abc*	86	86b	79	77	102	90	110bc	77
Manure 5000 gal	79bc	79	92b	92	70	113	90	132a	77
Manure 7500 gal	114a	132	86b	80	73	117	107	126ab	89
Fertilizer (wheat)	68c	75	87b	70	68	105	83	92c	99
Fertilizer (fallow)	103ab	87	135a	92	96	99	95	119ab	73
Control	91abc	84	105b	76	68	83	89	99c	94

* - Means followed by different letters (a,b,c...) within a column differ significantly ($P<0.05$ Fisher's LSD means comparison)
** - Values are the means of four replicates.

4.1.4.2 Effect of Manure Rate on M-III P Distribution

Figures 4.13 and 4.14 show the distribution of M-III P concentration within the soil profile after liquid hog manure application. The application of hog manure did not result in a significant treatment x depth effect in June, however the data exhibits a definite increase in M3P with increasing rate of manure in the first 10 cm (Figure 4.13a). The concentration of M3P near the soil surface (0-10cm) for different treatments was 13, 16, 17 and 23 mg kg^{-1} for the control, M2500, M5000 and M7500 plots, respectively. The increase of M3P following phosphorus additions within the first soil sampling layer has been shown in other studies. Schoumans and Breeuwsma (1997) observed an increase of 3 to 15 mg P L^{-1} within the soil water of the topsoil after the application of manure. Also, Hountin et al. (1997) noted a significant linear rate effect on Total P and M3P following the long term application of manure with the maximum accumulation occurring in the topsoil.

By July 2002, the concentration of M3P under the M7500 treatment was higher than the other treatments to a depth of 45 cm, however the difference was not significant (Figure 4.13b). The increase of M3P at depth in the M7500 treatment may indicate P movement, however phosphorus is not very mobile. This increase in M3P concentration could possibly be the result of variability in soil P mineralization or spatial variability, as subsequent soil sampling does not indicate increased M3P levels at any depths below 10cm. The variability of phosphorus mineralization may also explain the large increase in the M5000 treatment, resulting in a significant treatment effect in September 2002 (Figure 4.13c). This increase is difficult to explain, as there is not a significant difference in soil moisture (Table 4.1) or crop uptake (Table 4.4). By October 2002, the distribution of M-III P is roughly the same as in June, except that the M7500 treatment is significantly greater than the control in the 0-10cm soil depth (Figure 4.13d).



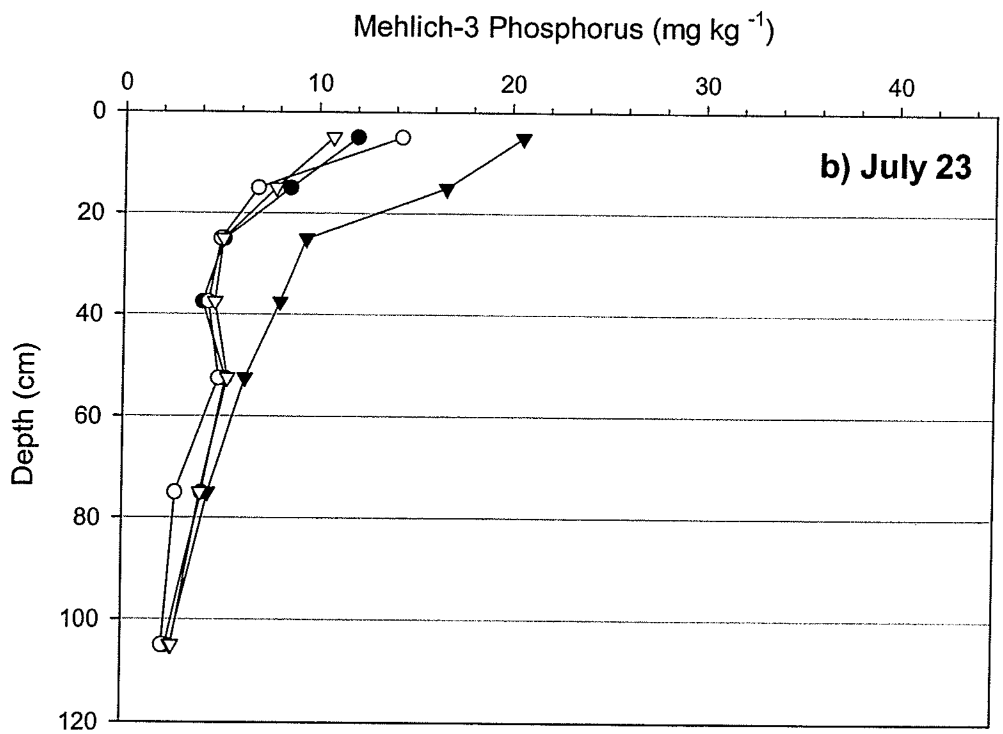
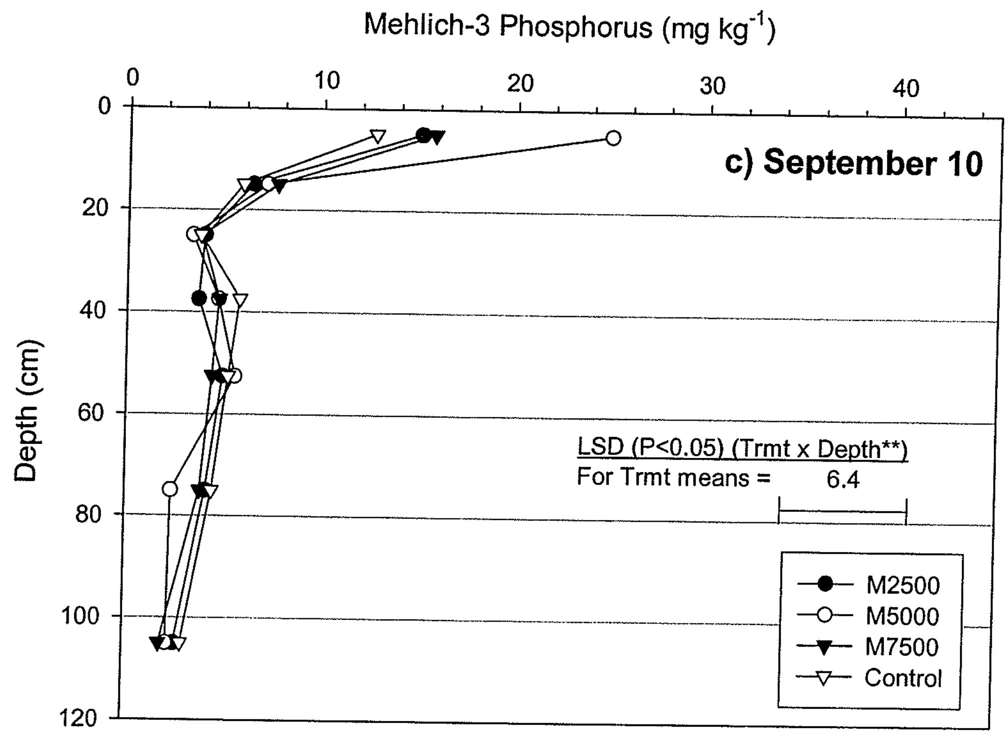


Figure 4.13: Comparison of M3P distribution in 2002 between plots receiving different rates of liquid hog manure.



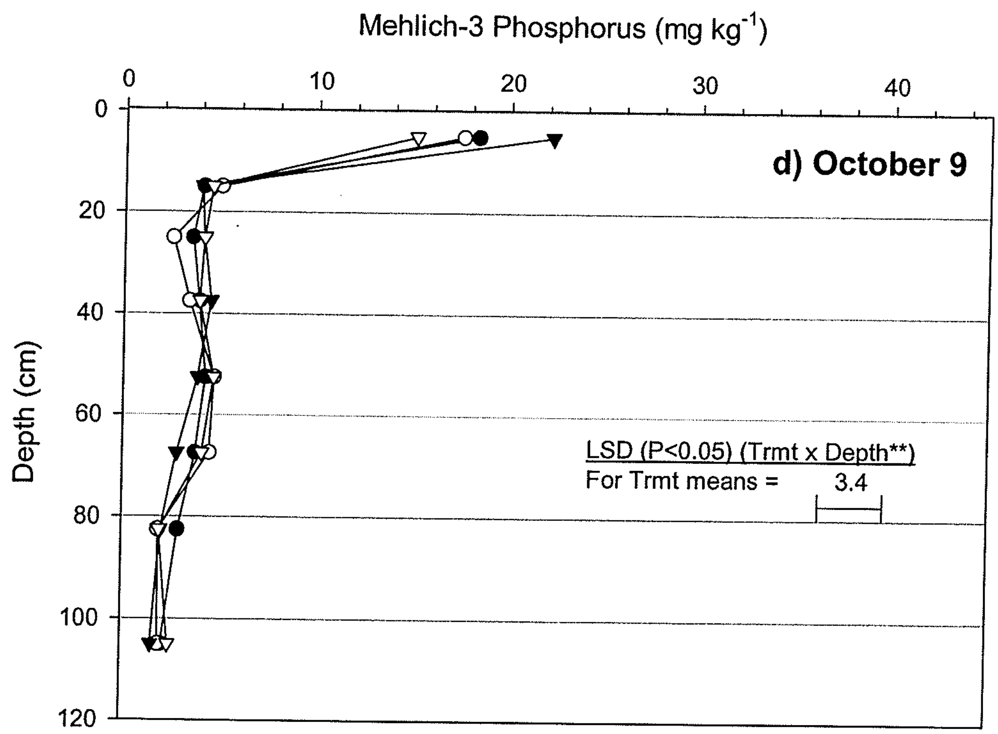


Figure 4.13: Comparison of M3P distribution in 2002 between plots receiving different rates of liquid hog manure.

In 2003, the M3P distribution within the soil profile was similar to M3P distribution in 2002 (Figure 4.14). The application of manure treatments resulted in a significant increase in M3P within the 0-10 cm soil layer at most sampling dates, and had little effect below this soil layer. The exception is a significant increase in M3P concentration at 60 cm within the M5000 treatment on August 19th (Figure 4.14d). This increase in M3P concentration is due to variability as there is no evidence of an increase in M3P concentration before or after this sampling date. The application of liquid hog manure resulted in an increase in M-III P concentration within the first soil sampling layer (0-10 cm) and had little effect on the lower soil profile during the two years of this study.

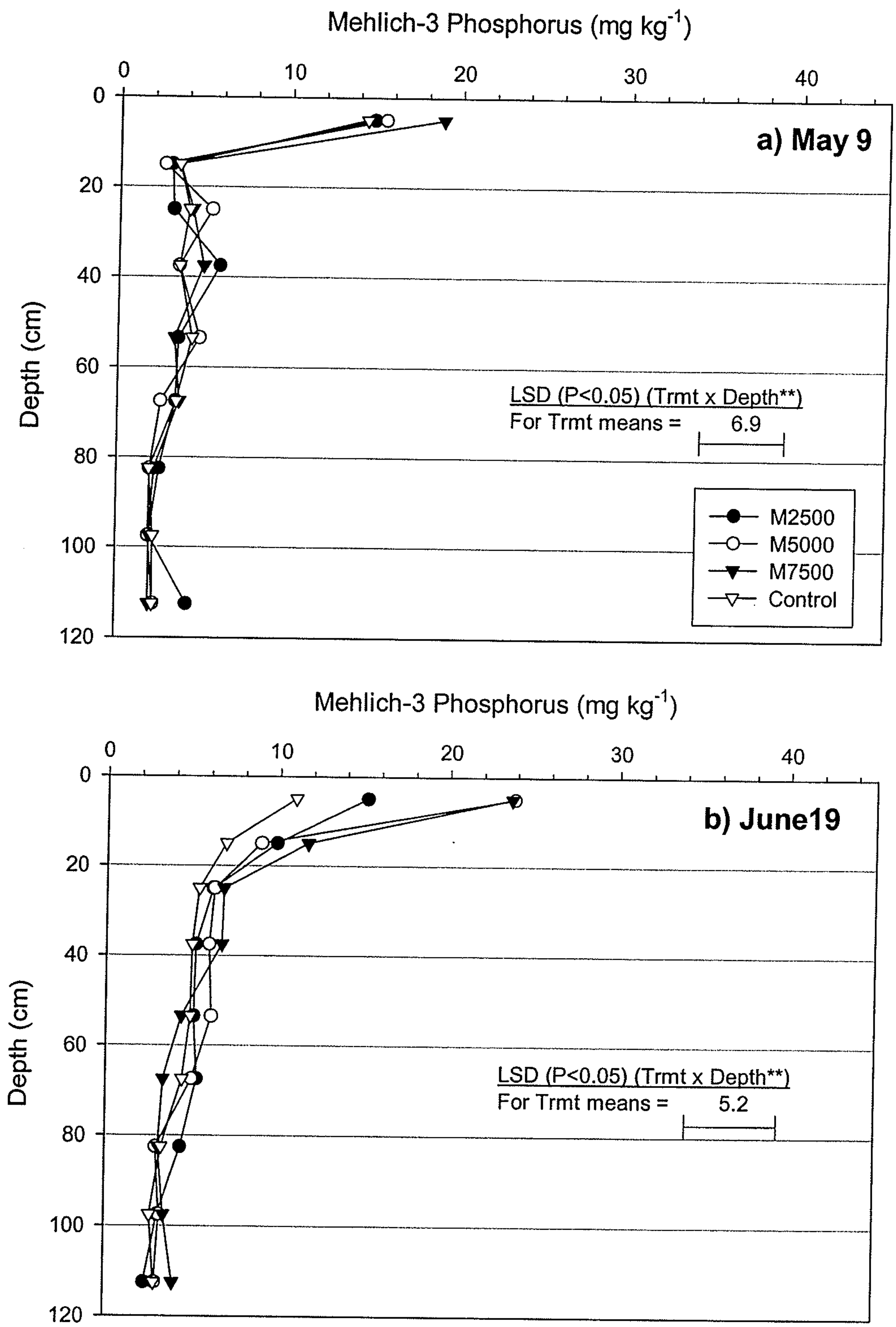


Figure 4.14: Comparison of M3P distribution in 2003 between plots receiving different rates of liquid hog manure.

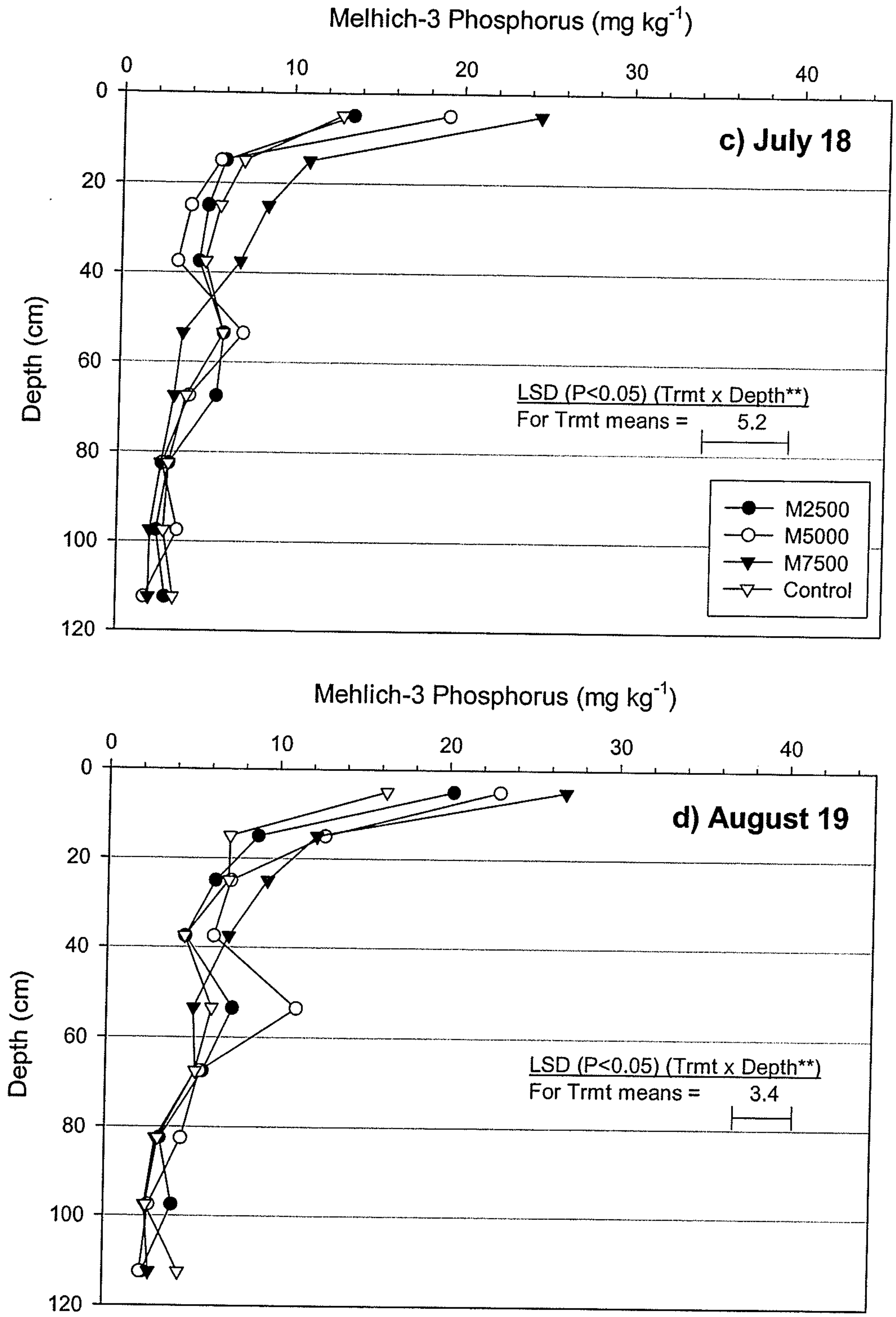


Figure 4.14: Comparison of M3P distribution in 2003 between plots receiving different rates of liquid hog manure.

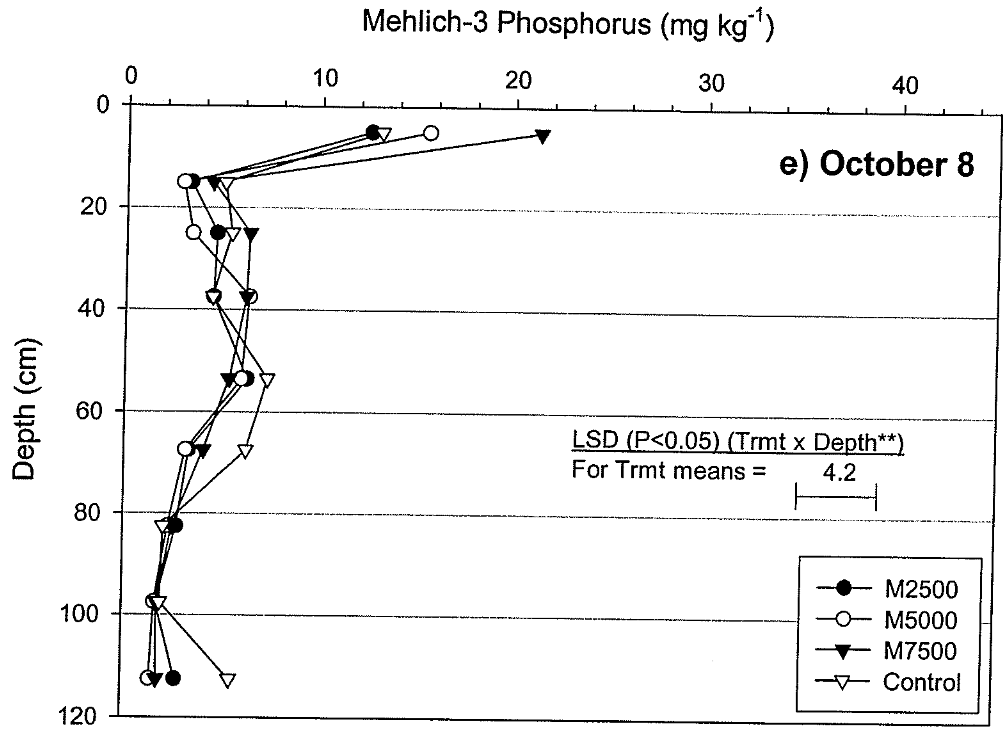


Figure 4.14: Comparison of M3P distribution in 2003 between plots receiving different rates of liquid hog manure.

4.1.4.3 Effect of P Source on M-III P Distribution

Figure 4.15 illustrates the distribution of M-III P within the soil profile in plots receiving equivalent rates of phosphorus from organic and inorganic sources under different cropping regimes in 2002. The application of the phosphorus resulted in wide variability between M3P concentrations from similar P sources, but little difference between different sources (M5000 vs. Fertilizer) (Figure 4.15a). The concentration of M3P varies between cropping systems even though the application of commercial fertilizer was at the same rate and source for the fertilizer and fallow plots.

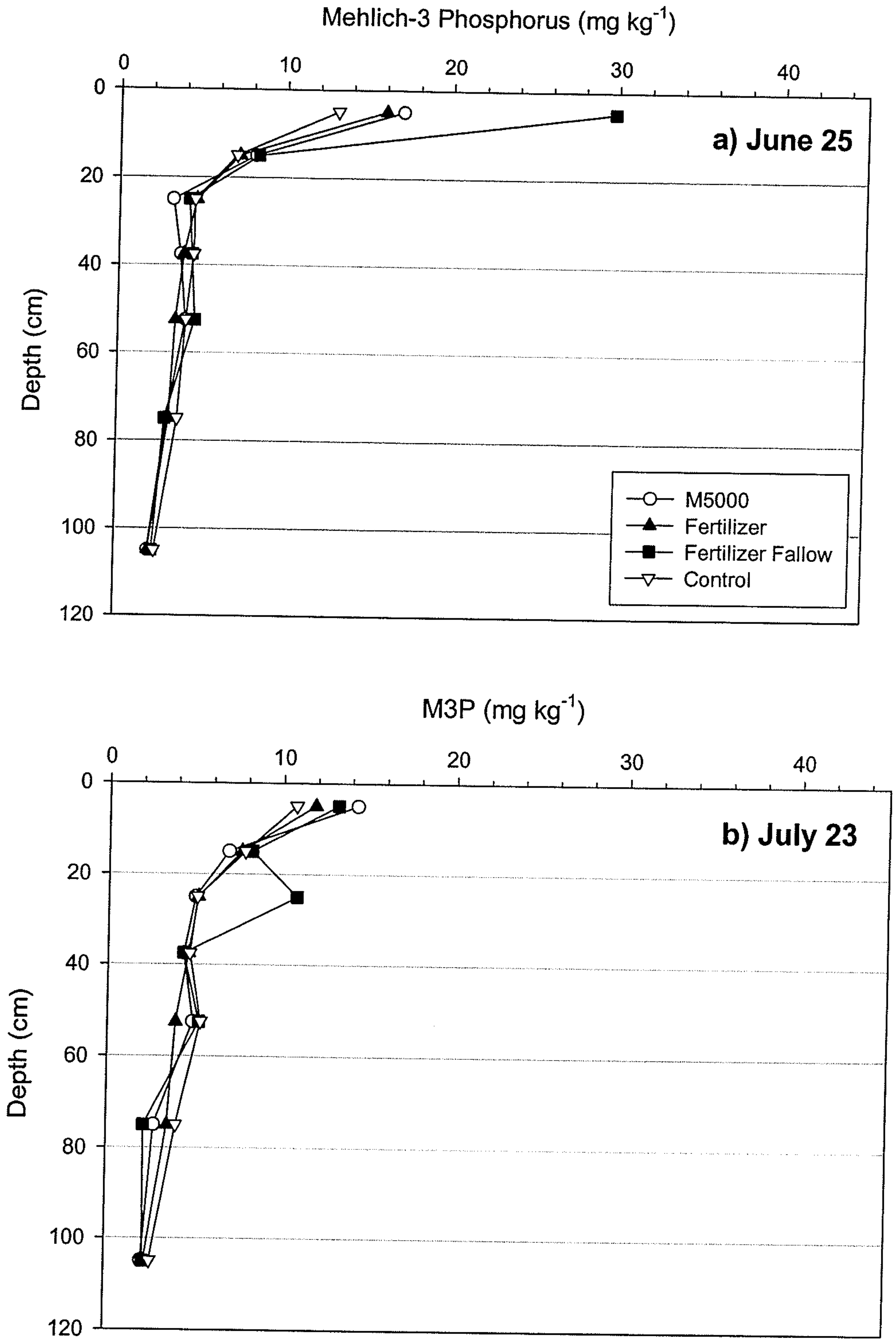


Figure 4.15: Comparison of M3P distribution between plots receiving equivalent amounts of phosphorus from liquid hog manure and commercial fertilizer under different cropping scenarios in 2002.

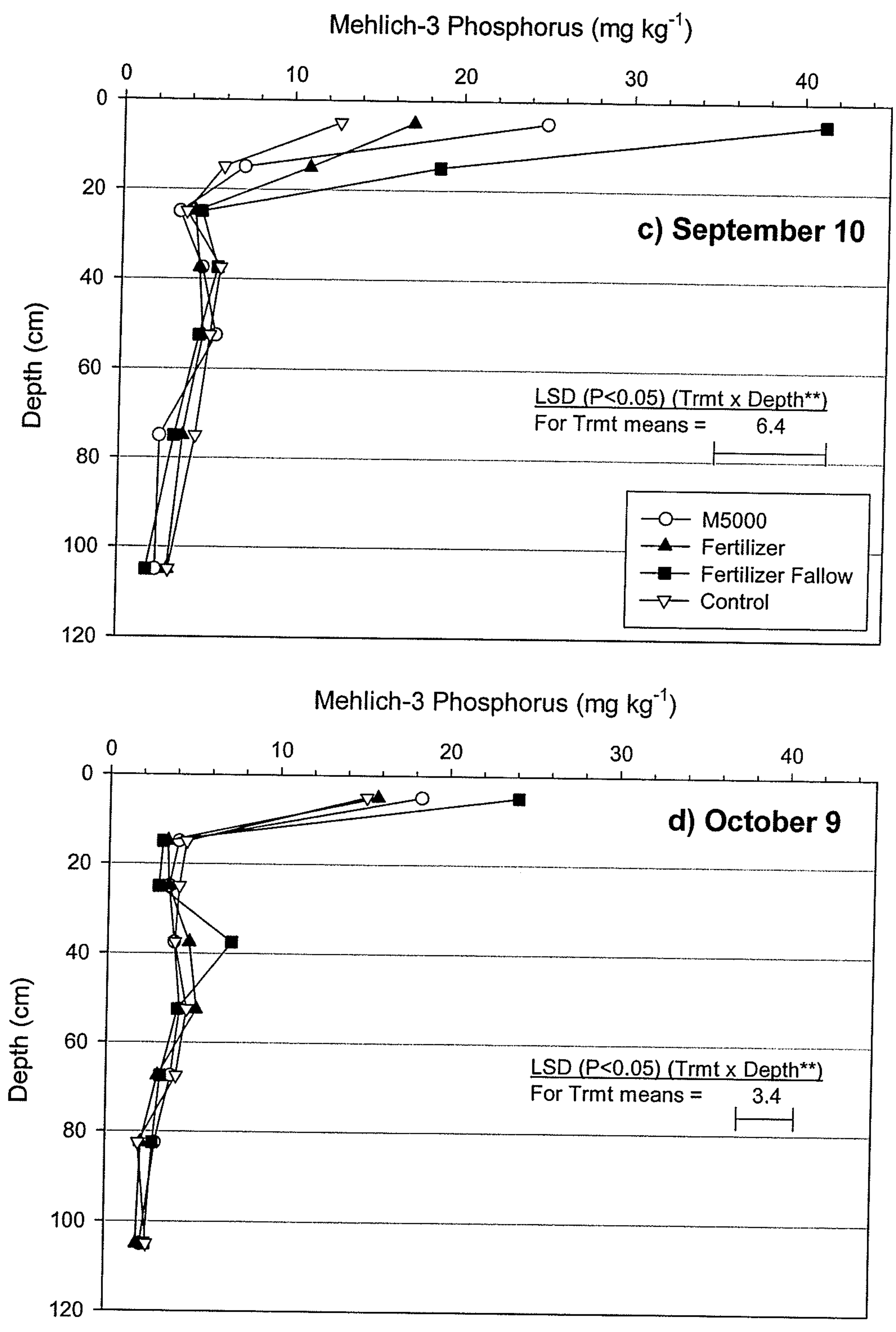


Figure 4.15: Comparison of M3P distribution between plots receiving equivalent amounts of phosphorus from liquid hog manure and commercial fertilizer under different cropping scenarios in 2002.

The variability of M3P concentration between cropping systems may be the result of spatial and sampling variability as a result of banding the phosphorus fertilizer granules with the seed, creating localized increases in M3P concentrations.

Figure 4.15b shows evidence of phosphorus movement under the fallow treatment. The M3P concentrations near the soil surface (0-10cm) decreased from 30 mg kg^{-1} in June to 13 mg kg^{-1} in July, resulting in an increase in concentration at the 30cm soil section.

By September, a significant difference in M3P concentrations was evident between the two sources of phosphorus (i.e. manure and commercial fertilizer) (Figure 4.15c). The M3P concentrations near the soil surface for the manure and cropped fertilizer plots were 25 and 17 mg kg^{-1}, respectively. This difference is due to P mineralization. The fertilizer fallow plot had an M3P concentration significantly greater than all other treatments near the soil surface. The higher mineralization rate in fallow fertilizer plot was due a greater amount of soil moisture in the fallow versus cropped plots.

By October 2002, M3P distribution within the soil profile is similar to levels at the June 2002 sampling date due to immobilization of P and possibly some downward movement of P (Figure 4.15a and d). Below 20 cm the P has not changed much, except for the significant concentration of M3P at 45 cm under the fallow treatment (Figure 4.15d). This high concentration of M3P at 45 cm may be evidence of some M3P movement. In the top 10 cm, the fallow treatment exhibits a significantly higher M3P concentration than the control or cropped fertilizer plots. The M3P concentration is not significantly different when comparing the source of the phosphorus.

Soil sampling in the spring of 2003 shows an increase in M3P concentration under the fallow treatment due to moist soil conditions in the fall of 2002 and spring of 2003, however very little change is evident in the other treatments (Figure 4.16a). The application of manure and fertilizer resulted in a significant increase in M3P concentration in the upper 10 cm of the M5000 and cropped fertilizer plots (Figure 4.16b). No fertilizer was added to the fallow plot in 2003.

Between July and October of 2003, M3P distribution within the soil profile was similar to 2002 (Figure 4.16c – e). Changes in M3P concentrations occurred mainly near the soil surface (0-10cm) and were mainly due to P soil interactions, such as mineralization and immobilization. After two years of this study, the distribution of M3P within the soil profile was not much different than the background concentrations, where the 0-10 cm soil depth was 15 mg kg^{-1} and the remaining profile had a concentration of 4 mg kg^{-1} (Table 3.1). In comparison, on October 9, 2003, averaging all treatments, the 0-10cm depth had a M3P concentration of 18 mg kg^{-1} and the remaining soil profile had a concentration of 5 mg kg^{-1} (Figure 4.16e).

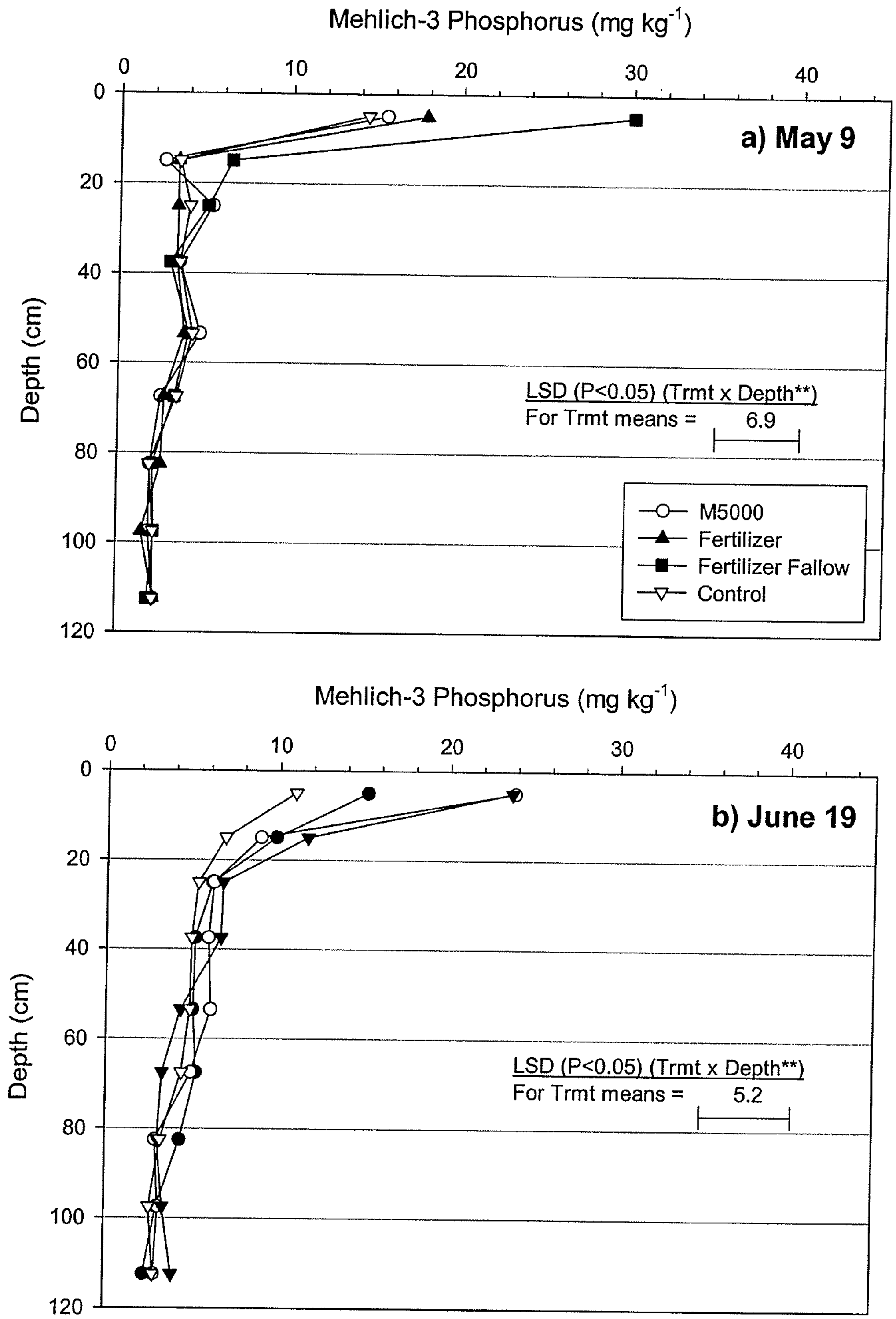


Figure 4.16: Comparison of M3P distribution in 2003 between plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios.

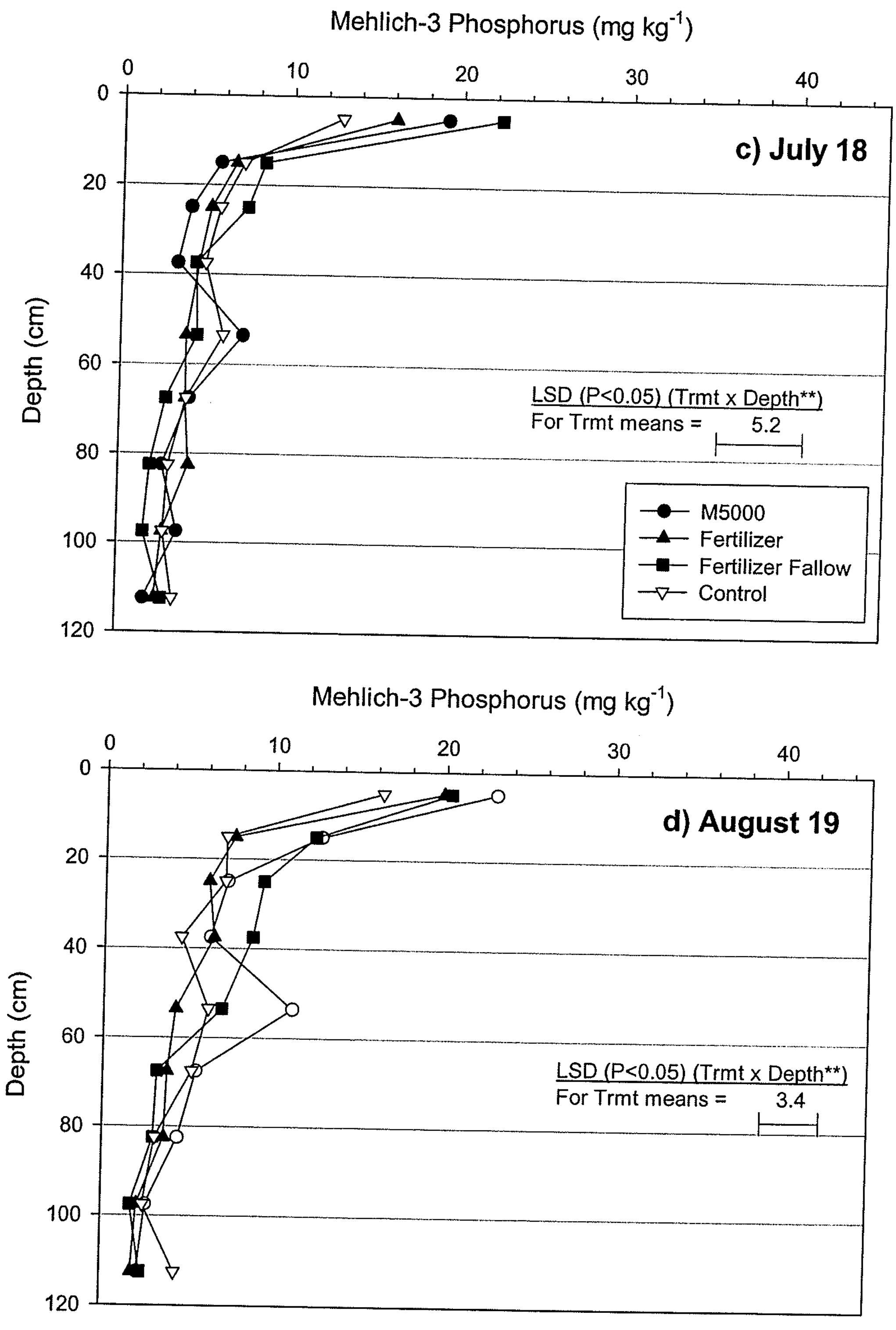


Figure 4.16: Comparison of M3P distribution in 2003 between plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios.

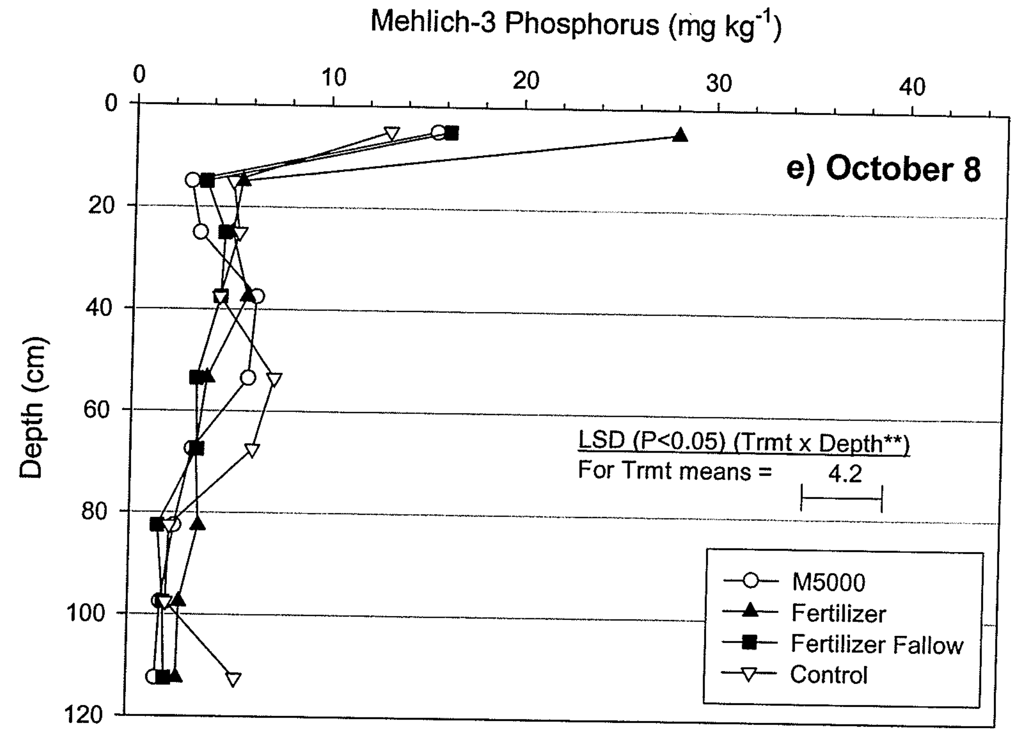


Figure 4.16: Comparison of M3P distribution in 2003 between plots receiving equivalent amounts of nitrogen from liquid hog manure and commercial fertilizer under different cropping scenarios.

The application of treatments did increase M3P concentrations in the 0-10 cm soil layer, however treatment effects were not evident beyond the surface layer. From the soil sampling data, M3P does not appear to have been lost from the soil profile due to leaching, and the lysimeter does not show any losses of phosphorus due to leaching (data not shown). Chardon (1997) observed very little P (0.5 to 0.8% of applied P) in a leaching experiment using 70 cm of sandy soil.

Heckrath et al. (1995) suggested that measuring P using a bicarbonate extraction solution (Olsen P) can be a good indicator of P leaching. These authors observed that a change point occurred above 57 mg Olsen-P kg^{-1}, after which an increase in P leaching losses occurred. Olsen-P was measured for the upper to soil layers (0-10 and 10-20 cm) at our site, and most samples indicated very little Olsen-P with the greatest concentration being 15 mg Olsen-P kg^{-1}. The results obtained from the M3P and Olsen-P analysis methods would suggest that minimal leaching of P occurred during 2002 and 2003.

4.1.5 Wheat Yield and N uptake

Table 4.4 shows that wheat yields were not significantly affected by the application of treatments in 2002, although yields in the fertilizer treatment were higher than all other treatments. A possible reason for no significant treatment effect was the higher variability between replicates, especially comparing block 1 to the other blocks (Appendix F). The site had a gentle slope (~1%) with block 1 at the top of the rise and block 4 towards the bottom of the slope. The spatial variability of the soil properties, with the top of the knoll having the poorest soil may have contributed to the variability in wheat yield data in 2002. The yield patterns and variability in 2003 were similar to that in 2002 (Table 4.4). In 2003, wheat yields were slightly lower than 2002 due to below normal rainfall during the growing season. In both 2002 and 2003, wheat yields were significantly affected by precipitation amounts, as yields were one-half of expected values (Manitoba Agriculture, 2004). Mooleki et al. (2002) observed decreases in crop yield when insufficient moisture in May and July stressed the plants.

Table 4.4: Total wheat yield and amount of N uptake

Treatment	Wheat Grain Yield (kg ha^{-1})	Annual N Application (kg ha^{-1})	Annual P Application (kg ha^{-1})	N uptake by Wheat (kg ha^{-1})	P uptake by Wheat (kg ha^{-1})	Apparent N recovery (%)*	Total NO_3-N 0-120cm (kg ha^{-1})**
				2002			
M2500	1207a	64	10	45b	5.8a	6.3	114bc
M5000	1256a	129	19	49ab	6.0a	6.2	94bc
M7500	1299a	195	29	56ab	7.1a	7.7	136b
Fertilizer	1567a	129	19	63a	8.2a	17.1	109bc
Control***	1096a	-	-	41b	6.0a	-	54c
				2003			
M2500	1059ab	64	10	41ab	4.2b	6.3	154bc
M5000	998b	129	19	36b	3.8b	-0.8	210ab
M7500	1073ab	195	29	43ab	4.4ab	3.1	306a
Fertilizer	1285a	129	19	48a	5.5a	8.5	205ab
Control	1042ab	-	-	37b	4.2b	-	66c

* - Apparent N recovery = (N uptake in Treatment - N uptake in Control) x 100 / N uptake in Treatment

** - Cumulative amount of NO_3-N within rooting zone at harvest

*** - Cumulative amount of NO_3-N before application of treatments in 2002 was 43 kg ha^{-1}

Although, wheat yields increased slightly with increasing rate of manure, the application of different rates of hog manure did not significantly increase the yield of wheat over the control plot in either 2002 or 2003. This result was not expected given the low fertility of the soil. Mooleki et al. (2002) found that wheat grain yield increased with increasing rates of liquid swine manure to a rate of 200 kg N ha^{-1}, and decreased thereafter in a field experiment in Saskatchewan.

In 2003, the highest wheat yield was in the fertilizer plot (1285 kg ha^{-1}), which was significantly higher than the M5000 plot (998 kg ha^{-1}). The reason for such low yields in the M5000 plot is unknown as the yield in the M5000 plot was lower than the control. Vos and van der Putten (2000) found that the source of nitrogen (manure vs. commercial fertilizer) did not cause a significant difference in yield of cereal crops (spring wheat and oats). Although, Yanan et al. (1997) observed that manure application resulted in lower yields in wheat crops over a

12 year study compared with yields from inorganic fertilizer. When comparing crop yield between manure and fertilizer treatments, the main consideration is the nature of the nitrogen source, and thus the availability of nitrogen to the crop (Angle et al., 1993; Mikkelsen, 1997). Manitoba Agriculture (2001a) suggests that of the total nitrogen supplied by liquid hog manure, approximately 80% will be available to the crop in the first year. This value includes the two fractions of nitrogen found in hog manure: ammonia, where the entire ammonia fraction is considered available (Beauchamp, 1986) and organic nitrogen, where about 25 to 30% is available in the first year of application.

None of the manure treatments had a significantly higher N uptake than the control in either 2002 or 2003 (Table 4.4). The amount of N uptake was slightly affected by the rate of manure applied in 2002, in that N uptake increases from 45 to 56 kg N ha^{-1} between the M2500 and M7500 plots. However, the difference between manure rates is not significant. The trend in 2003 is similar to 2002, although the differences in N uptake are smaller. The amount of N uptake in the M5000 plot is a reflection of the variability within the site discussed above. N uptake by the wheat was greater in the fertilizer plots than the manure plots in both 2002 and 2003 (Table 4.4). The fertilizer plot had significantly higher N uptake than the control plot in 2002 and 2003.

The apparent N recovery or N use efficiency by wheat was similar between manure treatments in 2002, 6.3%, 6.2% and 7.3% for the M2500, M5000, and

M7500 treatments, respectively (Table 4.4). The apparent N recovery in 2003 was similar for the M2500 treatment (i.e. 6.3%), however the values in the M5000 (i.e. – 0.8%) and M7500 (i.e. 3.1%) were lower than in 2002. These results contradict findings by Garand (1999) that the apparent N recovery of wheat treated with liquid swine manure was 5 and 17% in the first and second of a study, respectively. Muňoz et al. (2003) observed N recovery values of 5 to 6% for manure applied to corn. Mooleki et al. (2002) found that apparent N recovery decreased with increasing rates of manure. The highest recovery (50-60%) was at the lowest application rate (100 kg N ha^{-1}) and the lowest recovery (10-30%)was at the highest application rate (400 kg N ha^{-1}).

The apparent N recovery or N use efficiency by wheat was higher with fertilizer than with manure (Table 4.4). Although, the fertilizer plots only showed an apparent N recovery of 17% and 8% in the first and second year of the study, respectively. These values are well below historical N recovery data of 33% (Cowell and Doyle, 1993; Raun and Johnson, 1999) and approximately 50% (Malhi et al., 2001).

Crop growth is highly dependent upon the availability of nutrients and sufficient water. Drought conditions at Carberry prior to 2002 and during our field study reduced the nitrogen uptake and N use efficiency within the wheat crop. Gauer et al. (1992) determined that moisture conditions regulated fertilizer use efficiency more than rate of N fertilizer. When dry conditions are present, the use of fertilizer by crops is reduced (Cowell and Doyle, 1993), and nitrogen will accumulate within the soil profile (Deutsch and Lee, 1994; Morecroft et al., 2000). NO_3-N accumulation is evident at Carberry, especially in 2003 (the drier summer) where NO_3-N content within the soil profile was significantly greater in the M7500 and fertilizer plots than in the control plot (Figure 4.7e and 4.9e). The accumulation of NO_3-N within the soil profile can lead to the potential for leaching losses (Chang and Entz, 1996; Izaurralde et al., 1995; Muñoz et al., 2003; Racz, 1993).

4.2 Water and Nitrate Losses from the Lysimeter

4.2.1 Nitrogen Leaching Loss

In 2002, the lysimeters were sampled twice, on June 12 and August 28, however, no leachate was collected on either sampling date. The sampling protocol was to sample the lysimeters a few days after major precipitation events, however the fall of 2002 had below normal precipitation. In 2003, the lysimeters were sampled throughout the spring, summer and fall (Figure 4.10) resulting in the collection of leachate from seven of the 24 lysimeters. The most consistent production came from four lysimeters that were in fallow in 2002, two lysimeters with the highest rate of manure additions (7500 gal ac^{-1}) and a control plot without the addition of manure or fertilizer.

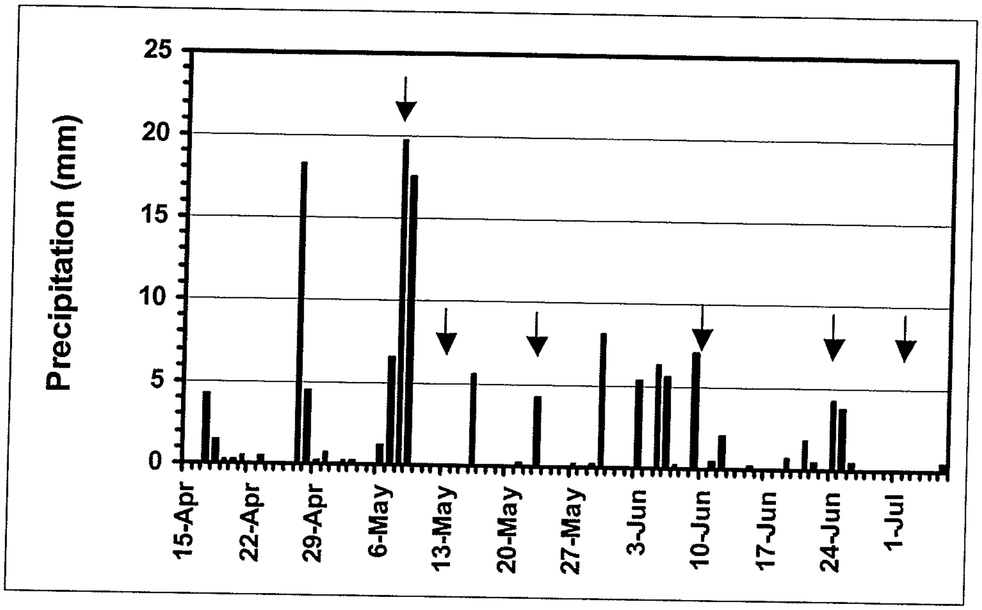


Figure 4.17: Precipitation amounts and lysimeter sampling dates (↓) at the experimental study site near Carberry MB in 2003.

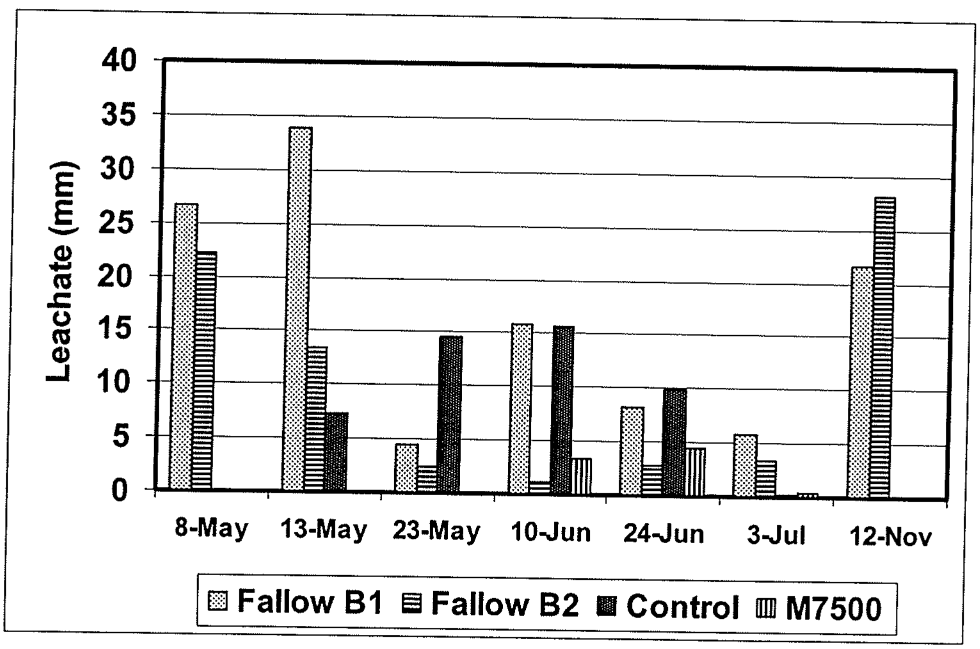


Figure 4.18: Amount of leachate collected on each sampling date from intact soil core lysimeters for selected plots near Carberry, MB in 2003.

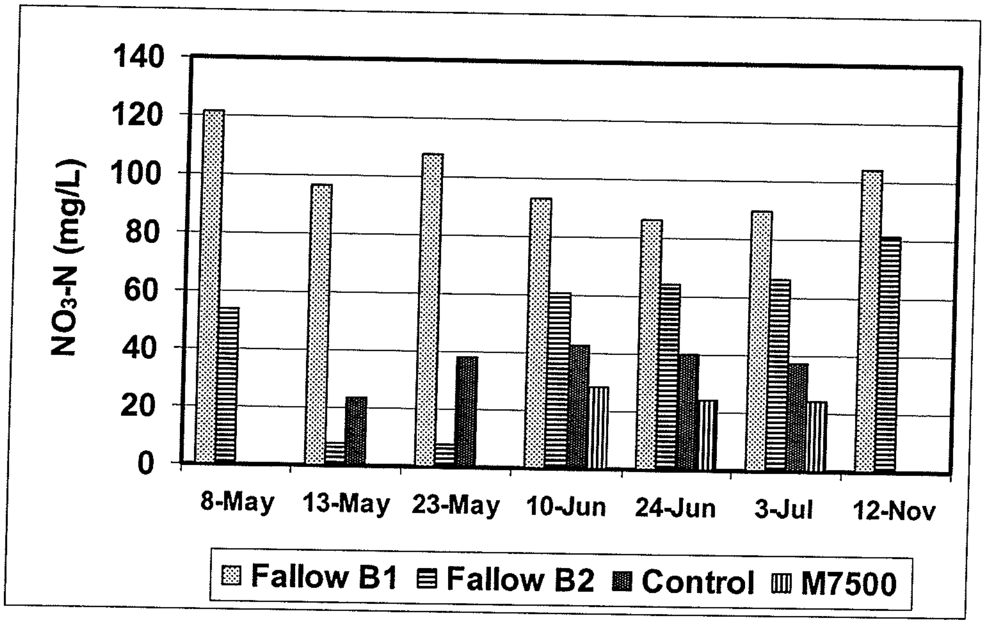


Figure 4.19: NO_3-N concentration collected in lysimeter leachate from selected plots near Carberry, MB in 2003.

On May 8th, the first leachate, representing spring recharge was collected from only two lysimeters in the two fertilizer fallow plots in block 1 and block 2 (Fallow B1 and Fallow B2) with leachate amounts of 27 and 22 mm of water (6.2 and 5.2 l, respectively) (Figure 4.18). The nitrate concentrations in the leachate were 122 and 54 mg L^{-1} (32 and 12 kg ha^{-1} NO_3-N, respectively) (Figure 4.19), which is well above drinking water standards of 10 mg NO_3-N/L (Water Quality Branch, 1995). Figure 4.17 presents precipitation events throughout the spring and early summer showing that between April 15th and May 8th more than 30 mm of precipitation was received at the study site. This precipitation, in combination with the relatively high soil moisture conditions following spring snowmelt, produced more than 20 mm of leachate from the root zone of the fallow plots. These values are similar to the predicted annual groundwater recharge rates for the ADA of 20 mm per year (Burton and Ryan, 2000). The ammonium concentration in this leachate was negligible while the phosphorus concentration was below the detection limit.

Figure 4.18 shows the leachate from the most productive lysimeters during the summer and fall of 2003, i.e., the two fallow plots, the control plot and the M7500 plot. The production of leachate from the fallow plots closely follows precipitation events and amount, as the soil water content was higher in these plots than either the control or M7500.

By May 13th, sufficient precipitation (Figure 4.17) had occurred that leachate was collected from the two fallow plots (34 and 13 mm) as well as from one of the control plot, which yielded leachate of 7 mm (1.7 l) with a nitrate concentration of 23 mg L^{-1} (2 kg ha^{-1}). The NO_3-N content of the leachate for the fallow plots was 97 and 7 mg L^{-1} (33 and 1 kg ha^{-1}) (Figure 4.18). By June 10th, the lysimeter treated with M7500 produced small amounts of leachate. The control and M7500 lysimeter show a delay in leachate production because these plots contained slightly less soil water than the fallow plots (Table 4.1).

By November, the two most productive fallow lysimeters had yielded a total of 116 and 73 mm of leachate containing 119 and 41 kg ha^{-1} nitrate-N, respectively. The amount of NO_3-N leached from the fallow plot in block 1 (119 kg ha^{-1}) is equivalent to the amount of nitrogen applied to the plot in the spring of 2002, indicating the rapid movement of NO_3-N even in a year with below normal precipitation amounts. The other two fallow plots (in blocks 3 and 4) produced leachate during the summer and fall totaling 9 and 3 mm of leachate containing 4 and 0 kg NO_3-N ha^{-1}. The control and M7500 plots had yielded 48 and 8 mm of leachate containing 18 and 2 kg NO_3-N ha^{-1}, respectively.

Leachate amounts were greater in spring and fall and small during the growing season (i.e. June, July and August) (Figure 4.18). This was consistent with documented occurrences for leaching losses in temperate regions (Owens et al., 2000). Gasser et al. (2002) determined that nitrate fluxes were moderate during cropping season, highest in fall, and lowest in winter-early spring in a study conducted in a humid region (Quebec). While leachate amounts were greater in spring and fall, the concentration of NO_3-N in the leachate was reasonably consistent within the leachate (Figure 4.19).

One of the possible reasons for the limited production of leachate from many of the lysimeters may be the variability of soil texture within the field plot. A comparison of the texture within plots illustrates the considerable variability of soil texture throughout the soil profile (Table 4.5). The upper 75-90 cm of soil is a fine sandy loam that overlays a 15-30 cm section of loam soil. The thickness of the loam and depth at which it occurs varies throughout the field and influences leaching volumes within the lysimeters. The loam section occurs deeper in the soil profile and is thinner near the top of the knoll, which is the location of block 1

Table 4.5: Soil Texture for selected plots at Carberry field plot

	Depth	Sand	Silt	Clay	Soil Texture
Plot 3 Block1	0-10	83.7%	1.4%	14.8%	Loamy Sand
	10-20	81.7%	6.0%	12.3%	Sandy Loam
	20-30	88.0%	1.1%	10.9%	Loamy Sand
	30-60	93.3%	0.5%	6.2%	Sand
	60-90	88.8%	5.3%	5.9%	Sandy Loam
	90-120	69.4%	19.7%	10.9%	Sandy Loam
Plot 8 Block 2	0-10	81.8%	5.4%	12.8%	Sandy Loam
	10-20	84.5%	6.1%	9.4%	Loamy Sand
	20-30	88.1%	3.6%	8.2%	Loamy Sand
	30-60	94.5%	3.5%	2.0%	Sand
	60-90	68.7%	15.3%	16.0%	Sandy Loam
	90-120	59.7%	23.2%	17.1%	Sandy Loam
Plot 17 Block 3	0-10	71.4%	17.9%	10.7%	Sandy Loam
	10-20	56.6%	27.2%	16.2%	Sandy Loam
	20-30	53.1%	34.2%	12.7%	Sandy Loam
	30-60	54.1%	26.1%	19.8%	Sandy Loam
	60-90	77.7%	8.6%	13.7%	Sandy Loam
	90-120	29.5%	43.9%	26.5%	Loam
Plot 22 Block 4	0-10	73.4%	16.4%	10.2%	Sandy Loam
	10-20	63.3%	24.8%	11.9%	Sandy Loam
	20-30	41.6%	38.7%	19.8%	Loam
	30-60	56.2%	27.9%	15.9%	Sandy Loam
	60-90	37.0%	35.3%	27.7%	Loam
	90-120	24.7%	49.3%	26.0%	Loam

and the trend reverses in the low slope position (block 4) (Table 4.5). The effect of the soil variability can be seen in the leachate results of the fallow plots (Appendix G). The amount of water and nitrate varied from greatest amounts at the top of the knoll (plot 4, block 1) to the least at the lower slope position (plot

19, block 4). As soil texture is an important factor leading to NO_3-N leaching (Stout et al., 1998), spatial variability of the soil texture may be a contributing factor to leachate variability.

Another possible reason for the lack of leachate from so many of the lysimeters is the type of lysimeter used. We have employed the use of large soil core lysimeters with zero-tension in the collection portion of the lysimeter, relying on gravity and the amount of soil water to provide the transfer of soil water from the soil into the collection area. Zhu et al. (2003) compared two types of lysimeters, zero-tension pan and passive capillary wick lysimeters. The wick lysimeter collected significantly more percolate than the pan lysimeter. The resulting collection efficiency of percolation water was found to be near 100% for the wick lysimeter, and only 40% for the zero-tension pan lysimeter.

4.2.2 Dissolved Organic Carbon Leaching Loss

Figure 4.20 shows the concentration of dissolved organic carbon (DOC) collected in the leachate. DOC concentrations are highest with the initial flush of leachate and then decrease during subsequent leaching events. The main period of leaching loss for DOC is during the spring leaching event as opposed to nitrate, which has main periods of leaching loss during the spring and the fall. The loss of DOC from the root zone may lead to the loss of NO_3-N at depth, as the presence of organic carbon is a prerequisite for denitrification (Angle et al., 1993; Campbell et al., 1984; Rochette et al., 2000).

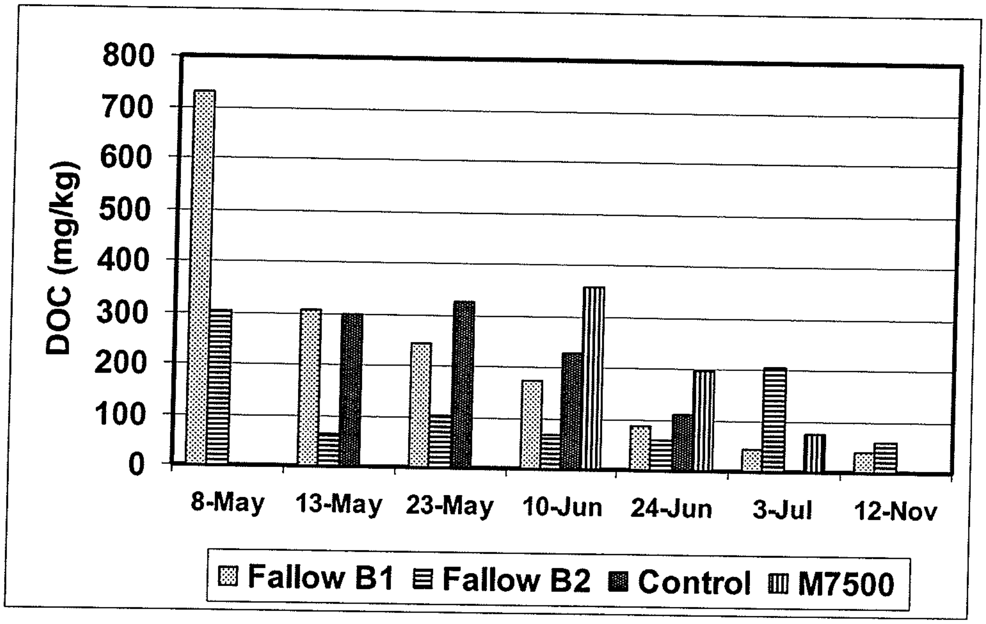


Figure 4.20: Dissolved organic carbon (DOC) concentrations collected in lysimeter leachate from selected plots near Carberry, MB in 2003.

4.2.3 Lysimeter Study Summary

While leachate containing nitrate was expected from the fallow lysimeters as a result of fertilizer addition and water accumulation in 2002, the amount of water (48 mm) and nitrate (18 kg ha^{-1}) leached from the control lysimeter shows that soil organic matter breakdown can result in loss of nitrate from these sandy soils without the additions of fertilizer or manure. While the soil sampling data shows possible evidence of NO_3-N leaching losses from the control and M7500 plots, the lysimeters confirm that NO_3-N losses did occur under these treatments. Comparing the NO_3-N leaching losses values from the lysimeters of the control and M7500 plots would indicate that a NO_3-N loss from the M7500 plot was from soil residual nitrogen and not from added manure. The combination of the soil sampling and lysimeter studies can provide a better overall understanding of NO_3-N dynamics within the soil profile.

5. SUMMARY AND CONCLUSIONS

The objective of this study was to determine how the application of different nutrient sources to an agricultural system affects the potential for nutrient leaching and which method of measuring nutrient leaching gives a better representation of the nitrogen dynamics in the soil. A field study was used to investigate the distribution of nutrients within the soil and the fate of nutrients, particularly the losses via leaching. Three rates of liquid hog manure (2500, 5000 and 7500 gal ac^{-1}) and one rate of commercial fertilizer (i.e. similar in Total nitrogen to the 5000 gal ac^{-1} manure treatment) were applied to field plot to determine nutrient rate and source effects on nutrient movement within the soil profile.

The overall dry climatic conditions during the two years of this study, limited the response of the crop to the nutrient additions. The crop yields from plots receiving nutrient additions did not significantly differ from the control plot in both study years. As well, the application of different rates of hog manure did not produce significant crop yield responses in either study year, although crop yield did increase with increasing rate of hog manure. The application of hog manure compared to commercial fertilizer did not result in a significant difference in crop yield the first study year, however, in second study year the crop that received commercial fertilizer had a significantly higher yield than the crop that received hog manure.

The application of liquid hog manure and commercial fertilizer affected the distribution and cumulative amount of nitrate-nitrogen within the soil profile. Nitrate-nitrogen concentrations were highest near the soil surface and decreased with depth. The addition of water, through precipitation, resulted in the downward movement of nitrate-nitrogen within the soil profile. The application of different rates of hog manure increased nitrate-nitrogen concentrations above the control throughout most of the root zone. There was a distinct rate effect, where nitrate-nitrogen concentrations within the soil profile increased within increasing rates of hog manure application. The application of 7500 gal ac^{-1} of hog manure is not recommend under these low moisture conditions due to the significantly higher nitrate-nitrogen concentrations than the control, indicating that excessive amounts of hog manure have been applied. Because all hog manure treatments appeared to have nitrate-nitrogen leaching losses after two years, the 2500 gal ac^{-1} rate of hog manure is recommended to reduce the amount of nitrate-nitrogen lost.

The application of different sources of nitrogen (i.e. liquid hog manure and commercial fertilizer) increased nitrate-nitrogen concentration within the root zone of the soil profile. Crop yields in the plots receiving the commercial fertilizer were higher due the greater availability of nutrients from the inorganic source compared to the organic nutrient source (i.e. liquid hog manure). The greater crop yields in the commercial fertilizer plots required greater amounts of soil water, thus limiting the amount of soil water available to transport nitrate-nitrogen. The downward movement of nitrate-nitrogen was limited in the commercial fertilizer plots because of this reduction of soil water in the soil profile. As such, nitrate-nitrogen tended to accumulate in upper portion of the root zone under the commercial fertilizer treatment due to limited movement of soil water. This lead to a greater nitrate-nitrogen concentration in the commercial fertilizer plot than in the hog manure plot in the upper portion of the root zone. This trend was reversed near the bottom of the root zone. The results indicate that, when added at equivalent rates of total NO3-N, nitrogen from commercial fertilizer was more available than the hog manure. This led to greater crop yield, higher moisture use and a reduced penetration of nitrate-nitrogen into the soil profile.

Due the dry conditions during the two years of this study, the crop uptake of nitrate-nitrogen was lower than expected, resulting in the accumulation of nitrate-nitrogen within the soil profile under all treatments. The cumulative amount of nitrate-nitrogen within the root zone of the control, 2500 gal ac^{-1} and 5000 gal ac^{-1} treatments was significantly lower than the 7500 gal ac^{-1} and commercial fertilizer treatments, after two years. As well, the 7500 gal ac^{-1} and commercial fertilizer treatments contained cumulative amount of nitrate-nitrogen within the root zone that exceeded the current Manitoba Agriculture guidelines (<160 kg N ha^{-1} to 120cm). The results indicate that the application of 7500 gal ac^{-1} of hog manure and this rate of commercial fertilizer exceeded the requirements of the crop and resulted in a significant accumulation of nitrate-nitrogen.

The application of liquid hog manure and commercial fertilizer increased the concentration of Mehlich-3 phosphorus near the soil surface, with little evidence of treatment effects beyond this surface layer (0-10 cm). From the soil sampling data, Mehlich-3 phosphorus does not appear to have been leached from the root zone, and the lysimeter data supports this conclusion.

Only a limited comparison of the two different methods for determining nitrate-nitrogen leaching was possible due to below normal precipitation levels. Soil sampling indicated that leaching of nitrate-nitrogen occurred under all treatments. While the soil sampling data points to evidence of NO_3-N leaching from the control and M7500 plots, the lysimeters confirmed that NO_3-N losses did occur under these treatments. The data suggests that the loss of nitrate-nitrogen by leaching was highly dependent upon the soil texture, as leachate collection resulted from lysimeter containing coarser textured soils throughout the root zone. Nitrate nitrogen dynamics can be better understood when more than one measurement method is incorporated as each method measures different components of the N systems.

After two years, this study shows that nitrate-nitrogen will be lost from a dryland agricultural system subjected to various rates and sources of nitrogen application. Under these conditions (below normal moisture levels), nitrate-nitrogen leaching can not be avoided, but can be minimized.

6. CONTRIBUTION TO KNOWLEDGE

The results from this field study show that, during two years of below normal precipitation, nitrate-nitrogen was transported beyond the root zone in all treatments, even the control treatment which did not receive nitrogen additions. The greater nutrient availability of the commercial fertilizer compared to the hog manure resulted in higher crop yields, which lead to lower levels of soil water within the soil profile and limited nitrate-nitrogen movement. The application of nutrients increased Mehlich-3 phosphorus levels near the soil surface, however little or no movement of Mehlich-3 phosphorus was observed after two years. The amount of leachate collected from spring snowmelt was similar to the estimated rate of recharge of the Assiniboine Delta Aquifer.

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8. APPENDICES

Appendix A: Particle size distribution for each field plot near Carberry,MB.

		Plot 1			Plot 3			Plot 5		
	Depth	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Block 1	0-10	86.8%	0.4%	12.8%	83.7%	1.4%	14.8%	80.1%	9.4%	10.5%
	10-20	85.2%	3.8%	11.1%	81.7%	6.0%	12.3%	82.6%	6.3%	11.1%
	20-30	82.4%	13.3%	4.3%	88.0%	1.1%	10.9%	80.7%	4.7%	14.6%
	30-60	83.2%	4.9%	11.9%	93.3%	0.5%	6.2%	88.8%	2.6%	8.6%
	60-90	93.2%	4.8%	6.8%	88.8%	5.3%	5.9%	89.1%	4.3%	6.6%
	90-120	60.9%	22.0%	17.2%	69.4%	19.7%	10.9%	62.0%	21.0%	17.0%

		Plot 8			Plot 10			Plot 12		
	Depth	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Block 2	0-10	81.8%	5.4%	12.8%	78.8%	5.6%	15.6%	73.0%	12.4%	14.7%
	10-20	84.5%	6.1%	9.4%	76.6%	8.4%	15.0%	67.8%	17.6%	14.6%
	20-30	88.1%	3.6%	8.2%	73.5%	14.7%	11.8%	63.3%	24.8%	11.9%
	30-60	94.5%	3.5%	2.0%	76.5%	8.4%	15.0%	66.4%	20.2%	13.5%
	60-90	68.7%	15.3%	16.0%	65.4%	18.9%	15.7%	47.7%	28.3%	23.9%
	90-120	59.7%	23.2%	17.1%	58.8%	19.7%	21.5%	34.7%	39.1%	26.2%

		Plot 13			Plot 15			Plot 17		
	Depth	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Block 3	0-10	78.4%	12.4%	9.1%	77.1%	11.9%	11.1%	71.4%	17.9%	10.7%
	10-20	76.2%	13.6%	10.2%	69.5%	12.8%	17.7%	56.6%	27.2%	16.2%
	20-30	73.8%	14.0%	12.1%	69.4%	19.9%	10.7%	53.1%	34.2%	12.7%
	30-60	79.7%	10.1%	10.2%	75.6%	12.8%	11.6%	54.1%	26.1%	19.8%
	60-90	61.0%	31.4%	7.6%	74.1%	14.5%	11.4%	77.7%	8.6%	13.7%
	90-120	28.0%	49.5%	22.5%	65.6%	19.7%	14.8%	29.5%	43.9%	26.5%

		Plot 20			Plot 22			Plot 24		
	Depth	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Block 4	0-10	76.8%	15.8%	7.3%	73.4%	16.4%	10.2%	74.1%	13.4%	12.5%
	10-20	65.7%	19.1%	15.2%	63.3%	24.8%	11.9%	63.4%	16.9%	19.7%
	20-30	62.6%	22.3%	15.1%	41.6%	38.7%	19.8%	61.5%	23.6%	14.9%
	30-60	60.1%	20.2%	19.7%	56.2%	27.9%	15.9%	59.7%	22.4%	17.9%
	60-90	48.1%	30.0%	21.9%	37.0%	35.3%	27.7%	36.0%	45.0%	19.0%
	90-120	31.1%	40.9%	28.0%	24.7%	49.3%	26.0%	58.9%	30.9%	10.2%

Appendix B: Bulk Density (g cm^{-3}) measurements for each field plot near Carberry, MB.

	Depth	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Block 1	0-10	1.41	1.34	1.40	1.42	1.31	1.33
	10-20	1.54	1.66	1.55	1.61	1.55	1.58
	20-30	1.53	1.59	1.56	1.63	1.57	1.44
	30-45	1.53	1.58	1.59	1.52	1.58	1.53
	45-60	1.55	1.53	1.59	1.59	1.75	1.63
	60-75	1.56	1.74	1.38	1.70	1.67	1.63
	75-90	1.65	1.71	1.62	1.80	1.66	1.85
	90-105	1.46	1.42	1.62	1.56	1.52	1.48

	Depth	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12
Block 2	0-10	1.27	1.39	1.24	1.22	1.35	1.13
	10-20	1.59	1.52	1.43	1.43	1.43	1.19
	20-30	1.51	1.59	1.50	1.44	1.33	1.33
	30-45	1.58	1.71	1.42	1.51	1.44	1.43
	45-60	1.81	1.67	1.56	1.53	1.51	1.49
	60-75	1.65	1.71	1.57	1.49	1.54	1.47
	75-90	1.52	1.54	1.62	1.49	1.42	1.41
	90-105	1.22	1.49	1.49	1.54	1.53	1.51

	Depth	Plot 13	Plot 14	Plot 15	Plot 16	Plot 17	Plot 18
Block 3	0-10	1.23	1.34	1.26	1.24	1.38	1.25
	10-20	1.43	1.55	1.34	1.31	1.30	1.31
	20-30	1.52	1.40	1.37	1.29	1.39	1.30
	30-45	1.58	1.54	1.49	1.43	1.47	1.43
	45-60	1.47	1.51	1.54	1.29	1.39	1.49
	60-75	1.53	1.51	1.52	1.39	1.30	1.43
	75-90	1.39	1.32	1.39	1.53	1.44	1.39
	90-105	1.47	1.42	1.53	1.39	1.43	1.30

	Depth	Plot 19	Plot 20	Plot 21	Plot 22	Plot 23	Plot 24
Block 4	0-10	1.35	1.37	1.27	1.29	1.05	1.30
	10-20	1.49	1.34	1.50	1.43	1.18	1.48
	20-30	1.43	1.32	1.31	1.27	1.04	1.50
	30-45	1.47	1.37	1.44	1.49	1.37	1.39
	45-60	1.56	1.44	1.50	1.49	1.06	1.39
	60-75	1.43	1.36	1.41	1.43	1.40	1.46
	75-90	1.48	1.38	1.52	1.48	1.29	1.45
	90-105	1.60	1.47	1.58	1.44	1.36	1.47

Appendix C: Gravimetric moisture content (%) for each field plot near Carberry, MB.

		25-Jun-2002				23-Jul-02			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	15.7%	15.9%	15.0%	11.6%	7.3%	7.6%	6.6%	5.4%
	10-20	13.5%	15.4%	14.4%	15.3%	6.6%	8.1%	6.6%	6.6%
	20-30	12.6%	14.6%	14.5%	17.8%	7.3%	7.7%	7.9%	8.9%
	30-45	10.4%	13.1%	11.4%	15.5%	6.7%	7.1%	7.2%	8.0%
	45-60	7.5%	10.3%	10.9%	13.5%	5.3%	6.6%	6.2%	8.1%
	60-90	5.5%	9.8%	8.3%	12.7%	4.9%	6.7%	7.2%	11.1%
	90-120	7.6%	11.7%	7.6%	13.1%	13.6%	11.1%	9.0%	12.8%
Manure 5000 gal	0-10	14.3%	15.7%	13.9%	11.6%	3.2%	8.9%	6.7%	6.7%
	10-20	12.4%	16.8%	12.1%	16.1%	5.5%	11.9%	6.5%	8.6%
	20-30	11.6%	17.0%	11.8%	16.3%	5.9%	9.9%	8.5%	8.0%
	30-45	9.4%	13.6%	10.4%	15.6%	6.6%	8.1%	7.5%	9.1%
	45-60	7.2%	12.4%	5.9%	14.3%	4.4%	7.6%	5.5%	12.3%
	60-90	6.8%	12.3%	10.6%	18.4%	4.1%	7.8%	11.3%	17.1%
	90-120	11.0%	14.8%	9.4%	21.2%	14.9%	12.9%	10.8%	14.3%
Manure 7500 gal	0-10	11.7%	15.7%	17.9%	13.6%	7.9%	6.0%	10.1%	7.9%
	10-20	9.9%	15.7%	17.8%	14.2%	4.3%	6.3%	12.9%	8.2%
	20-30	6.2%	11.2%	15.5%	16.2%	4.8%	6.5%	12.3%	11.7%
	30-45	6.7%	9.3%	15.9%	14.4%	3.9%	6.5%	13.1%	10.8%
	45-60	6.6%	6.8%	17.0%	12.1%	4.2%	5.2%	12.8%	14.9%
	60-90	6.3%	11.6%	11.7%	4.9%	4.3%	9.7%	14.2%	14.0%
	90-120	12.3%	7.2%	12.2%	9.0%	14.9%	17.3%	8.7%	15.5%
Fertilizer	0-10	14.3%	16.5%	16.2%	16.2%	6.4%	7.0%	9.1%	9.1%
	10-20	12.1%	15.1%	16.9%	16.9%	6.9%	6.7%	9.7%	9.7%
	20-30	11.4%	11.8%	19.0%	19.0%	7.1%	7.1%	10.8%	10.8%
	30-45	6.4%	12.5%	17.1%	17.1%	5.0%	7.0%	11.2%	11.2%
	45-60	5.9%	11.2%	16.1%	16.1%	5.2%	5.3%	11.7%	11.7%
	60-90	4.2%	10.1%	17.9%	17.9%	4.9%	6.5%	14.6%	14.6%
	90-120	14.0%	13.0%	16.9%	16.9%	14.0%	10.6%	15.1%	15.1%
Fertilizer Fallow	0-10	12.6%	16.3%	17.6%	14.0%	5.7%	7.1%	9.4%	12.1%
	10-20	11.1%	18.4%	16.4%	14.8%	6.0%	10.0%	14.9%	16.1%
	20-30	8.0%	16.7%	16.7%	15.0%	6.8%	13.4%	13.9%	13.8%
	30-45	6.4%	12.0%	14.2%	12.7%	6.1%	10.6%	13.4%	12.2%
	45-60	7.7%	7.7%	15.5%	12.6%	3.3%	8.4%	27.8%	10.6%
	60-90	6.8%	7.8%	15.4%	15.0%	5.9%	6.8%	18.5%	15.0%
	90-120	10.4%	13.5%	19.1%	13.7%	10.1%	18.4%	20.5%	19.6%
Control	0-10	12.3%	14.3%	16.4%	15.6%	5.1%	9.7%	8.0%	10.3%
	10-20	10.7%	15.7%	16.5%	14.9%	6.8%	9.7%	7.8%	10.0%
	20-30	8.0%	16.2%	12.5%	17.0%	5.2%	11.3%	9.6%	9.9%
	30-45	6.4%	14.8%	11.8%	14.2%	3.8%	9.1%	9.7%	10.9%
	45-60	6.8%	14.0%	9.5%	14.1%	4.0%	9.0%	9.4%	9.9%
	60-90	7.4%	9.8%	11.9%	10.1%	3.8%	10.8%	12.7%	11.0%
	90-120	21.2%	17.7%	20.4%	16.4%	10.9%	13.6%	19.0%	6.5%

		10-Sep-2002			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	14.3%	16.7%	17.8%	14.9%
	10-20	14.3%	15.0%	18.8%	16.8%
	20-30	12.8%	14.5%	19.3%	18.4%
	30-45	12.0%	8.6%	14.2%	13.2%
	45-60	5.6%	4.9%	12.3%	45.1%
	60-90	4.2%	6.4%	7.4%	8.3%
	90-120	5.5%	9.5%	9.5%	9.4%
Manure 5000 gal	0-10	13.2%	17.7%	16.3%	15.6%
	10-20	15.0%	22.2%	15.6%	17.4%
	20-30	14.0%	17.9%	14.6%	17.0%
	30-45	12.8%	10.6%	13.4%	15.2%
	45-60	10.0%	3.7%	9.4%	9.3%
	60-90	5.0%	8.0%	10.7%	11.7%
	90-120	13.9%	7.9%	14.5%	12.5%
Manure 7500 gal	0-10	12.4%	14.4%	18.8%	17.0%
	10-20	11.6%	14.1%	21.1%	18.6%
	20-30	12.0%	13.0%	20.5%	22.3%
	30-45	9.8%	10.4%	17.1%	17.9%
	45-60	5.2%	4.0%	10.5%	11.2%
	60-90	3.2%	8.7%	15.6%	9.9%
	90-120	4.2%	15.4%	17.8%	11.3%
Fertilizer	0-10	14.8%	14.0%	17.9%	17.9%
	10-20	12.9%	13.6%	19.6%	19.6%
	20-30	13.1%	12.3%	23.1%	23.1%
	30-45	6.2%	11.0%	16.1%	16.1%
	45-60	2.9%	3.1%	9.6%	9.6%
	60-90	3.6%	5.4%	11.8%	11.8%
	90-120	4.7%	10.8%	15.8%	15.8%
Fertilizer Fallow	0-10	13.2%	15.8%	19.6%	19.0%
	10-20	12.0%	17.7%	19.9%	18.8%
	20-30	10.6%	16.2%	25.0%	19.0%
	30-45	7.2%	12.9%	17.5%	12.2%
	45-60	7.2%	8.5%	17.4%	10.4%
	60-90	7.3%	11.4%	15.6%	17.7%
	90-120	5.8%	19.3%	21.8%	21.9%
Control	0-10	14.0%	18.7%	15.1%	17.9%
	10-20	14.8%	16.9%	16.6%	16.7%
	20-30	13.7%	19.7%	15.1%	18.8%
	30-45	9.2%	16.0%	10.1%	12.6%
	45-60	9.4%	9.3%	5.1%	7.4%
	60-90	6.6%	7.2%	15.1%	7.9%
	90-120	7.8%	14.1%	18.5%	11.0%

TRMT	Depth (cm)	9-Oct-02 Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	6.6%	13.0%	17.6%	11.8%
	10-20	11.9%	13.7%	17.8%	17.7%
	20-30	11.5%	12.2%	17.3%	14.4%
	30-45	8.9%	11.5%	13.5%	13.1%
	45-60	5.1%	5.2%	9.0%	8.2%
	60-75	2.7%	8.5%	5.8%	8.0%
	75-90	2.8%	9.7%	10.3%	10.5%
	90-120	13.3%	7.9%	11.3%	15.2%
Manure 5000 gal	0-10	9.0%	15.4%	14.0%	13.3%
	10-20	11.9%	15.7%	14.8%	14.1%
	20-30	11.2%	10.3%	11.4%	9.5%
	30-45	8.3%	8.7%	8.5%	13.6%
	45-60	5.5%	6.0%	8.7%	8.7%
	60-75	6.9%	7.4%	10.5%	12.0%
	75-90	7.2%	11.7%	12.6%	12.3%
	90-120	23.0%	9.2%	15.9%	12.8%
Manure 7500 gal	0-10	10.5%	11.5%	15.4%	15.3%
	10-20	9.8%	11.8%	21.5%	19.0%
	20-30	9.6%	7.8%	16.7%	18.6%
	30-45	5.5%	6.6%	16.5%	15.5%
	45-60	6.3%	7.3%	16.8%	13.7%
	60-75	8.4%	3.8%	14.4%	7.7%
	75-90	4.4%	13.9%	12.2%	7.3%
	90-120	5.2%	13.1%	11.9%	10.5%
Fertilizer	0-10	11.0%	13.7%	13.7%	42.0%
	10-20	10.9%	14.2%	14.2%	44.6%
	20-30	11.2%	13.0%	13.0%	51.4%
	30-45	6.5%	9.9%	9.9%	25.7%
	45-60	2.8%	5.0%	5.0%	23.7%
	60-75	4.9%	5.0%	5.0%	18.0%
	75-90	5.4%	8.2%	8.2%	22.1%
	90-120	16.8%	8.5%	8.5%	20.3%
Fertilizer Fallow	0-10	10.1%	12.4%	16.6%	11.6%
	10-20	9.2%	13.7%	21.1%	14.0%
	20-30	8.9%	11.4%	20.4%	13.2%
	30-45	7.3%	9.5%	15.6%	12.2%
	45-60	8.3%	8.4%	17.9%	9.3%
	60-75	4.8%	8.6%	13.4%	14.8%
	75-90	5.5%	16.3%	14.8%	22.1%
	90-120	22.6%	16.9%	17.0%	12.8%
Control	0-10	10.8%	13.8%	12.6%	13.1%
	10-20	13.7%	16.3%	12.2%	13.6%
	20-30	7.0%	17.1%	15.6%	18.1%
	30-45	5.7%	12.6%	10.7%	15.1%
	45-60	4.7%	9.0%	9.5%	11.1%
	60-75	4.8%	6.0%	11.4%	12.7%
	75-90	3.6%	13.8%	19.7%	9.3%
	90-120	12.1%	14.2%	18.1%	11.0%

		9-May-03				19-Jun-03			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	14.0%	15.9%	14.9%	14.7%	4.6%	10.4%	10.6%	9.3%
	10-20	13.3%	17.0%	15.0%	20.4%	7.5%	12.2%	13.5%	12.3%
	20-30	11.4%	15.0%	16.5%	18.3%	7.5%	11.9%	14.8%	12.3%
	30-45	10.7%	13.2%	13.8%	11.0%	9.0%	11.4%	13.6%	12.5%
	45-60	7.1%	10.0%	12.5%	12.2%	8.1%	10.3%	13.7%	13.3%
	60-75	5.4%	7.1%	11.1%	13.0%	5.5%	8.5%	11.7%	20.2%
	75-90	5.3%	8.2%	10.2%	11.8%	3.6%	7.5%	21.0%	23.1%
	90-105	16.9%	10.6%	11.1%	17.2%	4.8%	8.7%	19.2%	16.9%
	105-120	20.5%	14.6%	21.1%	13.3%	17.3%	9.1%	17.7%	5.8%
Manure 5000 gal	0-10	12.6%	15.4%	13.6%	14.9%	9.5%	8.4%	9.0%	8.1%
	10-20	12.1%	17.8%	28.1%	16.4%	8.8%	11.9%	10.2%	11.0%
	20-30	11.4%	14.5%	15.4%	16.0%	9.3%	10.5%	10.0%	10.5%
	30-45	11.1%	11.5%	12.0%	14.9%	9.2%	9.3%	9.6%	11.1%
	45-60	9.2%	10.4%	7.2%	13.8%	7.4%	6.6%	6.6%	13.6%
	60-75	8.4%	7.1%	7.9%	16.1%	5.9%	7.6%	7.9%	10.4%
	75-90	6.0%	10.5%	12.0%	19.8%	5.2%	9.0%	15.3%	14.0%
	90-105	19.3%	9.3%	13.0%	13.1%	15.0%	10.1%	15.8%	19.8%
	105-120	19.6%	13.4%	12.1%	5.5%	17.9%	13.4%	19.1%	16.0%
Manure 7500 gal	0-10	11.1%	13.3%	18.2%	16.0%	7.1%	7.6%	13.5%	11.9%
	10-20	12.5%	12.9%	24.7%	19.9%	7.6%	8.3%	16.0%	14.8%
	20-30	9.8%	9.2%	19.8%	20.8%	5.9%	8.9%	16.9%	16.1%
	30-45	6.1%	7.5%	16.8%	17.0%	6.0%	5.2%	16.2%	16.6%
	45-60	7.0%	6.2%	16.9%	18.2%	6.0%	6.3%	18.8%	17.9%
	60-75	4.2%	6.5%	15.4%	16.7%	7.3%	13.0%	19.7%	18.3%
	75-90	9.3%	16.0%	12.6%	15.9%	5.3%	20.6%	20.6%	19.8%
	90-105	12.7%	18.5%	15.9%	15.3%	16.0%	19.2%	17.9%	15.5%
	105-120	11.2%	11.4%	15.3%	16.7%	16.0%	20.2%	17.0%	16.4%
Fertilizer	0-10	12.8%	14.0%	14.7%	14.6%	10.0%	5.4%	10.1%	10.8%
	10-20	11.4%	14.3%	21.6%	19.8%	9.8%	8.4%	11.5%	15.0%
	20-30	12.2%	12.2%	20.6%	21.5%	9.6%	9.3%	15.7%	17.4%
	30-45	7.3%	11.3%	17.8%	19.6%	9.3%	8.1%	15.2%	15.4%
	45-60	4.8%	6.2%	17.4%	17.1%	6.3%	6.5%	17.1%	8.3%
	60-75	17.0%	5.8%	14.2%	17.1%	4.1%	6.7%	17.2%	17.0%
	75-90	8.3%	7.9%	14.4%	17.2%	6.0%	8.9%	17.5%	17.7%
	90-105	29.3%	15.7%	17.0%	16.7%	15.6%	7.2%	15.6%	14.7%
	105-120	36.6%	12.6%	13.9%	18.4%	19.3%	14.0%	15.8%	16.6%
Fertilizer Fallow	0-10	10.4%	11.4%	15.6%	14.3%	12.7%	12.0%	16.9%	14.1%
	10-20	11.8%	12.4%	22.4%	14.1%	12.0%	12.3%	15.7%	17.9%
	20-30	8.3%	11.3%	21.6%	13.9%	10.2%	12.0%	19.4%	16.2%
	30-45	8.1%	9.9%	17.8%	12.8%	7.1%	10.0%	16.7%	13.9%
	45-60	9.9%	7.2%	18.2%	12.3%	7.1%	8.8%	20.1%	13.4%
	60-75	8.6%	7.2%	19.2%	21.0%	9.7%	5.9%	19.9%	15.7%
	75-90	8.8%	13.9%	16.6%	22.7%	5.5%	10.8%	21.2%	22.3%
	90-105	21.9%	18.5%	15.7%	28.6%	15.0%	18.8%	17.6%	24.7%
	105-120	23.1%	19.2%	16.5%	21.0%	20.2%	14.6%	14.3%	26.3%
Control	0-10	10.8%	14.7%	13.8%	15.0%	5.2%	9.8%	6.9%	10.5%
	10-20	12.5%	19.7%	15.8%	15.7%	5.7%	13.3%	9.2%	11.5%
	20-30	9.5%	19.3%	13.4%	19.5%	5.4%	13.4%	12.5%	14.9%
	30-45	6.8%	16.0%	12.4%	15.7%	5.3%	15.5%	0.7%	12.0%
	45-60	7.4%	13.8%	9.6%	12.9%	5.7%	12.1%	11.5%	11.1%
	60-75	6.3%	10.9%	13.6%	11.1%	5.7%	14.8%	14.2%	12.3%
	75-90	14.3%	11.8%	20.2%	10.1%	5.4%	13.4%	19.8%	13.0%
	90-105	22.1%	16.7%	20.5%	12.2%	17.9%	15.6%	24.3%	16.5%
	105-120	20.0%	17.7%	21.5%	19.9%	17.4%	17.1%	23.6%	15.8%

TRMT	Depth (cm)	18-Jul-03 Block 1	Block 2	Block 3	Block 4	19-Aug-03 Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	4.5%	8.3%	7.8%	7.3%	2.7%	5.3%	5.1%	2.5%
	10-20	5.2%	9.1%	8.4%	9.3%	5.1%	4.8%	8.4%	8.3%
	20-30	5.2%	8.7%	9.7%	10.0%	5.1%	6.3%	7.3%	8.6%
	30-45	4.1%	8.9%	8.3%	9.2%	5.3%	5.7%	5.8%	7.8%
	45-60	3.2%	7.8%	8.6%	9.2%	2.7%	5.3%	5.7%	7.5%
	60-75	3.3%	9.1%	7.8%	9.3%	2.5%	4.6%	5.2%	6.8%
	75-90	4.7%	10.2%	12.9%	14.9%	3.0%	8.7%	5.3%	7.2%
	90-105	6.7%	13.9%	11.1%	7.0%	7.5%	8.8%	6.7%	9.1%
	105-120	20.7%	13.4%	11.3%	3.4%	11.4%	9.5%	10.7%	13.3%
Manure 5000 gal	0-10	3.2%	7.1%	6.9%	5.7%	3.9%	3.2%	3.2%	3.2%
	10-20	5.0%	8.5%	7.4%	7.7%	4.2%	7.7%	6.7%	8.3%
	20-30	5.1%	7.6%	6.5%	7.5%	4.5%	6.7%	6.0%	8.6%
	30-45	4.5%	7.1%	5.7%	8.6%	4.5%	5.9%	5.2%	8.6%
	45-60	3.9%	6.4%	4.1%	9.4%	4.1%	5.3%	4.6%	9.1%
	60-75	5.9%	7.5%	6.6%	12.8%	4.3%	5.3%	5.0%	10.0%
	75-90	7.0%	9.5%	10.5%	14.2%	4.2%	8.0%	9.8%	10.4%
	90-105	21.4%	8.2%	14.3%	15.7%	6.5%	9.6%	12.3%	10.6%
	105-120	25.0%	8.6%	15.7%	15.9%	4.6%	11.3%	11.1%	11.1%
Manure 7500 gal	0-10	2.9%	4.6%	7.4%	7.3%	2.7%	3.2%	3.1%	2.8%
	10-20	5.2%	5.0%	8.9%	10.2%	3.9%	4.5%	11.3%	5.9%
	20-30	4.9%	5.1%	10.4%	10.5%	3.6%	3.7%	9.1%	7.3%
	30-45	3.9%	3.6%	8.8%	9.1%	3.8%	2.9%	9.7%	7.5%
	45-60	4.5%	3.8%	10.9%	11.3%	3.7%	2.4%	10.4%	6.7%
	60-75	5.3%	6.5%	12.3%	12.5%	3.7%	3.2%	12.1%	7.4%
	75-90	4.9%	17.6%	13.1%	14.5%	5.5%	11.0%	13.0%	5.7%
	90-105	14.5%	19.9%	12.6%	15.5%	13.8%	18.1%	15.4%	6.2%
	105-120	16.5%	22.9%	14.0%	14.3%	13.4%	20.3%	14.0%	8.9%
Fertilizer	0-10	3.2%	6.2%	7.8%	7.0%	4.5%	3.2%	3.7%	4.0%
	10-20	4.5%	6.9%	9.1%	9.5%	5.3%	5.6%	9.5%	8.9%
	20-30	4.1%	7.4%	10.0%	8.6%	5.0%	5.4%	9.5%	8.0%
	30-45	2.9%	7.5%	9.2%	7.0%	3.6%	4.9%	8.8%	8.9%
	45-60	3.0%	7.2%	12.1%	5.0%	3.0%	4.4%	8.9%	9.7%
	60-75	5.0%	5.8%	12.8%	5.9%	3.7%	3.9%	10.1%	8.7%
	75-90	3.6%	11.0%	12.9%	9.5%	3.9%	7.0%	8.7%	8.4%
	90-105	22.9%	11.9%	13.6%	10.7%	9.3%	8.1%	9.5%	8.1%
	105-120	17.0%	13.0%	14.2%	13.3%	15.9%	7.8%	9.2%	11.9%
Fertilizer Fallow	0-10	7.1%	12.2%	13.3%	9.6%	3.9%	3.9%	6.0%	8.5%
	10-20	7.5%	10.3%	19.3%	16.9%	5.3%	6.3%	10.6%	9.1%
	20-30	5.1%	10.5%	17.4%	15.6%	4.7%	5.5%	9.8%	10.8%
	30-45	5.0%	8.7%	16.3%	12.3%	4.4%	4.4%	9.1%	9.5%
	45-60	7.3%	5.2%	18.6%	13.5%	5.5%	3.2%	8.3%	5.0%
	60-75	8.2%	3.8%	22.2%	20.0%	4.1%	4.2%	12.8%	16.0%
	75-90	4.8%	7.6%	24.7%	21.1%	4.0%	8.5%	7.8%	24.8%
	90-105	17.0%	16.7%	23.2%	22.8%	13.6%	16.1%	15.2%	28.7%
	105-120	23.0%	20.8%	18.7%	23.2%	19.2%	20.3%	16.8%	2.5%
Control	0-10	2.8%	7.6%	6.4%	7.0%	2.9%	6.8%	4.7%	3.4%
	10-20	3.8%	9.6%	7.3%	9.1%	4.0%	6.1%	6.8%	7.2%
	20-30	3.2%	9.0%	7.2%	8.3%	3.6%	7.2%	6.6%	7.1%
	30-45	2.7%	8.2%	8.2%	6.7%	2.9%	6.4%	5.2%	6.6%
	45-60	2.6%	7.3%	8.0%	6.8%	2.7%	6.5%	4.7%	6.0%
	60-75	3.3%	9.1%	8.1%	7.0%	3.2%	4.3%	8.1%	7.1%
	75-90	4.5%	11.1%	12.8%	10.6%	4.8%	9.6%	11.6%	6.5%
	90-105	18.3%	13.5%	16.2%	10.0%	12.1%	10.1%	14.0%	9.8%
	105-120	15.5%	13.7%	20.0%	10.7%	14.0%	9.6%	16.2%	4.7%

		8-Oct-03			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	12.9%	14.9%	16.5%	13.4%
	10-20	12.5%	16.5%	24.7%	17.0%
	20-30	12.5%	11.8%	16.2%	19.7%
	30-45	10.2%	13.8%	13.3%	15.6%
	45-60	5.5%	7.7%	8.0%	12.5%
	60-75	5.2%	5.7%	5.9%	7.1%
	75-90	3.9%	5.1%	12.7%	9.5%
	90-105	17.4%	7.6%	10.6%	11.1%
	105-120	18.6%	14.3%	11.9%	13.3%
Manure 5000 gal	0-10	11.3%	10.2%	12.2%	13.0%
	10-20	13.6%	13.2%	13.5%	14.1%
	20-30	10.6%	11.7%	12.4%	14.8%
	30-45	9.5%	9.3%	10.7%	14.3%
	45-60	6.9%	8.4%	6.2%	12.0%
	60-75	6.7%	8.2%	7.5%	8.2%
	75-90	7.3%	8.4%	7.5%	9.1%
	90-105	19.4%	9.0%	7.4%	7.8%
	105-120	20.4%	12.8%	10.4%	8.6%
Manure 7500 gal	0-10	9.4%	11.7%	11.5%	14.5%
	10-20	11.9%	12.0%	18.9%	18.3%
	20-30	9.5%	7.5%	18.6%	18.6%
	30-45	7.4%	5.8%	12.9%	13.9%
	45-60	7.3%	8.2%	9.3%	10.0%
	60-75	5.1%	5.7%	10.8%	10.7%
	75-90	9.6%	14.4%	8.4%	12.0%
	90-105	13.2%	12.1%	11.9%	11.3%
	105-120	12.6%	15.1%	11.7%	14.0%
Fertilizer	0-10	11.6%	13.0%	16.6%	13.4%
	10-20	10.4%	16.1%	16.9%	16.5%
	20-30	10.4%	12.4%	18.8%	18.5%
	30-45	8.5%	11.3%	16.4%	14.0%
	45-60	5.7%	5.9%	14.4%	8.7%
	60-75	8.6%	6.3%	9.8%	8.3%
	75-90	6.0%	6.8%	8.4%	8.7%
	90-105	11.6%	7.8%	8.7%	10.3%
	105-120	22.0%	7.7%	9.7%	10.9%
Fertilizer Fallow	0-10	11.7%	13.8%	16.4%	14.2%
	10-20	11.5%	13.0%	25.0%	16.5%
	20-30	8.9%	7.7%	16.2%	18.8%
	30-45	5.1%	9.8%	16.4%	12.9%
	45-60	5.4%	11.1%	16.6%	12.0%
	60-75	2.9%	4.7%	16.0%	12.0%
	75-90	2.9%	11.1%	21.2%	20.2%
	90-105	7.2%	17.4%	15.0%	19.0%
	105-120	11.3%	12.1%	10.8%	15.3%
Control	0-10	10.9%	15.5%	12.8%	15.3%
	10-20	11.3%	19.0%	18.1%	14.1%
	20-30	10.0%	16.7%	17.2%	18.4%
	30-45	5.7%	15.3%	13.3%	12.8%
	45-60	5.5%	10.4%	11.3%	10.2%
	60-75	6.9%	4.0%	7.6%	6.9%
	75-90	8.2%	8.5%	16.6%	9.1%
	90-105	14.4%	10.6%	18.8%	10.2%
	105-120	10.7%	10.8%	16.1%	11.0%

Appendix D: Nitrate-nitrogen concentration (mg kg^{-1}) for each field plot near Carberry, MB.

		25-Jun-2002				23-Jul-02			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	9.4	11.75	60.65	34.1	2.3	3.2	4.85	4.2
	10-20	6.65	12.85	37.75	23.4	1.6	6.95	5.25	4.4
	20-30	5.8	11	19.7	17.85	1.95	7.65	4.55	4.1
	30-45	5.05	7.8	10.6	11.25	1.55	5.2	5.3	4.8
	45-60	4.8	5.15	4.85	7.15	2.4	3.2	4.15	2.55
	60-90	3.15	2.05	2.3	1.1	1.3	1.8	1.45	1.9
	90-120	1.85	1.3	1.6	2	0.95	1.2	1.15	1.4
Manure 5000 gal	0-10	31.85	37.15	13.1	10.7	9.25	6.65	4.15	9.6
	10-20	14.4	20.1	9.75	6.3	4.65	12	5.05	10.2
	20-30	12.4	12.3	7.7	4.4	4.55	16.25	4.25	6.95
	30-45	7.6	7.65	6.7	4.4	5.5	11.75	4.1	4.1
	45-60	4.35	3.95	2.85	2.65	5.2	5.15	2.75	2.95
	60-90	3.1	2.25	2.05	1.85	3.15	1.9	2.25	2.15
	90-120	1.9	1.4	1.5	1.35	3.7	1.75	1.05	1.55
Manure 7500 gal	0-10	53.95	65.8	65.55	12.2	15.3	17.95	5.85	11
	10-20	25.9	33.15	50.65	14.4	17.2	21.35	11	12.95
	20-30	15.05	15.25	17.2	12.2	14.2	15.8	10.75	13.25
	30-45	13.5	6.85	7.9	6.4	13.05	7.95	10.7	7.35
	45-60	5.75	4.1	9.4	3.3	10.7	5.55	5.3	3.9
	60-90	4.25	2.3	2.15	1	3.65	2.3	2.45	2.45
	90-120	3.25	1.95	1.55	0.6	2.8	1.95	1.25	1.45
Fertilizer	0-10	45.1	120	116.75	77	5.55	7.1	33.75	8.35
	10-20	17.9	65.2	65.05	28.45	4	9.9	9	16.6
	20-30	7.95	16.95	22.9	14.35	3.9	8.55	5.7	18.7
	30-45	4.7	10.8	10.05	7.75	2.55	9.35	4.05	11.95
	45-60	2.9	6.65	6.7	5.9	2	3.45	2.15	5.25
	60-90	1.55	3.8	2.9	2.15	1.05	2.7	1.6	2.4
	90-120	1.6	2.7	1.6	1.15	1.6	1.4	1.3	1.4
Fertilizer Fallow	0-10	79.25	79.25	47.4	77.25	46	46	29.6	36
	10-20	46.75	46.75	19.15	28.7	52	52	42.9	41.65
	20-30	14.4	14.4	10.15	16.95	52.8	52.8	69.35	32.05
	30-45	9.1	9.1	4.85	8.8	22.35	22.35	26.65	19.05
	45-60	4.4	4.4	3.9	5.4	7.4	7.4	8.8	11
	60-90	2.8	2.8	1.95	4.75	4.3	4.3	7.3	5.85
	90-120	2.25	2.25	1.25	3.2	2.05	2.05	6.75	5.5
Control	0-10	4.45	4.6	3.8	4.3	2.4	3.8	2.8	3.45
	10-20	3.35	5	3.9	3.9	1.8	5.6	3.2	3.05
	20-30	3.5	7.15	3.7	6.3	1.55	4.25	2.3	2.15
	30-45	4.1	7.05	3.25	5.2	1.65	2	1.25	1.4
	45-60	4.2	4.3	2.4	4.1	1.5	1.1	1	1.35
	60-90	4.2	2.1	1.3	2.15	1.5	1	1.2	1.2
	90-120	2.65	1.35	1.05	3.15	1.85	0.85	0.95	2.05

TRMT	Depth (cm)	10-Sep-2002			
		Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	5	7.95	11.3	9.5
	10-20	4.7	4.7	11.55	11.95
	20-30	3.15	13.05	15.45	16.6
	30-45	13.05	10.65	13.55	10.4
	45-60	29.2	2.6	7.05	2.15
	60-90	8.2	1.35	1.9	1.35
	90-120	3.1	1.3	1.85	1.3
Manure 5000 gal	0-10	1.8	3.65	7.25	15.4
	10-20	3	7.9	7.55	20.25
	20-30	2.7	4.7	9.5	26.45
	30-45	3.05	9.8	8	26.8
	45-60	5.7	2.2	4	6.3
	60-90	2.4	1.55	2.65	1.85
	90-120	2.15	1.2	3.7	1.2
Manure 7500 gal	0-10	5.4	5.4	15.1	6.95
	10-20	7.9	5.05	26.65	9.25
	20-30	8.45	11.55	41.8	17.9
	30-45	10.6	22.7	15.1	14
	45-60	11.45	7.85	5.05	13.05
	60-90	2.7	3.45	2.05	1.9
	90-120	1.6	3.6	1.8	1.3
Fertilizer	0-10	5.75	7.4	10.55	6.2
	10-20	4.75	6.4	9.45	9.45
	20-30	2	12.3	20.5	51.8
	30-45	19.35	18.4	10.4	30.3
	45-60	2.55	2.8	3.05	7.05
	60-90	2.85	1.45	1.15	2.35
	90-120	1.55	1.05	1.35	1.3
Fertilizer Fallow	0-10	3.15	3.15	22.75	8.55
	10-20	7.8	7.8	42.55	20.55
	20-30	31.8	31.8	69.6	16.35
	30-45	21.5	21.5	30.95	43.3
	45-60	23.25	23.25	12.9	42.6
	60-90	5.9	5.9	4.55	19.15
	90-120	4.1	4.1	1.8	4.15
Control	0-10	2.9	9.8	4.2	6.5
	10-20	1.5	10.9	6.5	6.05
	20-30	3.65	12.55	5.5	4.85
	30-45	3.45	3.8	2.65	4.05
	45-60	3.6	1.95	0.85	0.95
	60-90	2.2	2.25	1.05	1.05
	90-120	2	4.05	1.15	1.15

TRMT	Depth (cm)	9-Oct-02			
		Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	13.65	11.45	15.7	12.35
	10-20	7.3	9.4	10.35	11.1
	20-30	6.15	9.55	8.85	10.6
	30-45	7.35	10.2	6.1	8.1
	45-60	3.7	3.5	2.75	2.4
	60-75	1.9	1.55	2.35	2.3
	75-90	0.9	2.05	2.6	1.65
	90-120	1.55	1.75	2.15	2.5
Manure 5000 gal	0-10	5.8	18.85	16.6	12.4
	10-20	3.8	11.4	7.5	13.4
	20-30	2.4	10.1	6.25	10.25
	30-45	3.45	13	5.7	5.25
	45-60	6.7	4.3	3.9	2.45
	60-75	5.6	1.8	6.8	2.2
	75-90	3.65	2.75	3.75	1.35
	90-120	4.55	2.25	2.75	1.55
Manure 7500 gal	0-10	12.7	20.55	14.3	11.4
	10-20	7.4	15.25	10.8	6.6
	20-30	9.05	20	10.7	7.85
	30-45	14.85	16	10.65	12.25
	45-60	9.05	3.2	7.95	11.1
	60-75	2.25	1.7	2.6	2.2
	75-90	1.5	2.8	1.9	1.1
	90-120	2.55	2.5	2.15	1.7
Fertilizer	0-10	23.15	13.1	10.65	13.2
	10-20	19.5	24.5	4.55	10.3
	20-30	51.7	38.35	4.35	8.6
	30-45	34.65	27.35	5.4	11.6
	45-60	5.55	4	3.4	9.25
	60-75	1.4	2	1.2	5.05
	75-90	0.35	2.1	2	2.5
	90-120	1.35	1.85	2.15	1.25
Fertilizer Fallow	0-10	16	25.75	26.95	15.9
	10-20	11.15	22.55	25.2	19.9
	20-30	9.05	30.85	32.85	28.1
	30-45	12.1	21.3	34.35	26.1
	45-60	11.95	11.6	20.7	12.25
	60-75	6.45	8.2	6.4	12.1
	75-90	4.8	8.9	3.5	12.2
	90-120	13.25	5.35	2.15	5.95
Control	0-10	14.25	13.3	12.1	12.65
	10-20	5.75	7.65	7.05	4.55
	20-30	3.85	5.45	4.1	4
	30-45	3.45	3.45	2.3	3.05
	45-60	2.6	0.6	1.3	2.6
	60-75	1.85	0.65	1.5	2.4
	75-90	1.45	1.4	1.95	1.75
	90-120	1.7	2.95	2.45	2.35

TRMT	Depth (cm)	9-May-03 Block 1	Block 2	Block 3	Block 4	19-Jun-03 Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	9.35	13.7	12.4	5.3	34.6	10.2	20.25	32.9
	10-20	8.8	12.4	16.2	12.3	14.9	12.3	15	20.1
	20-30	6.05	9.9	20.7	11.15	16.45	8	11.35	13.5
	30-45	6.3	13.85	24	4.55	14.8	2.8	6.25	8.4
	45-60	6.5	10.8	22.9	3.3	8.95	9.45	2.7	7.5
	60-75	1.8	2.1	7.65	3.65	6.35	5.1	2.5	11.5
	75-90	1.05	5.5	1.75	2.45	3.3	1.9	3.35	7.85
	90-105	2	5.35	1.75	1.25	1.7	1.7	2.05	4.35
	105-120	1.65	4.4	2.5	0.95	2.3	4.7	1.65	2.9
Manure 5000 gal	0-10	5.2	1.35	15.45	8.8	91.1	28.5	55.65	13.05
	10-20	4.95	9.95	8.85	10.55	46.2	16.8	27.95	10.7
	20-30	4.35	4.95	7.15	8.15	22.75	11.7	15.7	13
	30-45	2.05	4.35	9.1	11.5	14.55	6.35	8.25	16.85
	45-60	11.15	4.6	7.85	8.85	3.55	6.5	4.5	20.6
	60-75	5.4	3.1	7.5	5.85	5.8	3.8	6.75	12.35
	75-90	1.35	2.4	6.95	4.45	4.8	2.7	7.9	7.65
	90-105	1.25	1.25	1.6	7.9	3.95	1.75	3.95	4.85
	105-120	0.9	1.65	4.85	3.7	3.25	3.65	3.65	5.2
Manure 7500 gal	0-10	6.3	7.85	18.7	18.7	55.05	36.3	82	82
	10-20	5.5	5.9	11.1	11.1	20.05	14.7	27.95	27.95
	20-30	4.9	6.2	7.05	7.05	9.4	9.3	16.95	16.95
	30-45	9.9	11.4	9.8	9.8	6.5	7.95	9.85	9.85
	45-60	9.45	10.05	9.6	9.6	13.6	17.55	10.7	10.7
	60-75	4.35	3.75	5.3	5.3	15.5	17.85	10.85	10.85
	75-90	2.4	3.5	3.3	3.3	10.1	17.75	6.3	6.3
	90-105	3.55	3.5	1.25	1.25	10.9	4.85	3.15	3.15
	105-120	3.1	2.15	1.2	1.2	5.65	4	4.25	4.25
Fertilizer	0-10	9.45	5.65	7.5	8.45	49.15	40.05	85.75	56.3
	10-20	7.75	5.6	9.75	9	27.55	17.05	40.3	24.75
	20-30	7.15	18.55	12.25	13	26.15	17.7	26.95	12.95
	30-45	12.5	39.5	22	22.6	25.1	13.8	15.25	8.55
	45-60	8	43.95	20.4	31.4	17.35	12.9	17.1	11.45
	60-75	1.9	9.15	1.65	6.75	3.7	7	12.85	13.3
	75-90	0.95	1.9	0.9	1.7	2.6	4.4	4.7	8
	90-105	2.6	0	0.8	0.9	4.05	3.55	2.55	3.75
	105-120	3.4	1.05	1.35	0.9	8.75	4.35	2.7	3.05
Fertilizer Fallow	0-10	25.65	33.3	26.75	18.85	4.4	22.65	33.2	24.25
	10-20	30.05	18.85	32.95	24.45	4.95	18.55	34.65	30.15
	20-30	30.9	15.65	50.25	26.75	3.45	20.2	24.2	20
	30-45	26.25	17.05	31.25	30.6	20.1	17.7	32.6	21
	45-60	34.75	10.35	16.45	32.5	13.3	17.55	33.25	53.1
	60-75	18	8.6	12.25	29.35	9.8	9.65	16.95	31.05
	75-90	8.1	9.7	4.5	12.4	13.7	11.35	9.2	22.45
	90-105	9.5	10.15	2.1	5.95	27.55	7.6	7.05	8.45
	105-120	4.45	8.1	1.55	1.95	18.8	6.5	4.05	5.9
Control	0-10	7.25	14.5	10.4	9.3	2.85	7.95	5.5	4.85
	10-20	5.15	13.15	11.15	12.1	2.9	8.65	6.85	6.15
	20-30	4.3	10.75	8.2	11.9	3.15	10.65	5.45	7.6
	30-45	2.55	7.6	7	6	3.4	7.75	3.8	6.95
	45-60	4.25	2.85	3.95	3.5	3.8	4.75	2.7	3.95
	60-75	3.65	1.5	2.65	1.9	4.75	2.6	2.7	3.2
	75-90	1.9	1.15	2.35	1.55	4.4	2.85	3.2	2.4
	90-105	2.8	0.9	2	1	4.95	2.85	1.5	2.25
	105-120	2.2	0.85	3.3	1.25	3.45	3.25	1.55	1.5

TRMT	Depth (cm)	18-Jul-03 Block 1	Block 2	Block 3	Block 4	19-Aug-03 Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	21.85	7.45	6.45	13.25	42.6	49.4	24	53.45
	10-20	6.9	6.15	7	3.95	20.3	24.4	7.6	17.15
	20-30	3.5	3.65	5.9	3.75	12.1	16.3	7.35	10.3
	30-45	4.25	3	3.3	2.35	8.15	10.05	4.2	5.6
	45-60	4.75	3	2.45	2.3	4.55	5.75	3	5.05
	60-75	2.65	2.5	2.2	3.05	5.05	3.7	2.8	5.9
	75-90	1.5	2.85	2.4	1.7	5.3	3.1	2.5	4.05
	90-105	1.9	4.75	1.95	1.1	2.6	3.3	2.25	2.8
	105-120	2.25	2.2	2	1.2	2.8	2.7	2.85	2.9
Manure 5000 gal	0-10	27.8	27.85	23.1	43.35	54.6	75.75	57.85	32.7
	10-20	7.35	16.05	3.9	14.25	30.05	23.4	23.65	18.3
	20-30	3.65	7.6	4.85	15.05	22.05	11.55	13.45	15.55
	30-45	3.1	5.1	3.75	19.4	10.85	8.55	8.65	10.25
	45-60	6	5.05	2.8	16.8	8.45	6.8	6.3	6.65
	60-75	5.9	4.35	4.9	5.25	9.75	3.15	7.1	4.25
	75-90	4.6	4.2	6.35	3.35	7.25	2.25	10.4	3.25
	90-105	8.7	2.5	15.25	3.45	6.05	2.4	4.85	2.65
	105-120	3.9	3.05	3.65	2.75	6.15	3	3.5	2.5
Manure 7500 gal	0-10	49.85	68.55	37.8	37.8	61.25	51.8	110.8	110.8
	10-20	17.05	22.35	17.95	17.95	35.25	15.7	29.8	29.8
	20-30	4.9	10.7	8.6	8.6	17.95	10.15	26.75	26.75
	30-45	4.75	5.55	7.1	7.1	10.85	10.2	15.75	15.75
	45-60	6.9	8.45	7.7	7.7	15.9	11.7	10.25	10.25
	60-75	7.5	10.8	5.35	5.35	15.3	7.15	7.85	7.85
	75-90	8.55	9.75	3.6	3.6	15.25	4.75	5.15	5.15
	90-105	9.25	3.05	2.25	2.25	12.65	3.4	4.4	4.4
	105-120	3.3	4.75	2.2	2.2	7.75	3	4.3	4.3
Fertilizer	0-10	30.55	34.05	70.45	13.25	32.95	42.8	50.8	52.8
	10-20	6.1	14.95	19.8	5.2	15.8	18.05	16.2	28.1
	20-30	6.55	12.9	16.85	3.95	9.65	25.9	12.55	13.55
	30-45	8.9	20.45	21.35	2.45	7.5	22.6	15.25	8.35
	45-60	6.65	18.95	25.15	4.35	7.5	16.2	15.9	9
	60-75	5	7.65	8.8	4.1	7.7	7.3	10.95	11.2
	75-90	2	4	5.15	2.5	4.75	6.9	6.15	7.95
	90-105	1.65	2.15	2.4	1.35	3.25	2.6	2.35	5.2
	105-120	3	2.15	2.15	1.4	2.9	2.65	2.2	2.35
Fertilizer Fallow	0-10	2.25	30.95	67.5	55.3	2.75	34.25	56.4	35.15
	10-20	2.3	35.5	43.35	22.3	2.3	17.35	38.45	39.45
	20-30	1.65	21.7	35.9	14.65	2.55	13.2	34.65	23.85
	30-45	30.6	18.15	38.3	2.6	17.35	12.8	33.45	13.5
	45-60	16.3	9.95	40.2	19.45	10.6	9.95	41.5	14.4
	60-75	14.75	6.5	29.15	28.05	10.35	6.65	35.9	23.75
	75-90	21.7	6.05	16.9	15.25	9.15	9	12.9	16.6
	90-105	38.8	5.3	11.7	12.25	12	7.35	6.95	9.8
	105-120	31.95	5	6.95	5.75	7.5	4.75	3.2	4.65
Control	0-10	3.05	1.8	2.7	8.6	12.05	21.5	10.95	17.25
	10-20	0.9	2.9	2.8	2.45	5.9	8.9	6.45	4.8
	20-30	0.95	2.25	3	1.8	3.15	7.3	4.25	3.65
	30-45	1	1.5	2.4	1.5	2.4	5.95	2.45	2.15
	45-60	0.85	0.8	1.9	1.15	2.6	4.65	1.3	1.65
	60-75	1.95	1	1.9	1.9	2.95	2.65	1.8	1.5
	75-90	2.25	1.3	1.65	1.95	2.75	2.35	1.7	1.55
	90-105	2.3	2	1.3	2.2	2.3	1.6	1.4	1.85
	105-120	1.65	2.3	1.4	1.6	2.55	1.95	1.65	1.75

Appendix E: Mehlich-III phosphorus concentration (mg kg^{-1}) for each field plot near Carberry, MB.

		25-Jun-2002				23-Jul-02			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	18.4	11.9	17.6	15.4	11.2	13.5	8.9	14.5
	10-20	7.3	8.1	8.9	7.6	8.5	9.4	8.1	8.3
	20-30	6.6	3.8	3.9	4.0	6.4	5.1	4.0	5.2
	30-45	9.5	3.2	3.1	2.8	6.7	4.0	3.2	2.5
	45-60	7.8	3.4	3.1	3.3	6.5	3.3	6.0	5.3
	60-90	5.7	4.2	2.7	1.9	5.3	7.0	2.5	1.7
	90-120	4.1	3.2	1.6	1.5	3.3	3.1	1.4	1.5
Manure 5000 gal	0-10	30.9	16.6	11.0	9.5	22.7	9.6	9.7	15.3
	10-20	7.8	14.2	5.7	4.9	4.7	5.3	7.0	10.5
	20-30	3.6	3.6	2.8	2.9	4.5	3.9	4.5	7.1
	30-45	6.2	2.8	3.5	2.3	6.6	3.2	3.6	4.2
	45-60	5.7	3.1	4.8	2.6	4.4	6.7	4.7	4.0
	60-90	4.1	3.7	2.2	2.1	3.7	2.6	3.6	1.2
	90-120	2.5	2.7	1.4	1.5	2.8	2.6	1.7	1.5
Manure 7500 gal	0-10	30.1	27.0	22.5	12.0	36.2	13.7	10.3	22.1
	10-20	8.0	10.1	11.3	6.3	28.9	9.2	7.0	21.4
	20-30	6.3	4.3	5.0	4.5	14.6	5.4	7.1	10.6
	30-45	10.3	6.5	5.1	3.7	13.7	6.7	5.4	6.4
	45-60	5.6	6.7	3.8	3.9	8.0	5.3	3.8	7.9
	60-90	4.5	2.8	3.7	5.5	5.4	2.8	3.3	6.2
	90-120	3.7	2.6	1.7	7.5	2.4	2.1	2.2	3.5
Fertilizer	0-10	16.5	15.3	16.0	16.0	9.8	16.3	10.7	10.7
	10-20	7.4	9.1	6.1	6.1	4.8	9.0	8.4	8.4
	20-30	5.0	2.8	5.4	5.4	5.0	5.7	5.0	5.0
	30-45	5.3	3.5	3.4	3.4	7.2	3.9	3.7	3.7
	45-60	4.1	3.6	3.1	3.1	5.2	4.1	3.3	3.3
	60-90	3.3	2.6	3.3	3.3	3.4	4.4	3.1	3.1
	90-120	2.3	1.7	2.1	2.1	1.8	1.9	2.8	2.8
Fertilizer Fallow	0-10	27.1	65.6	19.1	7.3	10.5	20.3	11.6	10.5
	10-20	8.5	14.4	6.8	3.8	4.0	10.9	9.7	8.2
	20-30	6.0	4.3	3.8	2.8	5.4	5.8	28.5	3.7
	30-45	9.9	3.4	2.0	2.3	7.1	4.4	3.8	2.2
	45-60	7.5	5.3	2.3	3.5	6.6	9.6	3.1	1.9
	60-90	4.6	3.2	2.2	1.7	2.4	2.9	1.0	2.4
	90-120	2.7	2.6	1.4	2.5	3.9	1.7	1.2	2.1
Control	0-10	13.2	18.1	11.3	9.7	14.1	11.9	9.0	8.1
	10-20	7.5	9.1	5.2	6.3	6.6	11.6	7.9	5.2
	20-30	6.3	5.8	2.2	4.0	6.0	8.5	2.5	3.4
	30-45	7.2	4.7	2.7	3.5	6.7	6.8	2.5	2.8
	45-60	4.6	4.4	4.7	2.7	5.8	6.3	6.0	3.4
	60-90	3.3	4.6	2.8	4.0	3.5	5.9	3.7	3.1
	90-120	2.3	3.0	0.9	3.5	2.0	4.5	1.3	2.8

		10-Sep-2002			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	13.3	14.2	20.9	12.0
	10-20	5.7	7.9	6.6	5.3
	20-30	6.4	4.5	2.5	2.5
	30-45	7.4	3.0	2.7	1.6
	45-60	10.1	4.1	2.8	2.9
	60-90	7.2	4.6	3.1	1.8
	90-120	5.0	2.7	1.5	1.4
Manure 5000 gal	0-10	24.6	18.6	25.5	31.0
	10-20	7.1	5.2	8.5	7.8
	20-30	3.5	4.3	3.0	2.7
	30-45	6.8	4.9	4.7	2.5
	45-60	6.1	9.2	3.3	3.7
	60-90	3.9	2.9	1.3	1.6
	90-120	3.0	3.2	1.6	1.3
Manure 7500 gal	0-10	20.2	18.2	15.5	9.1
	10-20	8.2	8.1	7.7	6.7
	20-30	6.1	2.9	3.3	3.0
	30-45	6.1	6.1	3.8	3.0
	45-60	5.8	4.5	4.4	3.0
	60-90	6.2	3.0	3.5	2.8
	90-120	3.6	1.8	0.6	1.5
Fertilizer	0-10	22.2	20.4	12.9	12.9
	10-20	16.8	14.3	6.4	6.4
	20-30	5.3	2.5	4.6	4.6
	30-45	7.0	4.3	3.5	3.5
	45-60	6.5	4.6	4.1	4.1
	60-90	4.3	3.8	3.4	3.4
	90-120	3.4	2.0	3.3	3.3
Fertilizer Fallow	0-10	33.7	65.7	51.1	14.5
	10-20	10.8	26.0	32.0	5.7
	20-30	7.6	2.9	2.5	5.5
	30-45	11.5	5.6	2.6	2.9
	45-60	6.9	5.4	3.1	2.9
	60-90	4.8	3.6	2.0	2.5
	90-120	2.9	1.6	1.2	1.2
Control	0-10	9.5	14.8	12.3	14.4
	10-20	6.0	7.0	4.1	6.5
	20-30	4.8	5.6	2.0	2.7
	30-45	5.6	7.8	2.0	7.8
	45-60	5.6	8.5	3.6	3.3
	60-90	4.4	7.6	3.0	3.0
	90-120	3.0	5.4	2.0	1.6

		9-Oct-02			
TRMT	Depth (cm)	Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	24.8	12.7	12.6	23.4
	10-20	4.7	4.8	3.1	3.7
	20-30	6.5	3.4	2.0	2.3
	30-45	8.6	2.5	2.1	2.5
	45-60	6.7	3.6	3.7	3.0
	60-75	6.1	4.9	2.6	1.6
	75-90	5.0	3.2	2.6	0.9
	90-120	3.8	2.5	0.9	1.2
Manure 5000 gal	0-10	16.8	16.6	19.5	17.3
	10-20	4.2	3.2	5.9	6.8
	20-30	2.6	2.5	2.5	2.5
	30-45	4.4	3.0	3.9	2.3
	45-60	6.9	5.3	4.2	2.4
	60-75	3.4	5.6	2.0	7.0
	75-90	3.0	1.2	1.3	2.2
	90-120	2.7	2.0	1.3	1.7
Manure 7500 gal	0-10	31.0	22.5	16.0	19.2
	10-20	4.1	2.8	4.9	4.3
	20-30	5.2	4.5	3.2	3.6
	30-45	5.6	5.9	3.6	3.0
	45-60	4.4	3.3	3.9	3.8
	60-75	3.8	2.4	2.5	2.6
	75-90	3.1	1.4	1.9	1.8
	90-120	2.3	2.1	1.0	0.9
Fertilizer	0-10	19.4	16.8	16.8	10.1
	10-20	4.3	3.0	3.0	3.4
	20-30	6.9	2.3	2.3	2.6
	30-45	9.4	3.8	3.8	2.2
	45-60	4.4	4.4	4.4	7.6
	60-75	4.0	3.2	3.2	1.8
	75-90	3.4	2.1	2.1	0.8
	90-120	1.7	2.2	2.2	1.4
Fertilizer Fallow	0-10	34.1	19.7	23.7	18.8
	10-20	3.7	2.6	3.0	3.3
	20-30	4.6	2.4	2.4	2.3
	30-45	5.1	16.7	2.6	4.8
	45-60	3.1	6.4	3.4	3.6
	60-75	4.0	4.2	1.3	3.3
	75-90	2.8	1.3	6.3	0.8
	90-120	2.4	1.5	4.9	0.7
Control	0-10	17.4	17.8	10.8	14.4
	10-20	5.4	5.4	3.8	3.6
	20-30	6.5	5.7	2.0	2.5
	30-45	4.6	7.2	1.7	2.3
	45-60	4.0	8.2	3.6	2.9
	60-75	3.6	8.5	2.1	2.4
	75-90	2.8	3.2	0.3	1.4
	90-120	1.9	3.7	0.6	3.7

TRMT	Depth (cm)	9-May-03 Block 1	Block 2	Block 3	Block 4	19-Jun-03 Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	20.7	8.8	19.8	10.0	24.9	11.0	11.1	13.9
	10-20	3.9	2.7	2.7	2.7	9.3	14.2	6.8	9.2
	20-30	6.5	2.3	1.7	2.0	13.0	3.7	3.7	4.2
	30-45	14.3	2.5	4.7	1.9	10.7	3.5	3.6	3.0
	45-60	4.8	3.4	3.0	2.7	9.5	3.7	4.1	3.1
	60-75	4.5	5.4	2.3	1.2	9.2	5.9	3.5	2.6
	75-90	3.9	2.7	2.0	1.1	8.8	3.5	1.8	3.5
	90-105	3.1	2.3	1.3	1.1	5.5	3.2	2.4	1.3
	105-120	10.9	2.7	1.2	1.9	3.4	2.6	2.1	1.3
Manure 5000 gal	0-10	13.6	11.6	10.8	26.0	36.7	16.6	26.9	15.1
	10-20	2.3	2.3	3.1	2.7	11.9	6.1	8.3	9.6
	20-30	14.7	2.1	2.3	2.4	10.6	3.1	7.0	4.3
	30-45	7.3	2.4	2.0	2.2	8.9	7.7	3.7	3.5
	45-60	3.8	5.4	6.5	3.2	7.7	5.9	7.5	3.4
	60-75	3.9	2.2	2.0	1.9	8.0	7.2	2.6	2.3
	75-90	2.7	1.8	1.7	1.6	4.0	3.3	2.2	2.3
	90-105	1.7	3.0	1.4	1.5	2.5	3.7	5.5	1.1
	105-120	2.0	2.8	1.3	2.7	3.1	4.3	2.2	2.3
Manure 7500 gal	0-10	21.1	14.4	15.8	24.3	31.1	15.4	20.5	27.7
	10-20	3.7	3.2	3.6	3.3	11.4	12.1	10.3	12.9
	20-30	6.6	3.8	4.2	2.3	9.0	6.8	6.5	4.9
	30-45	6.2	8.2	3.3	2.0	12.1	5.2	4.1	5.3
	45-60	4.0	3.7	3.3	2.2	6.8	3.1	3.1	4.5
	60-75	6.0	2.7	4.0	1.6	3.3	2.4	3.4	4.3
	75-90	2.9	1.7	2.9	1.2	3.2	2.3	4.5	2.4
	90-105	2.5	2.2	1.7	1.4	3.6	2.6	5.2	2.3
	105-120	2.9	1.5	2.0	1.5	3.3	5.4	4.8	2.5
Fertilizer	0-10	26.4	17.2	17.6	10.2	30.8	19.6	36.5	14.4
	10-20	3.2	2.7	4.4	3.1	13.1	5.3	8.9	7.6
	20-30	5.8	2.4	3.7	1.6	10.6	8.3	4.8	3.4
	30-45	4.7	3.9	3.4	1.4	20.1	3.4	2.6	2.8
	45-60	5.1	4.0	4.1	2.1	7.3	4.7	3.3	3.2
	60-75	2.7	3.6	2.8	1.7	4.0	3.6	2.4	2.1
	75-90	4.7	1.8	2.0	1.7	2.6	2.7	2.2	2.7
	90-105	1.4	1.8	1.3	1.4	2.9	3.0	2.3	1.9
	105-120	4.0	1.3	1.9	1.8	4.6	2.9	3.4	1.6
Fertilizer Fallow	0-10	21.2	29.0	33.4	36.6	21.4	20.2	22.9	14.7
	10-20	5.2	11.3	6.2	3.3	8.8	5.2	19.0	14.6
	20-30	13.5	3.0	2.0	1.9	5.9	4.5	12.8	5.3
	30-45	3.5	3.9	2.4	2.1	9.8	4.3	4.2	4.8
	45-60	2.9	7.9	2.9	2.5	5.0	5.8	3.1	3.6
	60-75	3.3	3.8	1.8	4.3	2.4	3.9	2.8	2.0
	75-90	3.5	2.2	1.4	1.2	2.7	2.8	2.4	1.8
	90-105	4.1	1.9	1.9	1.0	1.8	2.0	2.8	2.3
	105-120	2.0	2.0	1.9	1.6	2.0	2.6	2.3	2.3
Control	0-10	13.6	21.4	9.4	13.3	6.5	14.7	11.5	11.2
	10-20	3.7	3.7	3.1	3.4	8.3	8.0	6.0	5.2
	20-30	7.6	4.2	2.3	2.1	7.4	6.5	4.4	3.1
	30-45	4.8	4.9	1.8	2.6	8.2	5.8	3.1	2.8
	45-60	3.7	4.6	5.1	3.8	6.7	5.0	3.7	4.3
	60-75	2.4	4.5	4.4	2.4	6.4	6.7	2.4	2.3
	75-90	2.1	3.4	1.1	1.0	3.3	4.4	3.0	2.3
	90-105	2.1	3.6	1.4	1.5	2.8	4.5	1.8	1.5
	105-120	1.7	4.8	1.2	1.1	2.8	4.6	1.8	2.5

TRMT	Depth (cm)	18-Jul-03 Block 1	18-Jul-03 Block 2	18-Jul-03 Block 3	18-Jul-03 Block 4	19-Aug-03 Block 1	19-Aug-03 Block 2	19-Aug-03 Block 3	19-Aug-03 Block 4
Manure 2500 gal	0-10	21.2	11.3	8.0	13.7	18.1	18.4	18.1	26.4
	10-20	7.5	6.9	5.6	4.0	11.3	9.5	7.0	7.3
	20-30	9.6	3.9	3.7	2.9	10.4	5.5	3.7	5.6
	30-45	9.5	3.6	2.7	2.5	7.4	3.9	3.0	3.8
	45-60	9.3	5.9	4.3	4.7	10.5	5.8	8.8	4.5
	60-75	9.0	7.8	3.5	2.5	6.4	9.1	5.7	1.5
	75-90	6.5	2.3	1.9	1.1	5.6	4.3	1.9	1.0
	90-105	3.7	2.7	1.9	1.2	8.3	2.9	3.6	1.0
	105-120	3.7	5.2	1.8	0.8	4.0	3.0	1.2	1.1
Manure 5000 gal	0-10	21.9	10.0	16.1	28.5	25.6	28.8	23.6	13.9
	10-20	4.9	10.0	1.2	6.9	15.0	10.2	9.4	16.3
	20-30	5.1	3.7	3.4	3.9	10.8	4.6	6.6	6.8
	30-45	3.6	2.8	3.7	3.0	8.6	5.0	6.1	5.2
	45-60	3.7	11.0	9.5	4.6	18.9	9.7	11.3	4.7
	60-75	3.2	8.4	3.0	1.8	8.0	8.9	3.2	1.8
	75-90	2.3	2.7	1.6	3.8	7.6	6.2	2.3	1.8
	90-105	1.2	1.8	9.4	1.7	3.2	1.8	1.4	4.2
	105-120	1.3	1.8	1.3	2.1	2.8	2.1	1.3	2.4
Manure 7500 gal	0-10	43.1	19.2	18.6	17.3	21.3	31.8	37.3	17.1
	10-20	21.0	10.6	7.1	5.1	21.9	6.2	11.2	9.7
	20-30	15.4	8.8	4.2	5.8	11.7	7.1	11.2	7.4
	30-45	6.7	8.1	10.3	2.8	8.5	10.3	4.9	4.6
	45-60	4.7	3.9	2.8	3.2	6.4	4.8	4.8	4.4
	60-75	4.8	2.5	3.0	2.6	5.8	7.0	5.1	3.0
	75-90	3.5	1.7	1.8	3.2	4.5	2.2	3.0	2.2
	90-105	2.1	2.6	1.6	1.4	3.6	2.5	2.1	1.3
	105-120	2.4	2.4	1.5	1.3	4.6	3.2	1.7	1.4
Fertilizer	0-10	24.5	10.5	10.0	19.3	16.7	23.8	18.0	20.9
	10-20	5.3	6.4	6.7	8.3	8.1	5.3	6.6	10.2
	20-30	5.8	6.0	4.9	4.1	7.9	5.0	5.8	5.7
	30-45	6.3	5.1	3.8	2.9	8.3	9.8	3.9	3.8
	45-60	5.2	4.3	2.2	3.7	6.2	3.7	4.7	2.4
	60-75	3.5	4.6	3.1	4.3	5.2	4.2	3.7	2.0
	75-90	3.2	2.1	9.5	1.7	8.5	2.4	2.2	1.5
	90-105	1.5	5.4	2.4	1.4	2.1	3.2	2.1	1.1
	105-120	1.7	4.1	1.9	1.5	2.0	1.9	2.1	1.4
Fertilizer Fallow	0-10	23.8	15.8	23.1	26.4	18.9	23.5	21.3	17.5
	10-20	9.4	12.1	7.4	4.5	9.2	8.5	14.6	17.2
	20-30	14.5	5.2	3.8	6.0	10.8	5.7	10.5	10.3
	30-45	9.1	3.9	2.3	2.3	12.8	10.8	7.2	4.0
	45-60	3.2	4.3	2.0	8.5	6.4	7.7	6.5	7.2
	60-75	3.3	4.2	2.0	1.5	3.7	4.6	2.6	1.8
	75-90	3.2	1.7	1.4	1.2	4.3	3.4	3.4	1.0
	90-105	1.9	1.7	1.4	1.3	1.8	1.8	2.0	1.4
	105-120	1.7	1.9	1.6	5.6	1.5	2.0	2.0	3.9
Control	0-10	14.1	11.3	5.4	20.7	14.5	20.6	10.5	19.6
	10-20	7.5	5.6	3.2	12.1	9.4	7.1	6.3	5.6
	20-30	9.4	6.4	2.3	5.0	12.3	7.6	3.8	4.4
	30-45	7.5	6.1	2.9	3.2	6.0	5.2	3.8	3.0
	45-60	4.9	8.0	6.8	4.4	5.3	6.7	10.0	2.6
	60-75	3.6	7.6	2.0	2.5	7.1	8.3	2.9	2.6
	75-90	3.1	5.3	1.6	1.9	4.4	4.6	2.3	1.3
	90-105	1.4	7.1	1.0	1.4	3.5	3.7	1.3	1.3
	105-120	2.9	7.9	1.4	1.2	8.1	6.0	2.1	1.4

TRMT	Depth (cm)	8-Oct-03 Block 1	Block 2	Block 3	Block 4
Manure 2500 gal	0-10	19.2	10.1	11.8	9.3
	10-20	4.7	3.3	2.5	2.7
	20-30	12.6	2.3	1.8	1.9
	30-45	6.6	4.2	4.7	2.6
	45-60	6.4	8.1	7.6	3.0
	60-75	5.5	2.9	3.5	1.4
	75-90	5.4	2.9	1.5	1.3
	90-105	2.7	2.4	1.2	0.7
	105-120	6.3	2.7	1.2	1.0
Manure 5000 gal	0-10	20.5	14.0	11.4	16.3
	10-20	3.3	3.4	2.4	2.5
	20-30	5.9	2.6	3.1	2.1
	30-45	11.9	3.8	6.0	3.8
	45-60	5.6	10.3	4.3	3.8
	60-75	4.0	4.2	2.0	2.5
	75-90	3.6	1.7	2.0	1.9
	90-105	0.9	1.7	1.5	2.6
	105-120	1.1	1.5	1.2	2.1
Manure 7500 gal	0-10	30.6	21.0	15.7	18.1
	10-20	4.3	3.2	6.4	3.8
	20-30	10.7	7.5	4.3	2.9
	30-45	5.4	8.6	7.6	3.2
	45-60	5.6	4.0	6.4	5.4
	60-75	4.2	3.0	5.5	3.9
	75-90	3.4	1.8	2.2	2.8
	90-105	1.5	2.7	1.8	1.1
	105-120	2.1	2.2	1.5	1.6
Fertilizer	0-10	33.4	41.7	19.8	17.4
	10-20	6.3	7.7	4.3	3.7
	20-30	8.7	4.4	4.9	2.2
	30-45	8.3	8.5	3.9	2.8
	45-60	5.8	4.0	3.1	2.7
	60-75	5.5	2.7	4.5	0.9
	75-90	6.0	2.3	3.8	2.1
	90-105	4.3	2.2	2.6	1.4
	105-120	1.8	3.1	3.0	2.4
Fertilizer Fallow	0-10	17.3	9.6	18.8	19.2
	10-20	6.4	2.4	3.1	2.7
	20-30	11.8	2.9	1.8	2.2
	30-45	3.7	7.0	3.7	3.7
	45-60	3.9	4.4	1.8	3.3
	60-75	4.9	3.7	3.5	1.6
	75-90	2.2	1.5	0.9	1.4
	90-105	3.1	1.4	1.3	1.4
	105-120	2.0	2.1	2.3	1.4
Control	0-10	16.2	16.7	4.9	14.7
	10-20	6.1	9.2	1.7	3.1
	20-30	13.2	4.1	2.3	2.0
	30-45	6.5	4.6	4.0	2.8
	45-60	3.5	7.0	13.3	5.7
	60-75	4.8	15.7	2.1	2.5
	75-90	2.9	2.6	1.4	1.4
	90-105	2.0	3.5	0.9	1.5
	105-120	3.5	16.1	1.3	1.4

Appendix F: Plant data for 2002 and 2003 for each field plot near Carberry, MB.

Table F1: Midseason biomass yield of wheat (kg ha^{-1}), July 23, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	1597	2144	1773	1368	1299	**1636b**
Block 2	1920	2492	2560	2381	1646	**2200ab**
Block 3	2597	1823	3119	2525	1803	**2373a**
Block 4	2209	1409	3073	2714	2068	**2295a**
Mean	**2081ab**	**1967b**	**2631a**	**2247ab**	**1704b**	

Table F2: Nitrogen Concentration of wheat biomass (%), July 23, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	1.92	2.05	2.47	1.92	1.81	**2.03a**
Block 2	2.17	2.34	2.19	1.97	1.98	**2.13a**
Block 3	1.83	2.17	2.02	2.47	1.70	**2.04a**
Block 4	2.02	2.22	2.08	2.42	1.58	**2.06a**
Mean	**1.99ab**	**2.20a**	**2.19a**	**2.20a**	**1.77b**	

Table F3: Phosphorus concentration of wheat biomass (%), July 23, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	0.22	0.21	0.21	0.22	0.24	**0.22a**
Block 2	0.21	0.23	0.21	0.21	0.25	**0.22a**
Block 3	0.21	0.23	0.21	0.22	0.24	**0.22a**
Block 4	0.25	0.23	0.21	0.23	0.22	**0.23a**
Mean	**0.22ab**	**0.23ab**	**0.21b**	**0.22ab**	**0.24a**	

Table F4: Total nitrogen uptake by wheat biomass (kg ha^{-1}) , July 23, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	30.7	43.9	43.8	26.3	23.5	**33.6b**
Block 2	41.7	58.4	56.0	46.9	32.7	**47.1a**
Block 3	47.5	39.6	62.9	62.3	30.7	**48.6a**
Block 4	44.5	31.3	63.9	65.7	32.6	**47.6a**
Mean	**41.1bc**	**43.3abc**	**56.6a**	**50.3ab**	**29.9c**	

Table F5: Total phosphorus uptake by wheat biomass (kg ha^{-1}), July 23, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	3.53	4.54	3.72	3.04	3.18	**3.6b**
Block 2	4.08	5.85	5.29	5.01	4.07	**4.9a**
Block 3	5.56	4.13	6.46	5.59	4.25	**5.2a**
Block 4	5.43	3.22	6.43	6.17	4.60	**5.2a**
Mean	**4.7ab**	**4.4ab**	**5.5a**	**5.0ab**	**4.0b**	

Table F6: Wheat grain yield (kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	793	1536	790	890	986	**999a**
Block 2	1198	1562	1139	1653	1206	**1352a**
Block 3	1479	1180	1690	2068	913	**1466a**
Block 4	1359	747	1574	1656	1279	**1324a**
Mean	**1207a**	**1256a**	**1299a**	**1567a**	**1096a**	

Table F7: Nitrogen Concentration of wheat grain (%), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	3.00	2.84	3.22	3.56	2.83	**3.09a**
Block 2	2.88	2.81	2.95	2.97	2.83	**2.89b**
Block 3	2.80	2.91	3.00	2.97	2.77	**2.89b**
Block 4	2.78	2.84	2.84	2.89	2.83	**2.84b**
Mean	**2.87b**	**2.85b**	**3.00ab**	**3.10a**	**2.82b**	

Table F8: Phosphorus concentration of wheat grain (%), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	0.42	0.38	0.50	0.42	0.41	**0.43a**
Block 2	0.40	0.39	0.38	0.45	0.47	**0.42a**
Block 3	0.37	0.39	0.51	0.48	0.45	**0.44a**
Block 4	0.42	0.42	0.36	0.38	0.48	**0.41a**
Mean	**0.41a**	**0.40a**	**0.44a**	**0.43a**	**0.45a**	

Table F9: Total nitrogen uptake by wheat grain (kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	23.8	43.7	25.4	31.7	27.9	**30.5a**
Block 2	34.4	43.9	33.6	49.1	34.1	**39.0a**
Block 3	41.4	34.3	50.7	61.4	25.2	**42.6a**
Block 4	37.8	21.2	44.8	47.9	36.2	**37.6a**
Mean	**34.4ab**	**35.8ab**	**38.6ab**	**47.5a**	**30.9b**	

Table F10: Total phosphorus uptake by wheat grain (kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	3.3	5.8	3.9	3.8	4.1	**4.2b**
Block 2	4.8	6.2	4.4	7.5	5.7	**5.7ab**
Block 3	5.5	4.6	8.6	9.8	4.1	**6.5a**
Block 4	5.7	3.2	5.7	6.3	6.1	**5.4ab**
Mean	**4.8a**	**4.9a**	**5.7a**	**6.8a**	**5.0a**	

Table F11: Straw yield of wheat (kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	1413	2283	2490	1587	1501	**1855b**
Block 2	2159	2628	2186	2681	2166	**2364ab**
Block 3	2506	2199	2965	3473	1746	**2578a**
Block 4	1895	1523	2709	2764	2097	**2198ab**
Mean	**1994ab**	**2158ab**	**2588a**	**2627a**	**1878b**	

Table F12: Nitrogen concentration of wheat straw (%), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	0.62	0.50	0.63	0.70	0.60	**0.61a**
Block 2	0.54	0.58	0.62	0.54	0.56	**0.57a**
Block 3	0.58	0.67	0.69	0.60	0.43	**0.59a**
Block 4	0.49	0.64	0.66	0.56	0.53	**0.58a**
Mean	**0.56ab**	**0.60ab**	**0.65a**	**0.60ab**	**0.53b**	

Table F13: Phosphorus concentration of wheat straw (%), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	0.06	0.05	0.06	0.07	0.06	**0.06a**
Block 2	0.04	0.04	0.05	0.05	0.06	**0.05a**
Block 3	0.05	0.06	0.06	0.05	0.04	**0.05a**
Block 4	0.04	0.06	0.05	0.04	0.05	**0.05a**
Mean	**0.05a**	**0.05a**	**0.05a**	**0.05a**	**0.05a**	

Table F14: Total nitrogen uptake by wheat straw (kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	8.7	11.5	15.6	11.2	9.0	**11.2b**
Block 2	11.7	15.2	13.5	14.6	12.2	**13.4ab**
Block 3	14.6	14.8	20.4	20.7	7.6	**15.6a**
Block 4	9.2	9.8	17.8	15.4	11.2	**12.7ab**
Mean	**11.1c**	**12.8bc**	**16.9a**	**15.5ab**	**9.9c**	

Table F15: Total phosphorus uptake by wheat straw (kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	0.9	1.1	1.4	1.2	0.9	**1.1ab**
Block 2	0.9	1.1	1.1	1.3	1.2	**1.1ab**
Block 3	1.2	1.4	1.9	1.8	0.7	**1.4a**
Block 4	0.7	0.9	1.2	1.2	1.0	**1.0b**
Mean	**0.9c**	**1.1abc**	**1.4a**	**1.3ab**	**1.0bc**	

Table F16: Total nitrogen uptake (grain + straw, kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	32.5	55.2	41.0	42.9	36.9	**41.7b**
Block 2	46.1	59.1	47.2	63.6	46.3	**52.5ab**
Block 3	55.9	49.1	71.1	82.1	32.8	**58.3a**
Block 4	47.0	31.0	62.5	63.3	47.4	**50.3ab**
Mean	**45.4b**	**48.6ab**	**55.6ab**	**63.0a**	**40.8b**	

Table F17: Total phosphorus uptake (grain + straw, kg ha^{-1}), September 6, 2002

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	4.2	6.9	5.4	4.9	5.0	**5.3b**
Block 2	5.7	7.2	5.5	8.7	6.9	**6.8ab**
Block 3	6.7	6.0	10.4	11.7	4.9	**7.9a**
Block 4	6.5	4.0	6.9	7.5	7.1	**6.4ab**
Mean	**5.8a**	**6.0a**	**7.1a**	**8.2a**	**6.0a**	

Table F18: Wheat grain yield (kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	514	620	722	547	581	**597c**
Block 2	998	1013	713	1376	1272	**1075b**
Block 3	1287	1116	1400	1651	1118	**1314ab**
Block 4	1435	1241	1455	1567	1197	**1379a**
Mean	**1059ab**	**998b**	**1073ab**	**1285a**	**1042ab**	

Table F19: Nitrogen Concentration of wheat grain (%), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	3.17	3.05	3.09	3.19	2.84	**3.07a**
Block 2	3.04	2.23	3.08	2.51	2.65	**2.70b**
Block 3	2.86	2.93	3.05	3.04	2.77	**2.93ab**
Block 4	2.94	2.80	2.88	3.04	2.67	**2.87ab**
Mean	**3.00ab**	**2.75ab**	**3.02a**	**2.95ab**	**2.73b**	

Table F20: Phosphorus concentration of wheat grain (%), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	0.27	0.35	0.35	0.40	0.34	**0.34a**
Block 2	0.36	0.32	0.31	0.31	0.31	**0.32a**
Block 3	0.35	0.31	0.36	0.38	0.38	**0.36a**
Block 4	0.33	0.31	0.31	0.41	0.35	**0.34a**
Mean	**0.33a**	**0.32a**	**0.33a**	**0.37a**	**0.34a**	

Table F21: Total nitrogen uptake by wheat grain (kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	16.3	18.9	22.3	17.4	16.5	**18.3c**
Block 2	30.3	22.6	21.9	34.6	33.7	**28.7b**
Block 3	36.8	32.7	42.7	50.2	30.9	**38.7a**
Block 4	42.2	34.8	41.8	47.7	32.0	**39.7a**
Mean	**31.4ab**	**27.2b**	**32.2ab**	**37.5a**	**28.3b**	

Table F22: Total phosphorus uptake by wheat grain (kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	Mean
Block 1	1.4	2.2	2.5	2.2	2.0	**2.1c**
Block 2	3.6	3.2	2.2	4.3	3.9	**3.5b**
Block 3	4.5	3.5	5.1	6.2	4.2	**4.7a**
Block 4	4.8	3.9	4.6	6.4	4.1	**4.8a**
Mean	**3.6b**	**3.2b**	**3.6b**	**4.8a**	**3.6b**	

Table F23: Straw yield of wheat (kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	1063	1109	1316	1021	1052	**1112c**
Block 2	1697	1614	1220	1927	1972	**1686b**
Block 3	1973	1720	2639	2764	1810	**2181a**
Block 4	2510	2216	2368	2529	1865	**2298a**
Mean	**1811a**	**1665a**	**1886a**	**2060a**	**1675a**	

Table F24: Nitrogen concentration of wheat straw (%), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	0.69	0.80	0.67	0.82	0.62	**0.72a**
Block 2	0.50	0.62	0.76	0.45	0.46	**0.56b**
Block 3	0.52	0.43	0.52	0.49	0.55	**0.50b**
Block 4	0.44	0.43	0.50	0.49	0.46	**0.46b**
Mean	**0.54a**	**0.57a**	**0.61a**	**0.56a**	**0.52a**	

Table F25: Phosphorus concentration of wheat straw (%), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	0.05	0.07	0.05	0.07	0.03	**0.05a**
Block 2	0.03	0.05	0.06	0.03	0.04	**0.04ab**
Block 3	0.03	0.02	0.04	0.03	0.04	**0.03b**
Block 4	0.03	0.03	0.03	0.04	0.04	**0.03b**
Mean	**0.03a**	**0.04a**	**0.04a**	**0.04a**	**0.04a**	

Table F26: Total nitrogen uptake by wheat straw (kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	7.4	8.9	8.8	8.4	6.5	**8.0b**
Block 2	8.6	10.0	9.3	8.7	9.0	**9.1ab**
Block 3	10.2	7.4	13.6	13.6	9.9	**10.9a**
Block 4	11.1	9.6	11.7	12.4	8.5	**10.7a**
Mean	**9.3ab**	**9.0ab**	**10.9a**	**10.8a**	**8.5b**	

Table F27: Total phosphorus uptake by wheat straw (kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	0.5	0.8	0.6	0.7	0.3	**0.60a**
Block 2	0.5	0.8	0.7	0.5	0.7	**0.64a**
Block 3	0.6	0.4	1.1	0.9	0.8	**0.77a**
Block 4	0.7	0.6	0.7	0.9	0.7	**0.74a**
Mean	**0.59a**	**0.65a**	**0.79a**	**0.76a**	**0.64a**	

Table F28: Total nitrogen uptake (grain + straw, kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	23.7	27.8	31.1	25.9	23.0	**26.3c**
Block 2	38.9	32.6	31.2	43.3	42.7	**37.7b**
Block 3	47.0	40.0	56.3	63.8	40.8	**49.6a**
Block 4	53.3	44.4	53.6	60.1	40.4	**50.4a**
Mean	**40.7ab**	**36.2b**	**43.1ab**	**48.3a**	**36.8b**	

Table F29: Total phosphorus uptake (grain + straw, kg ha^{-1}), August 19, 2003

	Manure 2500 gal	Manure 5000 gal	Manure 7500 gal	Fertilizer	Control	**Mean**
Block 1	1.9	3.0	3.1	2.9	2.3	**2.5c**
Block 2	4.1	4.0	2.9	4.8	4.6	**4.1b**
Block 3	5.1	3.8	6.2	7.1	5.1	**5.5a**
Block 4	5.5	4.5	5.3	7.3	4.8	**5.5a**
Mean	**4.2b**	**3.8b**	**4.4ab**	**5.5a**	**4.2b**	

Appendix G: Lysimeter leachate data for field plots near Carberry, MB.

Date	Plot	Treatment	Leachate Volume	NH_4	NO_3	DOC	Leachate Collected	Total Leachate Collected	NO_3 in leachate	Total NO_3-N
			---- g ----	---------- mg/kg		------------	--------- mm	---------	--------- kg/ha	-------
10-Jun-2003	Plot 2	M7500	15	0.14	0.5		0.1		0.00	
24-Jun-2003		M7500	19	0.29	0.1	62.5	0.1	0.1	0.00	0.00
13-May-2003	Plot 3	Control	1687	0.01	23.4	298	7.2		1.69	
23-May-2003		Control	3377	0.14	38.1	324	14.5		5.53	
10-Jun-2003		Control	3647	0.57	43.1	227	15.7		6.75	
24-Jun-2003		Control	2303	1.20	39.7	110.9	9.9		3.92	
3-Jul-2003		Control	56	0.39	37.1		0.2	47.5	0.09	17.98
8-May-2003	Plot 4	Fert Fallow	6213	0.14	121.5	730	26.7		32.38	
13-May-2003		Fert Fallow	7877	0.16	96.5	304	33.8		32.61	
23-May-2003		Fert Fallow	1029	0.18	107.8	241.6	4.4		4.76	
10-Jun-2003		Fert Fallow	3667	0.15	93.2	174.3	15.7		14.67	
24-Jun-2003		Fert Fallow	1907	0.16	86.5	88.2	8.2		7.08	
3-Jul-2003		Fert Fallow	1337	0.10	89.6	44.3	5.7		5.14	
12-Nov-2003		Fert Fallow	5026	0.09	104.4	39.8	21.6	116.1	22.51	119.1
8-May-2003	Plot 7	Fert Fallow	5157	0.12	53.9	301.5	22.1		11.92	
13-May-2003		Fert Fallow	3111	0.05	7.3	64.3	13.4		0.97	
23-May-2003		Fert Fallow	575	0.23	7.4	103.6	2.5		0.18	
10-Jun-2003		Fert Fallow	241	0.13	60.7	65.2	1.0		0.63	
24-Jun-2003		Fert Fallow	643	0.24	64.4	59.4	2.8		1.78	
3-Jul-2003		Fert Fallow	777	0.10	66.0	202.8	3.3		2.20	
12-Nov-2003		Fert Fallow	6532	0.11	81.3	58.2	28.0	73.1	22.79	40.5
10-Jun-2003	Plot 8	M7500	793	0.04	28.1	356	3.4		0.96	
24-Jun-2003		M7500	1019	0.63	24.0	197.8	4.4		1.05	
3-Jul-2003		M7500	73	0.02	24.0	74.9	0.3	8.1	0.07	2.08
12-Nov-2003	Plot 16	Fert Fallow	2112	0.04	39.0	35	9.1	9.1	3.53	3.53
23-May-2003	Plot 19	Fert Fallow	683	0.00	0.0	1394	2.9		0.00	
10-Jun-2003		Fert Fallow	57	0.04	0.6	213.2	0.2	3.2	0.00	0.00