The Effect of Integrated Management Practices on Crop and Soil Nutrient Dynamics

by

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A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfilment of the requirements of the degree of

Master of Science

Department of Plant Science

University of Manitoba

Winnipeg, Manitoba, Canada

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ACKNOWLEDGEMENTS

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Aunt Mildred

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AGVISE Laboratories, Inc.

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ABSTRACT

Slawinski, Karl Ryan. M.Sc. The University of Manitoba, February, 2010. The Effect of Integrated Management Practices on Crop and Soil Nutrient Dynamics. Major Professor; Cynthia A. Grant.

This study was undertaken to evaluate the pattern of release and uptake of N for durum wheat (*Triticum durum* Desf. cv. AC Avonlea) grown on field pea (*Pisum sativa* L.) stubble in 2002 and 2003 under a range of management systems including (i) organic (no inputs), (ii) organic with composted beef cattle (*Bos taurus*) manure, (iii) synthetic fertilizer, no pesticides, (iv) Pesticide Free Production (PFP™) (synthetic fertilizer, pesticides used before crop growth and in other crops in the rotation, no pesticides applied to the growing target crop and no residual pesticides) and (v) integrated management (synthetic fertilizer, pesticides applied as required). Regardless of management system, the greatest soil NO_3^- contents were generally observed between the time of seeding and the first crop stage sampled with maximum crop N accumulation occurring by anthesis. Measured soil and crop N variables tended to be greatest in systems receiving synthetic fertilizer. The strictly legume and legume and composted manure based fertility systems were not able to supply sufficient N for optimum crop production based on a sufficiency N concentration of 2 to 3% in the whole plant prior to filling. Systems receiving synthetic urea fertilizer without pesticides also experienced N limitations in response to competition from significantly higher weed biomass. The PFP™ system was able to produce dry matter and final grain yields comparable to the integrated management system suggesting effective crop production may be possible in a reduced pesticide system as long as adequate nutrients are available to meet crop demand. The effectiveness of Plant Root Simulator™ (PRS) probes and the Illinois soil N test

(ISNT) for predicting soil N release through the growing season were also evaluated. Good relationships were found between mid season PRS-NO_3^- and crop N uptake (r = 0.51* and 0.64**) in 2002 and 2003 respectively. Although a greater correlation was observed between mid season soil NO_3^- content and crop N uptake compared to mid season PRS-NO_3^- and crop uptake, no significant correlation was observed between early season NO_3^- concentrations and crop N uptake. There was no correlation between ISNT-N and crop N uptake in either year of study. The ISNT was not a reliable indicator of potential N release under Manitoba conditions, based on the critical value of 300 mg kg^{-1} suggested for soil samples collected from a 0-15 cm depth from corn sites in Illinois. The lack of strong, consistent relationships between early season assessment of N release potential and crop N uptake make it difficult to use these indices for adjusting recommended fertilizer rates.

FOREWORD

This thesis has been prepared in paper style format as outlined in the Department of Plant Science's Guide to Thesis Preparation. Manuscripts were formatted according to The Canadian Journal of Plant Science.

1.0 INTRODUCTION

Nitrogen is a major constituent of all plants and thus is considered one of the most important nutrients in crop production. Before synthetic N fertilizer was widely available, farmers relied almost entirely on N_2-fixing crops and animal manures to sustain crop yields (Stanford, 1982; Pang and Letey, 2000). Successful commercialization of the Haber-Bosch process, where N_2 is reacted with H_2 over an iron substrate to produce NH_3, in 1913 permitted fixation of N_2 on an industrial scale (BASF, 2009). The NH_3 produced could be used directly as a fertilizer (anhydrous NH_3) or used to manufacture other fertilizer N products (Havlin et al., 1999) and by 1945, the use of synthetic N fertilizer had increased dramatically (Stanford, 1982).Toda y, commercial fertilizer supplies basic food needs for at least 40% of the global population (Fixen and West, 2002). It is estimated that at least 60% of humanity will eventually rely on N fertilizers for basic nutritional needs as global population increases and diets in developing countries improve (Smil, 2001; cited in Fixen and West, 2002). The challenge is to continue meeting human needs while minimizing the potential negative influence of N on the environment through improved N use efficiency (Fixen and West, 2002).

Organic farming systems have been promoted as being environmentally friendly and more sustainable than conventional farming systems (Pang and Letey, 2000) and have been suggested as an alternative to increased use of synthetic fertilizer for meeting future nutritional requirements of humans (Fixen and West, 2002). In a review of the sustainability of agricultural systems in Europe and North America, Rigby and Caceres (2001) summarized that relative to conventional farming systems, organic farming improved floral and faunal diversity, conserved soil fertility and system stability, resulted

in lower or similar NO_3^- leaching rates, and improved energy efficiency. However, problems have also been identified in strictly organic farming systems which exclude commercial fertilizers (Pang and Letey, 2000; Fixen and West, 2002). According to Pang and Letey (2000), it is very difficult to meet peak nutrient demands of crops with only organic sources of N without excessive N in the soil before or after crop growth. For example, application of a large amount of manure based on available N to satisfy crop N demand would leave much organic N which could potentially become available later in the growing season and result in leaching or denitrification losses (Pang and Letey, 2000). Fixen and West (2002) reported that lower yields of organic systems would require an expansion of agricultural land into areas marginal for farming at the expense of forests and wildlife areas. Also, organic systems often rely on external organic inputs derived from other land areas, reducing the sustainability of these areas for crop production (Fixen and West, 2002). Thus, Fixen and West (2002) suggest that organic farming may not be the best means for improving crop yields while minimizing environmental pollution.

Besides organic crop production, other initiatives have been proposed that are aimed at reducing inputs and improving sustainability. Pesticide Free Production™ (PFP) is a production system developed by researchers and farmers in Manitoba, Canada to reduce the use of pesticides in cropping systems (University of Manitoba, 2008). Under PFP management, crops are grown without the use of in-crop chemical pesticides during the crop year (University of Manitoba, 2008). Pesticides may be applied in non PFP years and in PFP years provided they are not applied directly to the crop (pre-seeding/post-

harvest application) or have no residual activity (University of Manitoba, 2008). Synthetic fertilizers may also be used.

Regardless of the production system employed, maximizing crop yields requires inorganic N be present in the soil at the time and in the quantity required by the crop (Pang and Letey, 2000; Grant et al., 2002).Th erefore, fertilizer N is commonly applied to make up the difference between what the crop requires for optimum growth and what can be provided by the soil. In Manitoba, fertilizer N recommendations are commonly based on the level of extractable soil NO_3^- found in the soil prior to seeding (Flaten, 2001). While the soil NO_3^- test has proven relatively effective under Manitoba conditions, it relies on a measurement of the stored soil NO_3^- at the time of sampling and does not provide a specific prediction of the N that may become available to the crop over the growing season through mineralization. A reliable method of estimating N release potential of soils could improve a farmer's ability to synchronize N supply with crop demand which would improve both production efficiency and environmental sustainability.

One method proposed to measure the potential of a soil to mineralize N is the Illinois soil N test (ISNT).The ISNT uses micro diffusion in a Mason jar to measure easily mineralizable N directly on the soil sample without the need for acid hydrolysis or chemical extraction (Khan et al., 2001). The resulting soil test values were found to be highly correlated with amino sugar N, which has been identified as a possible labile fraction of organic soil N that readily supplies plant available N through mineralization (Mulvaney et al., 2001). Other researchers have used ion-exchange resins (IERs) to measure soil NO_3^- release rates as an estimate of potentially available soil N (Adderley et

al., 1998; Adderley et al., 2006; Flaten and Greer, 1998; Giblin et al., 1994; Greer et al., 1997; Jowkin and Schoenau, 1995; Jowkin and Schoenau, 1998; Kolberg et al., 1997; Qian and Schoenau, 1995; Qian and Schoenau, 2000; Qian and Schoenau, 2005; Qian et al., 1992; Subler et al., 1995; Ziadi et al., 1999). Resins are strong ion sinks and continually adsorb nutrient ions from the soil solution in a manner similar to plant roots (Dobermann et al., 1994). The resulting nutrient measurement should therefore more closely represent the portion in the soil which is bio-available (Skogley, 1992). The Plant Root Simulator™ (PRS) probe is a diffusion-sensitive synthetic IER consisting of an ion-exchange membrane encapsulated in a plastic probe which is inserted into the soil (Western Ag Innovations Inc., 2001).

Limited information exists on the N dynamics of different management systems under Manitoba conditions. It is important to evaluate N release from the soil and uptake by the crop under different management systems so that applied nutrients are utilized more efficiently. The objectives of this study were: 1) to evaluate the pattern of release and uptake of N by durum wheat on a range of management systems including (i) organic, (ii) organic with composted beef cattle manure, (iii) synthetic fertilizer, no pesticides, (iv) Pesticide Free Production™ (PFP) and (v) integrated management and 2) to assess the effectiveness of Plant Root Simulator™ (PRS) probes and the Illinois soil N test as means of predicting N release through the growing season in systems with N being produced by decomposition of legume residues, composted manure, and mineral N fertilizers.

2.0 LITERATURE REVIEW

2.1 Relevance of Nitrogen to Crop Production

Healthy plants normally contain higher concentrations of N than any other mineral nutrient (Salisbury and Ross, 1991). Nitrogen is involved in the structure of amino acids, proteins, chlorophyll, nucleic acids, and many enzymes (Mills and Jones, 1996) and is essential for carbohydrate utilization (Olson and Kurtz, 1982; Havlin et al., 1999). Since N is a major component of so many essential plant compounds, it is not surprising that N is the most frequently deficient nutrient in crop production (Salisbury and Ross, 1991). Most non-legume cropping systems require additions of fertilizer N for profitable yields (Havlin et al., 1999) and N fertilizers are regularly applied in large quantities (Mills and Jones, 1996). Where N supply is inadequate, yield potentials and maximum economic returns will not be realized. Conversely, excessive fertilization results in not only unnecessary costs, delayed maturity, and lodging, but also raises concerns about the possible negative influence of N on the environment through NO_3^- contamination of surface and groundwater and N_2O emissions into the atmosphere. In order to optimize agricultural production while minimizing the potential negative effects of N fertilization on the environment, the supply of plant available N should be matched to crop demand.

2.2 Forms of Nitrogen in the Soil

Soil N occurs in both organic and inorganic forms. Organic soil N consists of proteins, amino acids, amino sugars, and other complex N compounds (Havlin et al.,

1999). These organic N materials may comprise 95% or more of total soil N but are not immediately plant available (Havlin et al., 1999). To become plant available, organic N must be converted to inorganic N through the process of mineralization. Inorganic forms of soil N include ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O), nitric oxide (NO), and elemental N (N_2) (Havlin et al., 1999). Ammonium and NO_3^- are of greatest interest to crop nutrition (Havlin et al., 1999) since both forms are readily available for plant uptake.

Amino sugars occur as structural components of a broad group of substances (Stevenson, 1982). They have been identified in the cell walls of bacteria and fungi, in bacterial extracellular polysaccharides and antibiotics, and in insect exoskeletons and other animal tissues (Parsons, 1981). More recently, amino sugar N has been identified as a possible labile fraction of organic soil N that readily supplies plant available N through mineralization (Mulvaney et al., 2001).

Nitrate is normally the primary form of N absorbed by plants due to the rapid nitrification of ammonium to nitrate (Mills and Jones, 1996). Since NO_3^- is repelled by the overall negative charge of soil colloids, it is highly mobile and easily transported via mass flow in response to transpirational water uptake by the plant (Olson and Kurtz, 1982). The rate of NO_3^- uptake is further influenced by its concentration in the soil solution and plant metabolism (Olson and Kurtz, 1982).

Exchangeable NH_4^+ is the main form of N available to crops under reducing conditions where the process of nitrification is inhibited (Olson and Kurtz, 1982). The attraction between exchangeable NH_4^+ and negative exchange sites on soil colloids restricts its movement in and with soil water (Olson and Kurtz, 1982) but it is still readily

available through cation exchange reactions. In many soils, the amount of non-exchangeable NH_4^+ greatly exceeds the readily available mineral forms (exchangeable NH_4^+ and NO_3^-) (Young and Aldag, 1982). Non-exchangeable NH_4^+ consists of NH_4^+ trapped between the layers of 2:1 clay minerals in response to negative charges arising from isomorphic substitution (Young and Aldag, 1982) or adsorbed to soil organic matter (Flaten, 2009) and is generally considered unavailable to plants and microorganisms (Young and Aldag, 1982).

2.3 Nitrogen Supplying Capacity of Soils

The supply of plant available N is derived mainly from residual mineral N, mineralization of organic soil N and incorporated crop residues, biological N_2 fixation, and the contribution from applied organic and inorganic N sources (Keeney, 1982a; Havlin et al., 1999; Cassman et al., 2002). The relative contribution that each component makes to available N depends largely on the many management and environmental factors affecting N mineralization, immobilization, and losses of NH_4^+ and NO_3^- from the soil (Havlin et al., 1999).

2.3.1 Residual Mineral Nitrogen

Residual mineral N refers to inorganic soil N arising from mineralization of organic N or application of fertilizer N that is not utilized by a crop in a given season and carries over to the period of growth of the succeeding crop (Broadbent, 1984). The contribution of residual mineral N to the plant available pool can be substantial (Soper and Huang, 1963) and is influenced by numerous N-cycle processes including

mineralization, immobilization, nitrification, denitrification, leaching, and plant uptake (Khan et al., 2001). Most residual N accumulates as NO_3^- since NH_4^+ is readily nitrified by bacteria to form NO_3^-. In drier climates, such as the Canadian prairies, most soil NO_3^- will not be readily lost by denitrification or leaching (Flaten, 2001) and research in Manitoba has shown the amount of NO_3-N in the soil profile at the time of seeding to be an effective soil test for predicting cereal responses to applied N fertilizer (Soper et al., 1971). Under wet conditions, soil NO_3^- is more susceptible to leaching and denitrification losses (Flaten, 2001). Consequently, a pre-plant soil test for NO_3^- is not as reliable in humid climates (Flaten, 2001; Khan et al., 2001).

2.3.2 Nitrogen Mineralization

Nitrogen mineralization is the transformation of N from an organic state into the inorganic forms of NH_4^+ or NH_3 (Jansson and Persson, 1982). The process of N mineralization is facilitated by heterotrophic microorganisms in two separate reactions (Havlin et al., 1999). In the first reaction, termed aminization, proteins are degraded into amines, amino acids, and urea. The products of aminization are further decomposed to release NH_4^+ or NH_3 in a second reaction called ammonification.

As N mineralization is proceeding, the process of N immobilization is occurring simultaneously. Nitrogen immobilization is defined as the transformation of inorganic N compounds (NH_4^+, NH_3, NO_3^-, and NO_2^-) into an organic state (Jansson and Persson, 1982), and is basically the reverse process of N mineralization (Havlin et al., 1999). In this process, soil organisms assimilate inorganic N compounds and transform them into organic N constituents of their cells and tissues (Jansson and Persson, 1982). The two

processes are often referred to collectively as mineralization immobilization turnover (MIT). The amount of N available for crop production will be strongly influenced by the rate and balance of the MIT processes.

2.3.2.1 Effect of Soil Temperature on Mineralization

Soil temperature and moisture are the major environmental factors that control N mineralization (Sierra, 1997) by influencing the survival (Pulleman and Tietema, 1999) and activity of soil microorganisms (Havlin et al., 1999). In general, the rate of microbial activity increases with increasing temperature (Stanford et al., 1973), with an optimum temperature between 25 and 35°C (Havlin et al., 1999). Soil microbial activity is also related to previous temperature conditions. The temporary increase in microbial activity following the thawing of frozen soil can be attributed to the rapid decomposition of soluble organic materials released from microbial cells ruptured during freezing (DeLuca et al., 1992). The rate of N mineralization and the total amount of N mineralized may be increased with freezing and thawing (DeLuca et al., 1992) above a soil kept at a stable temperature.

2.3.2.2 Effect of Soil Moisture on Mineralization

Maximum aerobic microbial activity and N mineralization normally occurs between 50 and 70% water-filled pore space (Havlin et al., 1999). Anaerobic conditions reduce the rate of mineralization (Havlin et al., 1999) and may lead to an accumulation of NH_4^+ or NH_3 since the process of nitrification is inhibited and there is a greater potential for NO_3^- loss through denitrification (Jansson and Persson, 1982). Drying and rewetting

of soil may increase mineralization of carbon and N from biomass-derived substrate and other organic materials made available by the soil disruption (Van Gestel et al., 1993). Soil microbial activity is further influenced by the interaction between temperature and moisture. In general, N mineralization is more responsive to temperature when moisture content is favorable for the process (Sierra, 1997; Zak et al., 1999).

2.3.2.3 Effect of Crop Residue Quality on Mineralization

The carbon to nitrogen ratio (C/N) of crop residues is an important measure of residue quality that is often used to predict the net effects of crop residues on soil mineral N dynamics (Trinsoutrot et al., 2000). Incorporation of crop residues with a low C/N ratio (< 30:1), such as fresh legume residues, will normally result in an initial release of plant available N upon decomposition (Schoenau and Campbell, 1996). Addition of cereal crop residues, which typically have a high C/N ratio (> 30:1), generally causes a temporary immobilization of plant available N (Schoenau and Campbell, 1996) since the material does not provide adequate N to soil microorganisms relative to the supply of energy (Jansson and Persson, 1982). As the residue is decomposed, the C/N ratio declines as carbon is oxidized and net mineralization of N follows (Havlin et al., 1999).

Although the C/N ratio of the crop residue being decomposed provides some indication whether N will be mineralized or immobilized (Havlin et al, 1999), it is more difficult to predict how much nutrient will become available at a specific time (Schoenau and Campbell, 1996). In a field study conducted by Soon et al. (2001) to compare the effect of previous crop on the N dynamics of a wheat-soil system, approximately 18 kg N ha^{-1} was mineralized from red clover green manure residue over the following growing

season compared to negligible amounts from wheat and field pea residues. According to Soon et al. (2001), N uptake by the succeeding wheat crop was increased in the legume based rotations compared to continuous wheat, although the increased N uptake of wheat following field pea was attributed to a soil N conservation effect. Thus, N fertilizer recommendations should allow for greater mineralization of organic N following a crop with low C/N ratio residues (Soon et al., 2001). Conversely, incorporation of large amounts of N-poor residue at the time of seeding could enhance immobilization and reduce N availability, necessitating higher fertilizer additions (Schoenau and Campbell, 1996). However, over time, immobilized N can increase the capacity of soils to supply N through a build-up of readily mineralizable organic N to the extent that less fertilizer N is required in later years (Schoenau and Campbell, 1996).

2.3.2.4 Effect of Tillage System on Mineralization

Tillage practices have an important influence on the dynamics and availability of N to crop plants (Soon et al., 2001) by altering the physical, chemical, and biological properties of the soil. Tillage aerates and dries the soil (Weinhold and Halvorson, 1999). By incorporating crop residues, tillage also lowers the albedo (low albedo = high absorption of sunlight) of the soil, resulting in higher soil temperatures (Weinhold and Halvorson, 1999). The lack of soil mixing in reduced or zero-till (ZT) systems results in a build-up of crop residues on the soil surface which enhances soil water storage and minimizes temperature fluctuations (Schoenau and Campbell, 1996). Increased organic matter (OM) and microbial biomass and activity of the surface soil layers is frequently reported under ZT compared to conventional tillage (CT) systems (Doran, 1980; Doran,

1987). In time, ZT will gradually increase water-stable aggregation relative to CT, thus reducing the susceptibility of the soil to erosion (Schoenau and Campbell, 1996). Also, ZT offers protection of OM occluded within aggregates since physical disruption of the soil may increase microbial access to readily mineralizable OM that had been previously inaccessible (Cabrera and Kissel, 1988).

Crop residues that are buried in a tilled soil will normally decompose at a faster rate compared to residues retained on the soil surface in a no-till system (House et al., 1984; Schomberg et al., 1994; Schoenau and Campbell, 1996) since the most efficient level of microbial activity occurs when crop residues maintain intimate contact with the soil (Schomberg et al., 1994). In a study to determine the influence of water on the decomposition and N dynamics of crop residues in Texas, USA, Schomberg et al. (1994) reported mineralization of N from wheat residues occurred within 100 to 150 days when incorporated compared with 300 to 660 days when surface applied. Over time, the slower decomposition rates of crop residues in reduced tillage systems should increase the N supplying capacity of such soils by promoting the build-up of readily mineralizable forms of N (Schoenau and Campbell, 1996).

By immobilizing N at or near the soil surface, reduced tillage systems may also recycle N more efficiently than CT systems (House et al., 1984). In a comparison of ZT and CT systems in Georgia, USA, House et al. (1984) found the sum of all N inputs were close to N outputs under ZT, while a greater imbalance was observed in CT systems. Under a continuous wheat rotation in Alberta, Canada, Soon et al. (2001) found as the wheat crop approached maturity, more N was recovered from the ZT soil-plant system than the CT system suggesting N utilization was less efficient in the CT system, more N

was lost from the CT system, or both. The greater recovery of N under the ZT system may have been attributed to greater turnover of microbial biomass N in the ZT system (Soon et al., 2001). According to Soon et al. (2001), approximately 50 kg ha^{-1} more N was mineralized during crop growth under ZT than CT while N mineralization between fall and spring was greater under CT. This led Soon et al. (2001) to suggest the synchrony of soil N supply and crop N demand may be improved under ZT.

2.3.2.5 Effect of Priming on Mineralization

One definition of the priming effect is the phenomenon where N addition, whether as an organic source (Lohnis, 1926; Bingeman et al., 1953; Kuzyakov et al., 2000) or an inorganic source (Jenkinson et al., 1985) may stimulate short term changes in the turnover rate of SOM compared to an untreated soil. In each case, the acceleration or retardation of SOM turnover is thought to arise mainly from an increase in activity or amount of microbial biomass (Lohnis, 1926; Bingeman et al., 1953; Jansson and Persson, 1982; Kuzyakov et al., 2000). The effect of priming on the quantity of plant available N will depend on whether the added substance contributes to SOM formation or stimulates its decomposition (Kuzyakov et al., 2000).

2.3.3 Nitrogen Source

Since N is the most frequently limiting nutrient in soils, organic and synthetic sources of fertilizer N are often used to optimize crop production (Havlin et al., 1999). Historically most nutrients were added through organic sources such as biological N_2 fixation, crop residues, and animal manures (Russel, 1984; Havlin et al., 1999). With the

discovery of the Haber-Bosch process, chemical N fertilizers became more widely available and began to replace organic N sources. At present, synthetic fertilizer accounts for almost 60% of total fertilizer N applied to U.S. cropland (Havlin et al., 1999).

2.3.3.1 Previous Legume Crop

Legumes provide a residual benefit to the following crop that includes both N and non-N effects. The N fertilizer replacement value is a measure of the direct N benefit, and is defined as the amount of N required for a non-legume grown on non-legume stubble to produce the same yield as that of the non-legume grown on legume stubble (Beckie and Brandt, 1997). Therefore, the direct N benefit is the difference in yield of a cereal crop on cereal vs. legume stubble that can be compensated for by N fertilizer (Beckie and Brandt, 1997).Direct N b enefits may arise from rhizodeposition of root derived N, greater mineralization of N from legume residues, and reduced immobilization of N compared to cereal residues (Beckie et al., 1997). Based on a landscape study in the Black soil zone of Saskatchewan, Beckie and Brandt (1997) determined that the direct N benefit of field pea to a succeeding non-legume crop was 15 kg N ha^{-1} for every 1000 kg of seed produced. Often the difference in yield cannot be completely explained on the basis of a direct N effect indicating the involvement of some other factor or non-N benefit (Wright, 1990). Indirect or non-N benefits of legumes may include N conservation since legumes are capable of supplying a portion of their N requirements through biological N_2 fixation, increased mineralization of soil N, improved soil tilth, and reduced incidence and severity of weeds and diseases (Stevenson and van Kessel, 1996).

2.3.3.2 Manure

Manure is a valuable resource for crop production (Eghball, 2000) since 75 to 90% of the major nutrients in livestock feed may be excreted in the manure (Canadian Organic Growers Inc., 2001). Typically solid manure contains <1 to 6% total N (Havlin et al., 1999) of which about 50% is available for plant uptake, NH_3 volatilization, or leaching; the remainder is in organic forms that are slowly mineralized (Chang and Janzen, 1996). Fresh manure contains around 75 to 90% water (Havlin et al., 1999) which increases transportation and handling costs and decreases the distance manure can be economically transported to be used as a fertilizer (Schlegel, 1992). This often results in high rates of manure application on cropland near the source of manure which may elevate soil NO_3^- levels and promote environmental damage from NO_3^- leaching (Schlegel, 1992; Chang and Janzen, 1996).

2.3.3.2.2 Composted Manure

Composting, defined as the controlled process of organic matter decomposition by microorganisms in the presence of oxygen (Canadian Organic Growers Inc., 2001), is a useful method of improving the handling characteristics of fresh manure by lowering its density and volume (Canadian Organic Growers Inc., 2001), thus reducing transportation costs (Schlegel, 1992). When manure is composted, heat generated by microbial activity may also reduce pathogens, fly larvae and viability of weed seeds (Canadian Organic Growers Inc., 2001); however, composting may also reduce the fertilizer value of manure (Castellanos and Pratt, 1981; Schlegel, 1992). Eghball et al. (1997) found 20 to 40% of total N and 46 to 62% of total carbon was lost during composting of beef cattle feedlot

manure. In a greenhouse study, Castellanos and Pratt (1981) observed composted dairy manure provided only about 50% as much available N as noncomposted dairy manure. The incorporation of composted manure may initially result in low amounts of mineralized N since most of the easily convertible N is lost during the composting process and the remaining N is in a more stable form (Eghball, 2000). Since most of the soluble carbon substrates are also lost in the composting process, compost additions may not induce high rates of either mineralization or immobilization. Addition of manure or compost will generally increase soil organic matter (Eghball and Power, 1994) and therefore should increase the potential of the soil to supply N. Eghball and Power (1999) estimated 8% N availability from compost in the first residual year after application while Paul and Beauchamp (1993) reported 2.9% N recovery in the first residual year and 5.5% in the second residual year.

2.3.3.3 Synthetic Urea Fertilizer

Synthetic fertilizers are important sources of N for optimizing crop productivity. For the year ending June 30, 2006, 552,756 metric tonnes of total synthetic N fertilizer was applied in Manitoba of which 34% was applied as urea (Canadian Fertilizer Institute, 2006). Urea ($CO(NH_2)_2$) is a granular source of synthetic fertilizer that contains approximately 46% N (Havlin et al., 1999). When applied to warm, moist soil, urea is rapidly hydrolyzed by the enzyme urease to form ammonium carbamate (NH_4COONH_2), which quickly dissociates into NH_3 and carbon dioxide (CO_2) (Koelliker and Kissel, 1988). Once formed, the NH_3 enters a pH dependent equilibrium with NH_4^+ in soil solution (Nelson, 1982). Any NH_4^+ formed may be adsorbed to charged soil particles,

accumulated by crop biomass, or converted to NO_3^- through the process of nitrification. As soil pH increases (pH >7.5), the formation of NH_3 increases, which increases the potential loss of NH_3 through volatilization (Nelson, 1982). The NH_3 volatilization potential is generally reduced when synthetic urea fertilizer is banded compared to broadcast applications (Havlin et al., 1999).

2.4 Fertilizer Nitrogen Use Efficiency

The nitrogen use efficiency (NUE) of a cropping system has been defined as the proportion of all N inputs that are removed in harvested crop biomass, contained in recycled crop residues, and incorporated into soil organic matter and inorganic N pools (Cassman et al., 2002). Nitrogen not recovered in these N sinks is lost from the cropping system and contributes to N loading in environments outside the agroecosystem (Cassman et al., 2002). Fertilizer NUE of cereal crops in the year of application is generally reported as near 50% but has been more recently approximated as 33% worldwide (Raun and Johnson, 1999). Much of this lost fertilizer N may be attributed to gaseous plant emissions, immobilization, denitrification, surface runoff, volatilization, leaching, and competitive plant uptake by weeds (Keeney, 1982b; Raun and Johnson, 1999). Therefore, the overall NUE of a cropping system can be increased by maximizing crop uptake of applied fertilizer N and reducing the amount of N lost from soil organic and inorganic N pools (Raun and Johnson, 1999; Cassman et al., 2002). Important considerations may include crop rotation, cover crops, N-fixing legumes, tillage system, organic N sources, the rate, timing and placement of fertilizer N, urease and nitrification inhibitors, and soil and tissue testing (Keeney, 1982b).

2.5 Nitrogen Uptake and Assimilation

Plants can absorb N as NO_3^- or NH_4^+ (Goos et al., 1999; Havlin et al., 1999). Nitrate generally accounts for most of the N that enters a cultivated crop since NH_4^+ is readily nitrified to NO_3^- under most soil conditions and hence is the form that the plant has access to through most of the growing period (Olson and Kurtz, 1982; Salisbury and Ross, 1991; Mills and Jones, 1996). Although plants can be grown with a single source of N, many crops grow best when provided with a mixture of NO_3^- and NH_4^+ (Goos et al., 1999; Havlin et al., 1999; Wang and Below, 1992).

The actual process of N uptake by plants requires movement of ionic species of N to root surfaces for absorption (Olson and Kurtz, 1982). Nitrate is very water-soluble and moves readily to plant roots via mass flow (Havlin et al., 1999). Exchangeable NH_4^+ is adsorbed to cation exchange sites and its movement in and with soil water is much less than that of nitrate (Olson and Kurtz, 1982). When the concentration of N near root surfaces becomes depleted relative to the bulk soil solution, the process of diffusion becomes appreciable (Olson and Kurtz, 1982).

2.5.1 General Pattern of Nitrogen Uptake

The majority of N uptake by wheat generally occurs in the early plant growing stages (Boatwright and Haas, 1961; Carpenter et al., 1952; Cowell and Doyle, 1993; Darroch and Fowler, 1990; Gregory et al., 1979; Johnston and Fowler, 1991). Darroch and Fowler (1990) reported 89% of the final N in no-till winter wheat in Saskatchewan had accumulated by anthesis. Johnston and Fowler (1991) found 100% of the final N in no-till winter wheat was present by Zadocks 45 (boot just swollen). Beyond anthesis, crop N

uptake often becomes less and total N content of the plant may decline (Boatwright and Haas, 1961; Gregory et al., 1979). Other researchers have reported N uptake may continue to maturity when both N and phosphorus are limiting (Boatwright and Haas, 1961) or as long as sufficient moisture and available N exist in the soil (Gregory et al., 1979). Therefore, early season availability of N is important for overall crop uptake since a large portion is accumulated prior to anthesis. Any N that becomes available after anthesis that is not accumulated by the crop or incorporated into soil microbial biomass is at a greater risk of being lost from the system through leaching, denitrification, or volatilization.

2.6 Factors Affecting Nitrogen Uptake

Crop N demand is determined by crop dry matter yield and the physiological requirements for tissue N (Cassman et al., 2002). Of the many factors that affect crop dry matter accumulation, crop management practices and climate have the greatest influence (Cassman et al., 2002). Climate varies from year to year, causing large differences in yield potential by affecting solar radiation, temperature, and moisture regimes (Cassman et al., 2002). Management practices influence dry matter yield by affecting nutrient supply, weed competition, and insect and disease pressure (Cassman et al., 2002). Thus, annual variation in on-farm yields resulting from the interaction of climate and management practices causes large variation in crop N requirements (Cassman et al., 2002).

Crop physiological N requirements are controlled by the efficiency with which N in the plant is converted to biomass and grain yield (Cassman et al., 2002). With respect to

cereal grain production, the most relevant measure of physiological N efficiency is the change in grain yield per unit change in N accumulation of above ground biomass which is largely governed by the genetically determined mode of photosynthesis and the grain N concentration of the crop (Cassman et al., 2002). Grain N concentration is also under genetic control (Olson and Kurtz, 1982; Cassman et al., 2002) but is affected by N supply, as well (Cassman et al., 2002).

2.6.1 Effect of Dry Matter Production on Nitrogen Uptake

Crop N uptake is strongly associated with dry matter production (Clarke et al., 1990). In general, dry matter and N accumulation follow a sigmoidal pattern (Johnston and Fowler, 1991) where crop N accumulates rapidly to anthesis while dry matter accumulates most rapidly between jointing and anthesis (Boatwright and Haas, 1961). According to Gregory et al. (1979), the major period of nutrient uptake is coincident with the period of rapid shoot growth. Beyond anthesis, crop N uptake often becomes less and may decline while dry weight of stems and chaff decreases and that of heads increases (Boatwright and Haas, 1961). Many studies have also shown a decrease in total dry matter yield from anthesis to maturity (Boatwright and Haas, 1961; Daigger et al., 1976; Karlen and Whitney, 1980; Darroch and Fowler, 1990). Possible explanations for this decrease in dry matter include leaf senescence (Karlen and Whitney, 1980), loss of plant parts (Boatwright and Haas, 1961; Daigger et al., 1976) and sampling error (Boatwright and Haas, 1961).

Crop dry matter accumulation is in turn related to available water (Clarke et al., 1990). In a study to examine soil water use, biomass production, and grain yield of no-till

winter wheat on the Canadian prairies, Domitruk et al. (2000) found above-ground biomass accumulation was directly related to water consumption. When drought stress was terminal, above-ground biomass accumulation was terminated between heading and anthesis (Domitruk et al., 2000). Under intermittent and high rainfall environments, crop biomass accumulated through to maturity (Domitruk et al., 2000). Using spring wheat, Bauer et al. (1987) found dry matter production increased as either fertilizer N or water level increased with the response to water larger than that to fertilizer N. According to Campbell et al. (1977a), spring wheat grown on stubble land in Saskatchewan, Canada at two moisture levels and seven rates of N produced approximately twice as much dry matter in the wet treatment as in the dry for all levels of N.

2.6.2 Effect of Temperature on Nitrogen Uptake

Temperature and moisture have a major impact on plant N uptake since they control the rate of dry matter production (Olson and Kurtz, 1982). Using spring wheat grown in a growth chamber at three rates of N fertilizer, five soil moisture stresses, and day/night temperatures of 27°C/12°C (T27/12) and 22°C/12°C (T22/12), Campbell and Davidson (1979) reported temperature was the most important factor influencing growth and maturation. In the study, plant height, leaf size, total photosynthetic area, and rate of dry matter accumulation were greater at T22/12 than at T27/12 (Campbell and Davidson, 1979). According to Campbell and Davidson (1979), the 5°C increase in day temperature hastened senescence and reduced the maturation period of spring wheat by 12%. Campbell and Davidson (1979) also observed the rate of moisture use was generally more rapid at T27/12 in response to increased transpiration. This was supported by a

similar study where Campbell et al. (1977a) reported low temperatures will reduce the rate of water and nutrient uptake. Under dry conditions, high temperatures may inhibit efficient water and nutrient uptake by causing roots near the surface to desiccate and die (Campbell et al., 1977a).

Soil temperature is also known to influence shoot and root growth and nutrient and water uptake (Bowen, 1991). Temperatures below the plant's optimum range usually result in increased relative investment of biomass in roots because water and nutrient uptake are reduced (Clarkson et al., 1988; Li et al., 1994; Lambers et al., 1995). Gavito et al. (2001) observed the relative allocation of biomass to roots of winter wheat grown under greenhouse conditions was higher at soil temperatures of 10°C than at 15°C with a more pronounced increase in allocation to roots when N was severely limiting.

2.6.3 Effect of Soil Moisture on Nitrogen Uptake

Movement of nutrients to roots by root interception, mass flow, and diffusion is directly influenced by soil moisture (Havlin et al., 1999). Roots intercept more nutrients when growing in a moist soil compared to a dry soil (Havlin et al., 1999) because root exploration is more extensive when soil is moist (Salisbury and Ross, 1991). Mass flow of nutrients in soil solution to roots in response to transpirational water demand of the crop is highly dependent on the volume of water consumed by the plant (Olson and Kurtz, 1982). Diffusion of nutrients from areas of high concentration to areas of lower concentration occurs more rapidly when the soil moisture content is near field capacity (Salisbury and Ross, 1991). Thus, a lack of soil moisture may impede the movement of nutrients to the root, resulting in reduced plant uptake (Gregory et al., 1979).

Soil moisture may also indirectly affect nutrient uptake by influencing the metabolic activity of the plant (Havlin et al., 1999) and the loss of available soil nutrients. In a comparison of N in the above-ground biomass of seven spring wheat varieties, McNeal et al. (1968) observed the amount of N translocated from top growth to grain averaged 66.2% under irrigation compared to 74.8% under dryland conditions. The results of McNeal et al. (1968) suggest a greater amount of N is translocated from top growth to grain when late season crop uptake is limited by a lack of soil moisture. Campbell et al. (1977b) found spring wheat grown on stubble land under dry conditions accumulated > 70% of its total N by the shot blade stage but only 50-65% of its dry matter. Under wet conditions spring wheat accumulated 33-60% of its total N and 25-40% of its dry matter by the shot blade stage (Campbell et al., 1977b). In a study to determine the effects of available water on N uptake of spring wheat, Clarke et al. (1990) found 67-102% of total plant N had accumulated by anthesis. According to Clarke et al. (1990), total plant N uptake was proportional to available water with greater uptake of N under moist than under dry environments.

Loss of available soil nutrients, and hence reduced crop uptake, is commonly observed under conditions of excessive soil moisture. Since NO_3^- is very soluble in water and not tightly held by soil colloids, it is very prone to leaching losses when both soil NO_3^- content and water movement are high (Havlin et al., 1999). Nitrate leached below the root zone reduces the supply of plant available N but also increases the potential for surface and groundwater pollution. When soils become waterlogged, the diffusion of O_2 to sites of microbial activity is impeded (Havlin et al., 1999). Rapid denitrification can result as facultative anaerobic bacteria use NO_3^- and NO_2^- as an electron acceptor with

the accompanying release of N_2 and N_2O. Denitrification can cause significant N losses but has also raised increasing concerns about N_2O emissions into the atmosphere. It is important to match crop N demand with total supplies of soil and applied N, particularly in humid regions where readily available soil N is much more likely to be lost from the agricultural system.

2.6.4 Effect of Soil Nutrient Supply on Nitrogen Uptake

Both the pattern and the amount of N accumulated in crops are affected by the supply of available nutrients (Boatwright and Haas, 1961; Carpenter et al., 1952). In studies conducted on soils with widely differing N supply, Carpenter et al. (1952) observed that wheat plants on both the high and low N soils had accumulated 38% of their total N content by the jointing stage. Crop N uptake on the low N soils declined rapidly after heading while post heading N accumulation on the high N soils increased to nearly three times that of the wheat grown on the low N soils (Carpenter et al., 1952). Boatwright and Haas (1961) observed little or no post heading accumulation of N in spring wheat when both N and P were sufficiently available, continued N uptake until soft dough when P is limiting, and N uptake until maturity when both N and P are limiting. A study by Campbell et al. (1977a) using spring wheat grown at two moisture levels and seven rates of N fertilizer showed N accumulation increased with N applied, moisture, and time. In the study by Campbell et al. (1977a), higher rates of fertilizer N produced larger leaf areas which resulted in increased transpiration and consequently a more rapid use of soil moisture. Although total dry matter and N uptake increased to maturity in all treatments, plants receiving fertilizer rates > 67.5 kg N ha^{-1} under dryland

conditions experienced moisture stress by anthesis and their rate of dry matter production and N accumulation was depressed (Campbell et al., 1977a).

Matching the supply of available soil nutrients with crop demand throughout the growing season without excess or deficiency is the key to optimizing trade-offs amongst yield, profit, and environmental protection (Cassman et al., 2002). If N is not present at the time of crop demand, crop production and economic returns are depressed. Available N not accumulated by the crop or immobilized in soil organic N pools is vulnerable to losses from volatilization, denitrification, and leaching (Cassman et al., 2002). Having sufficient, but not excessive N available in the root zone when the crop needs it is especially important in wet areas since potential losses of N are much greater in humid regions where N-cycle processes occur extensively (Khan et al., 2001).

2.7 Estimating Fertilizer Nitrogen Requirements

Fertilizer N requirements are influenced by numerous soil, climatic, management, and economic variables (Keeney, 1982a). Ideally, recommendations for fertilizer N would be a net amount resulting from the expected crop removal and losses minus residual inorganic N and expected contributions from soil organic matter, crop residues, N fixation, and animal manures with the efficiency of N use considered (Olson and Kurtz, 1982). In practice, many crops are fertilized on the basis of an expected yield or yield goal (Olson and Kurtz, 1982). In cooler, drier climates, the fertilizer N rate may be adjusted according to residual mineral N in the soil whereas in more humid climates the rate may be determined by multiplying the expected yield by a factor that has been found applicable to the area (Olson and Kurtz, 1982). According to Westfall et al. (1996),

fertilizer N rates are best determined by a combination of soil testing, producer experience, and projected N requirements.

2.7.1 Residual Profile Nitrate Nitrogen

In semi-arid to sub-humid climates, residual NO_3-N in the soil is an important source of available N to crops and should be accounted for in fertilizer N recommendations (Soper et al., 1971; Keeney, 1982a). Soil testing for NO_3-N either before planting (pre-plant) or after planting (pre-sidedress) is normally considered the best option for estimating soil NO_3-N availability (Khan et al., 2001). However, soil NO_3^- contents can vary dramatically in response to temperature and moisture effects on N-cycle processes (Khan et al., 2001), with concentrations rising and falling by orders of magnitude within days (Wander et al., 1995). Therefore, soil testing for residual NO_3-N may not be effective for predicting N availability over the growing season (Khan et al., 2001).

In drier climates where leaching and denitrification are limited, the concentration of NO_3^- present in the soil in late fall or spring will usually be available for crop uptake (Flaten, 2001). Research in Manitoba, Canada has shown the amount of NO_3-N in the profile at the time of seeding provided a reasonably good indication of the supply of N available to a crop when the sampling was of sufficient depth (Soper et al., 1971). According to Soper et al. (1971), the amount of NO_3-N in the soil at the 61 cm depth provided the best correlation with uptake of N by barley. In more humid regions, a pre-plant soil test for residual NO_3-N is of limited value because NO_3-N may be lost through leaching and denitrification before crop uptake in these soils (Mulvaney et al., 2001).

Although the annual NO_3^- soil test has proven to be effective for monitoring the dynamics of plant available N supply in western Canada, it fails periodically, especially when the soil contains large amounts of organic N that may be mineralized over the growing season (Flaten, 2001). Flaten (2001) suggested the limitations of using the soil NO_3^- test alone as an indication of available N may be overcome by replacing or supplementing the test with procedures that adjust fertilizer N rates based on field information, soil properties, and estimates of potentially mineralizable N. This is in agreement with other reports where researchers (Carter et al., 1974; Qian and Schoenau, 1995) concluded the prediction of N availability can be improved by using an index of soil organic N availability in conjunction with a profile NO_3-N test.

2.7.2 Indices of Soil Organic Nitrogen Availability

The need to account for mineralization of soil organic N in predicting fertilizer N requirements has long been recognized and many biological and chemical indices of soil N availability have been proposed (Bremner, 1965a; Stanford and Smith, 1972; Stanford, 1982; Campbell et al., 1994; Walley et al., 2002). The objective is to develop an index that correlates highly with some reliable biological measure of soil N availability such as N uptake, crop yield, or potentially mineralizable N (Stanford, 1982). Adoption of such an index by soil testing laboratories as a routine soil test would also require a procedure that is rapid and precise (Haney et al., 2001). At present, most such indices have proven inadequate because they do not measure the potential of the soil to mineralize N over the growing season or quantify soil N mineralization in response to weather conditions (Campbell et al., 1994).

2.7.2.1 Biological Indices of Soil Organic Nitrogen Availability

Biological methods that estimate the amount of mineral N produced by incubation of soil under optimum conditions are generally regarded as the best indices of soil N availability since the agents responsible for the mineral N produced in the incubation are those that make soil organic N available to crops during the growing season (Bremner, 1965a). In general, most biological indices are based on short term incubations (7-25 days) under either aerobic or anaerobic conditions (Keeney, 1982a). Aerobic incubation techniques generally involve measurement of the ($NO_3 + NH_4$)-N produced (Bremner, 1965a) but differ widely with respect to protocols for pretreatment and incubation of soil samples (Bremner, 1965a; Benbi and Richter, 2002). Anaerobic procedures are simplified in that only NH_4-N production needs to be determined since no NO_3-N is produced (Bremner, 1965a). Regardless of the incubation method, comparisons of N availability in soils are difficult unless the techniques are rigorously standardized (Bremner, 1965a; Benbi and Richter, 2002).

Even with standardization, results of short term incubations do not necessarily reflect the potential, long term capacities of soils to supply N (Stanford and Smith, 1972). In response, a long term incubation method was developed where soil is incubated for an extended period (up to 30 weeks) with the inorganic N removed at various times during the incubation (Stanford and Smith, 1972; Keeney, 1982a). The N mineralization potential is estimated from the cumulative amounts of N mineralized based on the assumption that N mineralization follows first order kinetics (Stanford, 1982; Campbell et al., 1994). Despite the improvement in predicting soil N availability (Stanford, 1982),

determining long term mineralization capacities of soils is generally not suited for routine soil testing because of the lengthy time periods required (Haney et al., 2001).

2.7.2.2 Chemical Extraction Indices of Soil Organic Nitrogen Availability

Chemical procedures are usually more rapid and convenient than biological methods and are generally more precise (Bremner, 1965a). Most chemical methods involve the use of mineral acids, bases, oxidants, or chelating reagents at different concentrations and temperatures, and range in severity of extraction from intensive to relatively mild (Stanford, 1982). Although developed in response to the need for rapid and reliable means of assessing soil N availability (Stanford, 1982), none of the proposed chemical methods have been widely adopted as routine soil tests (Stanford, 1982; Khan et al., 2001). The principal objection is that these indices are completely empirical (Bremner, 1965a; Khan et al., 2001) and make no consideration that N MIT is driven by the energy available for microbial processes (Bremner, 1965a). Other concerns include the feasibility of intensive extraction methods which potentially remove far greater amounts of soil N than are readily susceptible to mineralization (Stanford, 1982). Even mild acid treatments remove substantial proportions of relatively inert, biologically resistant organic N fractions (Stanford, 1982). Use of chemical methods of estimating potentially mineralizable soil N have been further limited because of low correlations with the production of mineral N and crop N uptake (Khan et al., 2001). Ideally, a soil test for predicting soil N supplying capacity would estimate a labile organic fraction that supplies the plant through mineralization (Khan et al., 2001; Mulvaney et al., 2001).

2.7.2.3 Illinois Soil Nitrogen Test

The development of the Illinois soil N test (ISNT) was stimulated by earlier reports that identified numerous sites throughout the north-central and northeastern USA where corn (*Zea mays* L.) did not respond to N fertilization (Mulvaney et al., 2001). In many such cases, excessive accumulations of NO_3^- were not predicted by soil testing for NO_3^- either before (preplant) or after (presidedress) planting and overfertilization resulted (Mulvaney et al., 2001). The goal was to identify and measure a fraction of soil organic N that is directly related to fertilizer N responsiveness and design a simple soil test procedure suitable for routine soil analysis (Mulvaney et al., 2001).

Previous studies regarding different forms of organic soil N have been largely based on identifying and estimating the N compounds released from soil by hydrolysis with hot mineral acids (Bremner, 1965b; Stevenson, 1982). According to Bremner (1965b), maximal release of different forms of soil-N from surface soils was obtained by hydrolysis under reflux for 12 hours using 6 *M* HCl. The different forms of N in the hydrolysate are then separated by steam distillation with a unique procedure for each form of N to be estimated. In all procedures, the specific form of N is converted to NH_3, collected in a H_3BO_3 indicator solution, and the quantity determined by titration with H_2SO_4 (Bremner, 1965b; Stevenson, 1982). The major fractions include total-N, NH_4-N, (NH_4 + amino sugar)-N, and amino acid-N. Amino sugar-N is taken as the difference between determinations of (NH_4 + amino sugar)-N and NH_4-N (Bremner, 1965b; Stevenson, 1982).

Studies to compare the distribution of soil organic N in different soils or among soils under different management systems have generally detected little variation in the

distribution of soil organic N using steam distillation procedures (Mulvaney et al., 2001). Further research by Mulvaney and Khan (2001) indicated that conventional steam distillation analyses were not quantitative for either amino sugar-N or amino acid-N due in part to defects in steam distillation methodology. These defects were overcome by developing simple Mason jar diffusion methods to fractionate N in soil hydrolysates that are accurate, specific, and reliable (Mulvaney et al., 2001).

Using Mason jar diffusion methodology, Mulvaney et al. (2001) compared N distribution analyses of soil hydrolysates from composite soil samples (0-30 cm depth) collected in early spring from 18 sites throughout Illinois with differing N fertilizer responsiveness by corn. Nonresponsive soils were found to have concentrations of amino sugar-N 33 to 1000% greater (P <0.001) than responsive soils, whereas no consistent difference was observed in their content of total hydrolyzable N, hydrolyzable NH_4-N, or amino acid-N (Mulvaney et al., 2001). Based on amino sugar-N, all 18 soils were classified correctly as responsive or nonresponsive to N fertilization suggesting the soil amino sugar-N fraction is a key factor affecting the responsiveness of corn to N fertilization (Mulvaney et al., 2001).

The determination of amino sugar-N in soil hydrolysates to detect sites that do not require N fertilization is complicated and time consuming for routine soil analysis so the ISNT was developed to estimate amino sugar-N without the need for acid hydrolysis by performing diffusion directly on the soil itself (Khan et al., 2001). In the procedure previously described in Khan et al. (2001) and ^{15}N Analysis Service (2002), a 1-g sample of air dried soil placed in a standard 473 mL wide-mouth Mason jar is mixed with 10 mL of 2 M NaOH and sealed with a lid that has been modified to support the bottom of a 60

mm diameter Pyrex petri dish containing 5 mL of H_3BO_3 indicator solution. The sealed jar is transferred to a hot plate for 5 hours at 48 to 50°C; converting (NH_4 + amino sugar)-N to gaseous NH_3 which is collected in the indicator solution. After 5 hours, the jar is removed from the hot plate, opened, and the petri dish removed. The indicator solution is diluted with 5 mL of deionized water and titrated with 0.01 *M* H_2SO_4. The soil test value in mg N kg^{-1} (ppm) is determined by multiplying the volume of H_2SO_4 used in the titration by the titer of the titrant (280 μg N mL^{-1} for 0.01 *M* H_2SO_4) and is highly correlated (r = 0.90) (P<0.001) with hydrolyzable amino sugar-N (Khan et al., 2001).

Based on a 30 cm soil sampling depth, a test value of 250 mg N kg^{-1} or higher indicates that corn will be nonresponsive to N fertilization in central or northern Illinois (^{15}N Analysis Service, 2002). A critical value of 300 mg N kg^{-1} would be appropriate for samples collected from a 15 cm depth (^{15}N Analysis Service, 2002). As designed, the ISNT does not recover NO_3-N to reduce soil test variability and eliminate the need for profile sampling (Khan et al., 2001). Since exchangeable NH_4-N is recovered along with amino sugar-N, the ISNT will not provide a reliable estimate of amino sugar-N for sites that have received a recent input of NH_4-N through application of ammoniacal fertilizer or manure (Khan et al., 2001). In such cases, soil test values should be corrected by subtracting NH_4-N determined by direct diffusion. Besides providing the potential capability to predict sites in Illinois where N fertilizer would not produce a yield response by corn, the considerable range in soil test values for either responsive or nonresponsive soils suggests the possibility of a quantitative soil test (Khan et al., 2001).

The applicability of the ISNT for other crops and or climatic conditions has been evaluated in recent studies. Research in Saskatchewan, Canada by Torrie et al. (2004)

found a poor correlation between ISNT-N and N response in wheat. In Iowa, Barker et al. (2006b) found no positive correlation between ISNT-N and corn N responses, relative yield, yield response to applied N, or economically optimum N rate across a range of soil and climatic conditions. Barker et al. (2006b) and Klapwyk and Ketterings (2006) reported the ISNT was unable to differentiate responsive from non-responsive corn sites in Iowa and New York, respectively. According to ^{15}N Analysis Service (2002), use of the ISNT with other crops and or climatic conditions may require different critical values.

2.7.2.4 Ion Exchange Resins

In general, most synthetic ion exchange resins (IERs) are solid organic polymers with an electrostatic charge that is neutralized by a selected counterion of opposite charge (Skogley and Dobermann, 1996). Although resins are manufactured with a wide range of specific properties, most are made from long chains of polymerized styrene which are reacted with divinylbenzene to produce cross-linkages (Skogley and Dobermann, 1996). The degree of polymer chain cross-linkage largely influences the physical and chemical properties of the resin (Skogley and Dobermann, 1996). Macroporous IERs (individual particles referred to as resin beads) are the most common forms of synthetic IERs used in soil research (Skogley and Dobermann, 1996; Qian and Schoenau, 2002). They are generally spherical in external shape, with large internal surface areas (Skogley and Dobermann, 1996). Other research has focused on using IERs in sheet or membrane forms (Qian and Schoenau, 2002). The polymers used to make membrane IERs are similar to those used for IERs in bead forms but are extruded into sheets during manufacture and combined with a reinforcing material to provide stability and strength (Skogley and Dobermann, 1996).

In early studies, IERs were used as an ion source to provide adsorbed ions to the medium for plant uptake (Qian and Schoenau, 2002). Other research has employed IERs to provide nutrient ions as a means of buffering nutrient solutions (Kervin et al., 1993). However, the majority of IER studies have focused on using IERs for the purpose of exchanging their initial counterions for other target ions in the medium and then analyzing the resin to determine the quantity of target ions accumulated by the resin during the extracting time (Skogley and Dobermann, 1996). This is considered to be using the resin as a sink (Skogley and Dobermann, 1996; Qian and Schoenau, 2002). When used as ion sinks, IERs continually adsorb nutrient ions from the soil solution in a manner similar to plant roots (Dobermann et al., 1994). Equilibrium of ions between soil solid and solution phases is prevented,thus stimulating fu rther release from soil solids (Qian et al., 1992). Nutrient ions that are not in the soil solution or can't diffuse through the medium to the resin will not be accumulated (Skogley, 1992). The resulting nutrient measurement should therefore more closely represent that which is bio-available (Skogley, 1992).

The use of IER in soil research initially focused on batch systems where a defined amount of soil and resin (beads or membrane strips) are mixed in an excess of water and shaken for extended periods of time (Qian and Schoenau, 2002). Using a batch system, Qian et al. (1992) found anion exchange membrane (AEM) extractable NO_3^- to be more highly correlated with actual N uptake of canola plants grown in a growth chamber compared to $CaCl_2$ extractable NO_3^-. Although batch procedures provide an indication of amounts of specific nutrients that can be derived from the solution phase of soil

suspensions, they do not account for the contribution of diffusion processes through the medium as they influence availability (Qian and Schoenau, 2002).

More recent focus has shifted towards diffusion-sensitive systems where the resin is positioned in the soil sample or directly inserted into the medium in situ without subsequent mixing (Skogley and Dobermann, 1996). Diffusion-sensitive systems integrate both the rates of release of ions from different soil surfaces and their diffusion to a sink into the measure of nutrient availability (Qian and Schoenau, 2002). Adsorption kinetics will also reflect size, exchange capacity, resin type, initial saturation of counterions of the resin, soil moisture content, and soil temperature (Skogley and Dobermann, 1996; cited in Qian and Schoenau, 2002). Using samples from 74 soils across Saskatchewan, Canada, Qian and Schoenau (1995) reported the amount of NO_3-N adsorbed to AEM strips placed directly in soil over a 2-week aerobic incubation was more closely correlated with plant N uptake by canola than the amount of NO_3-N removed by $CaCl_2$ extraction at the end of a 2-week aerobic incubation. Ziadi et al. (1999) buried AEM strips in surface soils (0-15 cm) of grass forage systems in Quebec, Canada for periods ranging from 13 to 240 days and found forage N uptake was better related with NO_3^- fluxes to the AEM than with NO_3^- concentration determined by water extraction.

Whether used in batch or diffusion-sensitive systems, certain considerations are required to optimize the performance of IERs in soil research (Qian and Schoenau, 2002). In general, the longer an IER resides in the soil, the more ions that can be adsorbed. Thus, longer term IER burials are usually considered to provide a measure that accounts for ion diffusion from greater distances and nutrient release from mineralization (Qian and

Schoenau, 2002). However, if the ion exchange capacity of the resin is exceeded, the resin will no longer function as a sink but as a dynamic exchanger (Qian and Schoenau, 2002). Although Skogley (1992) reported that IERs in bead form can be left in soil for months, Qian and Schoenau (1995) suggest IERs in sheet or membrane form be kept in soil no longer than 2 weeks. Other considerations include the effect of soil moisture and temperature on ion adsorption by the IER (Qian and Schoenau, 2002). At lower soil moisture contents and/or lower soil temperatures, ion adsorption is generally reduced in response to reduced microbial activity, and therefore mineralization, and restricted ion movement (Sulewski et al., 2002). The amount of ions adsorbed by the IER is also affected by competing ion sinks (Qian and Schoenau, 2002). Soil microorganisms may effectively compete for nutrient ions under N immobilizing conditions (Sulewski et al., 2002). Plant roots may also compete for ions when resins are placed in soils where plants are growing (Qian and Schoenau, 2002). In such a case, a cylinder can be inserted in the soil to isolate an area from plant roots and the IERs buried within the isolated area.

2.7.2.4.1 Plant Root Simulator™ (PRS) Probes

The Plant Root Simulator™ (PRS) is a diffusion-sensitive synthetic IER consisting of an ion-exchange membrane encapsulated in a plastic probe which is inserted into the soil (Western Ag Innovations Inc., 2001). However, much of the movement of nutrients to the root is via mass flow and the PRS does not "simulate" roots in this manner.The p robes are available with either a cation exchange (purple encasement) or anion exchange membrane (orange encasement) which is chemically pre-treated to adsorb charged ionic species (Western Ag Innovations Inc., 2001). Including both sides, PRS membranes have a total surface area of 17.5 cm^2 and a maximum ion capacity of

590 μg/10 cm^2 for NO_3-N (anion probes) and 2740 μg/10 cm^2 for NH_4-N (cation probes) (Western Ag Innovations Inc., 2001). When buried in the soil, PRS-probes continuously adsorb charged ionic species over the length of the burial (Sulewski et al., 2002). The amount of nutrient ion adsorbed on the probe at the end of the burial period is used as a measure of the potential nutrient supply rate to a plant and is reported in units of micrograms of nutrient sorbed per 10 square centimeters of probe surface over the burial time (μg 10 cm^{-2} duration of $burial^{-1}$) (Western Ag Innovations Inc., 2001). Short term PRS-probe burials of 1 to 24 hours can provide a "snapshot" of nutrient availability while longer term probe burials of 2 weeks can provide information on the dynamics of nutrient supply (Sulewski et al., 2002). If a longer measurement time is required, the existing PRS-probe can be replaced with a new one and the amount of nutrient ions supplied to the subsequent PRS-probe can be added to the previous to obtain a cumulative supply rate over the entire burial period (Sulewski et al., 2002; Qian and Schoenau, 2002).

Plant Root Simulator™ probes have been evaluated under both field and laboratory conditions. In a growth chamber study to assess soil N supply to canola as affected by addition of liquid swine manure and urea, Qian and Schoenau (2000) found a good correlation between plant N uptake and N supply rate as measured by AEM PRS-probes. A field study by Jowkin and Schoenau (1998) to determine the impact of tillage and landscape position on N availability and yield of spring wheat in southwestern Saskatchewan revealed the NO_3^- supply rate to AEM PRS-probes buried for 2-week periods was consistent with plant N uptake and soil N supply power determined with an ^{15}N tracer technique. Using field pea or lentil stubble in Saskatchewan, Canada, Adderley et al. (2006) observed grain yield and N accumulation by spring wheat corresponded with

cumulative soil NO_3^- supply rates measured over eight weeks by summing 2-week supply measurements to AEM PRS-probes. Thus, PRS-probe measured N supply rates appear suitable as a means of assessing soil N supplying power (Qian and Schoenau, 2005).

2.7.2.5 Interpreting Indices of Soil Nitrogen Availability

The utility of any soil N availability index depends on how well it correlates with reliable biological measurements of soil N availability on a broad range of soils (Stanford, 1982). Although the goal of such indices is to provide an estimate of a soil's potential to supply N, most indices may not reflect true mineralization for a given growing season (Stanford, 1982; Walley et. al., 2002). Even under optimal conditions, soils vary widely in their capacities to mineralize organic N (Stanford, 1982). Besides moisture and temperature, interpretation of relationships between N availability indices and N uptake or crop yield should also consider other factors related to supply of and demand for N such as soil properties, management practices, and weed and disease pressure (Walley et al., 2002). Since N uptake or yield reflects demand over the growing season, it may be independent of the rate of soil N mineralization (Walley et al., 2002). The extensive spatial and temporal variability of soil resources has led some researchers to conclude that we should not expect a high degree of correlation between any single measure of N availability and either crop growth or N accumulation (Walley et al., 2002). According to Harmsen and Van Schrevan (1955), reliable interpretations can only be expected when dealing with a single soil type, climatic zone, or farming system.

3.0 THE EFFECT OF MANAGEMENT PRACTICES ON NITROGEN RELEASE AND UPTAKE IN WHEAT CROPPING SYSTEMS IN MANITOBA, CANADA

3.1 Abstract

Nutrient supply should be matched to crop demand both through an individual cropping season and over the longer-term crop rotation to ensure both production efficiency and environmental sustainability. Therefore, it is important to be able to predict the pattern of nutrient release from soil and its relationship to nutrient uptake by the crop. The amount and timing of nutrient release from soils will be affected by factors including soil characteristics, environmental conditions, and crop management practices.

The pattern of soil N release and crop N uptake under different management systems were evaluated on a Newdale clay loam soil in Manitoba, Canada. Durum wheat (*Triticum durum* Desf. cv. AC Avonlea) was grown on field pea (*Pisum sativa* L.) stubble in 2002 and 2003 on a range of cropping systems including (i) organic (no inputs), (ii) organic with composted beef cattle (*Bos taurus*) manure, (iii) synthetic fertilizer, no pesticides, (iv) Pesticide Free Production (PFP™) (synthetic fertilizer,pesticides used before crop growth and in other crops in the rotation, no pesticides applied to the growing target crop and no residual pesticides) and (v) integrated management (synthetic fertilizer, pesticides applied as required). Soil samples to a depth of 60 cm and whole above ground plant biomass samples were collected at selected crop development stages during the crop year and analyzed for inorganic soil NO_3^- and total plant N respectively. Final grain yield was determined at maturity and subsamples were used to determine total N and protein concentration.

Management system influenced inorganic soil NO_3^- content, dry matter yield, final grain yield and protein concentration, crop N concentration, and crop N uptake. In general, measured soil and crop N variables were highest in systems receiving synthetic fertilizer. The highest soil NO_3^- contents were generally observed between the time of seeding and the first crop stage sampled. In late fall, soil NO_3^- contents were generally highest in the 15-60 cm soil depth in systems receiving synthetic fertilizer. In 2003, late fall surface soil NO_3^- contents were higher in the composted manure treated system compared to the untreated organic system. Maximum crop N accumulation had occurred by the early boot and anthesis crop stages in 2002 and 2003 respectively. The fertility systems based strictly on legume and on combinations of legume and composted manure were not able to supply sufficient N for optimum crop production. Systems receiving synthetic urea fertilizer without pesticides also experienced N limitations in response to competition from significantly higher weed biomass. The PFP™ system was able to produce dry matter and final grain yields comparable to the integrated management system. In order to optimize crop production under Manitoba conditions, producers should ensure adequate N is available in the system to meet crop demand and practice an effective means of in-crop weed control.

3.2 Introduction

Nitrogen is a major constituent of all plants and is required for high yields of most agricultural crops (Pang and Letey, 2000). The supply of plant available N is derived mainly from residual mineral N, mineralization of organic soil N and incorporated crop residues, biological N_2 fixation, and the contribution from applied organic and inorganic N sources (Keeney, 1982b; Havlin et al., 1999; Cassman et al., 2002; Mikha et al., 2006).

The relative contribution that each component makes to plant-available N depends largely on the many management and environmental factors affecting N mineralization, immobilization, and losses of NH_4^+ and NO_3^- from the soil (Havlin et al., 1999). Therefore, efficient use of fertilizer N requires matching soil N supply with crop N demand. Where nutrient supply is inadequate, yield potentials and maximum economic returns will not be realized. Conversely, excessive fertilization results in not only unnecessary costs, delayed maturity, and lodging, but also can lead to negative impacts on the environment through NO_3^- contamination of surface and groundwater and N_2O emissions into the atmosphere.

Legumes provide a residual benefit to the following crop that includes both N and non-N effects. The N fertilizer replacement value is a measure of the direct N benefit, and is defined as the amount of N required for a non-legume grown on non-legume stubble to produce the same yield as that of the non-legume grown on legume stubble (Beckie and Brandt, 1997). Therefore, the direct N benefit is the difference in yield of a cereal crop on cereal vs. legume stubble that can be compensated for by N fertilizer (Beckie and Brandt, 1997).Direct N b enefits may arise from rhizodeposition of root derived N, greater mineralization of N from legume residues, and reduced immobilization of N compared to cereal residues (Beckie et al., 1997). Based on a landscape study in the Black soil zone of Saskatchewan, Beckie and Brandt (1997) determined that the direct N benefit of field pea to a succeeding non-legume crop was 15 kg N ha^{-1} for every 1000 kg of seed produced. Often the difference in yield cannot be completely explained on the basis of a direct N effect indicating the involvement of some other factor or non-N benefit (Wright, 1990). Indirect or non-N benefits of legumes may include N conservation since legumes are

capable of supplying a portion of their N requirements through biological N_2 fixation, increased mineralization of soil N, improved soil tilth, and reduced incidence and severity of weeds and diseases (Stevenson and van Kessel, 1996).

Manure is a valuable resource for crop production (Eghball, 2000) since 75 to 90% of the major nutrients in livestock feed may be excreted in the manure (Canadian Organic Growers Inc., 2001). Typically solid manure contains <1 to 6% total N (Havlin et al., 1999) of which about 50% is available for plant uptake, NH_3 volatilization, or leaching; the remainder is in organic forms that are slowly mineralized (Chang and Janzen, 1996). Fresh manure contains around 75 to 90% water (Havlin et al., 1999) which increases transportation and handling costs and decreases the distance manure can be economically transported to be used as a fertilizer (Schlegel, 1992). This often results in high rates of manure application on cropland near the source of manure which may elevate soil NO_3^- levels and promote environmental damage from NO_3^- leaching (Schlegel, 1992; Chang and Janzen, 1996). Composting, defined as the controlled process of organic matter decomposition by microorganisms in the presence of oxygen (Canadian Organic Growers Inc., 2001), is a useful method of improving the handling characteristics of fresh manure by lowering its density and volume (Canadian Organic Growers Inc., 2001), thus reducing transportation costs (Schlegel, 1992). When manure is composted, heat generated by microbial activity may also reduce pathogens, fly larvae and viability of weed seeds (Canadian Organic Growers Inc., 2001); however, composting may also reduce the fertilizer value of manure (Castellanos and Pratt, 1981; Schlegel, 1992). Eghball et al. (1997) found 20 to 40% of total N and 46 to 62% of total carbon was lost during composting of beef cattle feedlot manure. In a greenhouse study, Castellanos and

Pratt (1981) observed composted dairy manure provided only about 50% as much available N as noncomposted dairy manure. The incorporation of composted manure may initially result in low amounts of mineralized N since most of the easily convertible N is lost during the composting process and the remaining N is in a more stable form (Eghball, 2000). Since most of the soluble carbon substrates are also lost in the composting process, compost additions may not induce high rates of either mineralization or immobilization. Addition of manure or compost will generally increase soil organic matter (Eghball and Power, 1994) and therefore should increase the potential of the soil to supply N. Eghball and Power (1999) estimated 8% N availability from compost in the first residual year after application while Paul and Beauchamp (1993) reported 2.9% N recovery in the first residual year and 5.5% in the second residual year.

Synthetic fertilizers are important sources of N for optimizing crop productivity. For the year ending June 30, 2006, 552,756 metric tonnes of total synthetic N fertilizer was applied in Manitoba of which 34% was applied as urea (Canadian Fertilizer Institute, 2006). Urea ($CO(NH_2)_2$) is a granular source of synthetic fertilizer that contains approximately 46% N (Havlin et al., 1999). When applied to soil, urea is hydrolyzed by the enzyme urease to form NH_4^+ (Havlin et al., 1999). Urea hydrolysis proceeds rapidly in warm, moist soils, with most of the urea transformed to NH_4^+ in several days (Havlin et al., 1999). The NH_4^+ thus formed is available for crop uptake or conversion to NO_3^- through the process of nitrification. Although synthetic fertilizer N may directly increase the concentration of bio-available inorganic soil N, other researchers have observed greater plant N uptake of soil derived N in fertilized treatments compared to unfertilized controls (Jenkinson et al., 1985). According to Jansson and Persson (1982), the newly

established inorganic pool of N supplied by the synthetic fertilizer is thought to lose N by immobilization and gain soil N by mineralization. This acceleration of SOM turnover is thought to arise mainly from an increase in activity or amount of microbial biomass (Lohnis, 1926; Bingeman et al., 1953; Jansson and Persson, 1982; Kuzyakov et al., 2000).

The majority of N uptake by wheat generally occurs in the early plant growing stages (Boatwright and Haas, 1961; Carpenter et al., 1952; Cowell and Doyle, 1993; Darroch and Fowler, 1990; Gregory et al., 1979a; Johnston and Fowler, 1991). Darroch and Fowler (1990) reported 89% of the final N in no-till winter wheat in Saskatchewan had accumulated by anthesis. Johnston and Fowler (1991) found 100% of the final N in no-till winter wheat was present by Zadocks 45 (boot just swollen). Beyond anthesis, crop N uptake often becomes less and may decline (Boatwright and Haas, 1961; Gregory et al., 1979a). Other researchers have reported N uptake may continue to maturity when both N and phosphorus are limiting (Boatwright and Haas, 1961) or as long as sufficient moisture and available N exist in the soil (Gregory et al., 1979). Therefore, early season availability of N is important for overall crop uptake since a large portion is accumulated prior to anthesis. Any N that becomes available after anthesis that is not accumulated by the crop or incorporated into soil microbial biomass is at a greater risk of being lost from the system through leaching, denitrification, or volatilization.

Limited information is available on the effect of different management practices on crop and soil nutrient dynamics under Manitoba conditions. The objective of this study was to evaluate the pattern of soil N release and crop N uptake by durum wheat under a range of organic to conventional crop management systems in Manitoba, Canada with N

being supplied by decomposition of legume residues, composted manure, and mineral N fertilizers.

3.3 Materials and Methods

3.3.1 Site and Experimental Treatments Description

This study was initiated in 2002 as part of an existing rotational study established in 2001 at Agriculture and Agri-Food Canada's (AAFC) Brandon Research Centre (BRC) Field Operations Site located 24 km north of Brandon, MB, Canada in the RM of Elton (S1/2 of 21-12-18W) (50°N, 100°W). The rotation was established in 2001 on a Newdale clay loam soil (black Chernozem developed on medium-textured, moderately calcareous boulder till of mixed shale, limestone and granitic rock origin) (Ehrlich et al., 1957) that had oats removed as a silage crop the previous season. Pre-plant soil samples were taken, air-dried and archived for later soil nutrient content and quality analysis. Monthly temperature and precipitation during the study are reported in Table 3.1.

The experimental design was a randomized complete block with a split plot arrangement. Five main plots were randomized within a block and each block was replicated four times. Main plot treatments consisted of management systems: (i) organic (A), (ii) organic with compost (B), (iii) nutrients, no pesticides (C), (iv) Pesticide Free Production (PFP™) (D), and (v) integrated management (E). The A system had no import of nutrients other than atmospheric N fixed by legumes; the B system received beef manure compost, and the C, D, and E systems received synthetic fertilizer. The A, B, and C systems were managed by conventional tillage (CT) and had no pesticides applied at any time. The D and E systems were managed by zero-tillage (ZT). In the D system, no pesticides were applied to the growing target crop and no residual pesticides were used.

However, pesticides were used before crop growth and in other crops in the rotation. Wheat and oats were the target D crops. The E system had pesticides applied as required for control of weeds, insects and diseases.

Table 3.1. Monthly temperature and precipitation received at AAFC's BRC field operations site during the 2001, 2002, and 2003 growing seasons.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Average	Total
Temperature (°C)									
2001	4.5	12.8	15.2	19.6	19.2	12.9	3.4	12.5	-
2002	1.7	7.9	17.6	20.2	17.3	12.2	-1.1	10.8	-
2003	5.0	11.6	16.0	20.0	21.6	12.1	6.6	13.3	-
Average (30 yr)	4.0	11.8	16.6	18.9	18.0	11.9	4.9	12.3	-
Precipitation (mm)									
2001	17.2	56.2	122.0	38.0	22.0	23.8	12.0	-	291.2
2002	16.4	7.8	75.0	51.0	101.0	38.0	12.2	-	301.4
2003	44.9	42.0	65.0	5.0	28.0	63.0	18.0	-	265.9
Average (30 yr)	29.3	52.6	75.7	69.2	48.3	28.5	18.6	-	322.2

Crop rotation treatments were applied to subplots within the management systems, with each subplot being 4 m wide by 10 m long. The two crop rotations were: (i) field pea (*Pisum sativa L.*)-durum wheat (*Triticum durum* Desf.) underseeded to yellow blossom sweet clover (*Melilotus officinalis L.*)-yellow blossom sweet clover-oats (*Avena sativa L.*); applied only to A, B, and C systems and (ii) field pea-durum wheat-flax (*Linum usitatissimum L.*)-oats; applied only to D and E systems. Each phase of the rotation was present each year with sampling conducted in the wheat and oat phases only. The varieties of durum wheat and oats used were AC Avonlea and AC Assiniboia respectively. In year one, annual alfalfa was seeded in place of sweet clover since sweet clover is a biennial. Each block and each main plot within a block was separated by a 15

m and 4 m buffer strip respectively. Buffer strips were seeded to wheat to maintain soil cover and kept mowed to control weeds. Total seeded area of the trial was 3200 m^2.

3.3.2 Beef Manure Compost

Compost was prepared at Agriculture and Agri-Food Canada's Brandon Research Center located in Brandon, MB, Canada using bedding material from beef cattle feedlot corrals. The material was transported to the composting site and formed into windrows in early June. Windrows were turned approximately 6 to 9 times over a 90 day period followed by a 40 day curing phase. After curing, 20 samples were taken from each windrow to determine the nutrient composition (Table 3.2). The compost was piled and left over winter before applying in early spring.

Table 3.2. Characteristics of compost prepared from beef cattle feedlot manure at AAFC's BRC in the summers of 2001, 2002, and 2003.

Parameters[†]	2001	2002	2003
pH	9.1	9.6	-
Electrical conductivity (dS m^{-1})	23.9	33.4	-
NO_3-N & NO_2-N (mg kg^{-1})	27.5	272	140
NH_4-N (mg kg^{-1})	137	233	219
Organic N (g kg^{-1})	10.7	12.6	13.5
Total N (g kg^{-1})	10.9	13.1	13.9
Available N* (kg $tonne^{-1}$)	1.8	2.4	2.4
Organic C (g kg^{-1})	-	-	-
Total C (g kg^{-1})	-	-	-
Total C/N ratio	-	-	-

[†]Dry mass basis

*(NO_3-N and NO_2-N + NH_4-N + 15% organic N)

3.3.3 Field Operations

Conventional tillage consisted of a single tillage operation in late fall and early spring with a heavy-duty chisel plow and a light field cultivator respectively. The tillage operation in early spring was followed by a packing operation perpendicular to the direction of seeding with a coil packer. Weed species emerging after seeding in conventionally tilled oat plots were targeted with a post-seeding harrowing operation in 2002. In 2003, wheat and oats in conventionally tilled systems were seeded 7.5-cm deep and received a 2.5-cm shallow tillage operation five to seven days after seeding. Crops were seeded deeper than normal to facilitate the post seeding tillage operation.

Beef manure compost was applied to plots to be seeded to wheat and oats in the B management system in early spring and incorporated into the soil with the spring tillage operations. Compost was applied based on available N (NO_3-N and NO_2-N + NH_4-N + 15% of organic N) on a wet mass basis according to soil test recommendations for N from soil samples collected the previous fall (Buckley, 2002). In 2002, compost was weighed using 20-L pails and broadcast manually at a rate of 54,750 kg ha^{-1} (80 kg N ha^{-1}) based on 1.46 kg $tonne^{-1}$ available N on a wet mass basis. Approximately 16 pails were applied to each plot. Lawn rakes were used to spread the compost evenly. In 2003, a model #TD75 plot scale turf spreader (Millcreek Mfg. Co., 2008) was used to broadcast the compost at a rate of 56,700 kg ha^{-1} (84 kg N ha^{-1}) based on 1.48 kg $tonne^{-1}$ available N on a wet mass basis. Soil samples collected just prior to seeding reflected the compost addition in the B system whereas fertility treatments in other management systems were applied with the seeding operation.

A Seed Hawk air seeder (Seed Hawk, 2008) with 20-cm row spacing was used for all primary seeding operations. Underseeding of sweet clover on plots seeded to wheat in

the A, B, and C systems was accomplished with the Seed Hawk in 2002 and with a Swift Current seeder in 2003. Synthetic fertilizer in the form of urea ($CO(NH_2)_2$) and monoammonium phosphate (MAP) ($NH_4H_2PO_4$) was side-banded and seed-placed respectively in the C, D, and E systems at the time of seeding based on soil test recommendations from soil samples collected the previous fall.

Plots in the ZT managed D and E systems received a pre-seeding application of Round-up™ (Original™ or Transorb™) (356 or 360-kg/m^3 glyphosate present as the isopropylamine salt and formulated as a solution). Tank mixes of Horizon™ (240- kg/m^3 clodinafop-propargyl formulated as an emulsifiable concentrate) and Curtail M™ (50- kg/m^3 clopyralid and 280- kg/m^3 MCPA ester) and of Banvel™ (480- kg/m^3 dicamba solution) and MCPA amine (500- kg/m^3 amine) herbicides were applied in-crop to wheat and oats respectively (at the 3 to 5 leaf crop stage) in the E system.

All 2002 wheat and oat crops were swathed at maturity and harvested when the grain was at 14.5% moisture content or lower. In addition, a 1-m^2 section was hand harvested to determine the harvest index. The hand-harvested sample was weighed for dry matter, harvested with a plot combine and the seed and straw were used for nutrient analysis. Grain yield was determined from seed collected from the entire plot. In 2003, wheat and oat crops in the A, B, and C systems were harvested at the anthesis growth stage by silaging to prevent seed rain from severe wild oat (*Avena fatua* L.) infestations. Harvest of the D and E systems was the same as previously described for 2002.

3.3.4 Field Sampling and Measurements

3.3.4.1 Soil

Soil samples were collected at the 0-15 and 15-60 cm depth from each oat and wheat crop-management combination at 6 stages in 2002: early spring (May 2), seeding (May 14), early boot (June 26), anthesis (July 17), maturity (Sept. 4), and late fall (Oct. 28). In 2003, soil samples were collected at 7 stages: early spring (May 1), seeding (May 14) (wheat was seeded on May 5; May 14 sampling in wheat plots was 0-15 cm only), late tillering (wheat: June 17, oats: June 27), early boot (wheat: June 30, oats: July 4), anthesis (July 12), maturity (Aug. 19), and late fall (Oct. 29). Additional soil samples were collected in 2003 from the 0-15 cm depth on May 28 and July 3 for wheat and May 23 and June 7 for oats. A 3-hole composite sample was collected for each 0-15 and 15-60 cm depth for soil samples taken in early spring 2002. All subsequent soil sampling involved a 3-hole composite sample for each 0-15 cm depth, while only one hole was used for each 15-60 cm depth. All in-crop sampling was done between plant rows.

Soil samples were naturally air-dried at room temperature after sampling. If soil samples could not be dried immediately, they were maintained in a cooler at 10°C. Soil samples were weighed before and after drying to determine gravimetric soil moisture content of each sample. However, gravimetric soil moisture content was not determined for 2002 early spring samples, 2002 maturity samples (replicates 3 and 4 only) and 2003 0-15 cm anthesis samples (oats only). All soil samples were ground to pass through a 2-mm sieve.

All soil samples were extracted with 2 *M* KCl (149.1-g KCl/L distilled/deionized water) using a 1:10 weight of dry soil/volume of extractant ratio (2.5-g soil/25-mL

extractant) (Carter, 1993) and filtered with Whatman #42 ashless circles (Whatman International Ltd., 2008). Extracts from samples collected in 2002 were stored frozen for several months prior to analysis. All subsequent extracts were refrigerated for several weeks before analysis.

All extracts were analyzed for NO_3^- and NH_4^+ colormetrically using a Technicon Autoanalyzer II with a single-channel colorimeter and a Technicon 2-pen recorder (Seal Analytical Inc., 2008). Calibration standards for NO_3^- and NH_4^+ were analyzed at the beginning of every autoanalyzer operation and subsequently after every second tray of 40 sample extracts. Output charts from the Technicon 2-pen recorder were read manually using a colored transparent chart reader. Values from repeat samples were averaged. If the sample peak exceeded the chart area, the extract was diluted with 2 *M* KCl and reanalyzed. The values for diluted samples were multiplied by the dilution factor.

Soil N content in kg ha^{-1} was determined by multiplying the concentration of N in ppm by a bulk density factor of 1.33 g cm^{-3}.

3.3.4.2 Plant

Whole plant samples cut 2 to 3 cm above the soil surface were collected from each oat and wheat crop-management combination at 2 stages in 2002: early boot (July 8) and anthesis (July 15). In 2003, plant samples were harvested at 3 stages: late tillering (wheat: June 20, oats: June 27), early boot (wheat: June 27, oats: July 4) and anthesis (wheat: July 8, oats: July 11). Each sample consisted of one meter of plant row harvested from the second row from the edge from either side of the plot for a total of 2 meters of plant row from each plot. Weeds were separated from the crop biomass samples. Plant

samples were weighed to determine total fresh weight and then mulched to improve the uniformity of the sample. A representative sub-sample was randomly selected from the mulch, and weighed to determine fresh sample weight. Sub-samples from the mulch were placed in nylon mesh bags and oven dried at 54°C. Once dry, samples were weighed again to determine dry weight. Straw and grain samples were collected at maturity. A 1-m length of row was hand harvested and threshed to determine grain and straw weight for calculation of harvest index. For determination of grain yield, the two outside rows of the plot were removed and the remainder of the plot threshed using a plot combine. Grain was dried overnight at 55°C and weighed. Grain moisture was measured and grain yield reported as adjusted to 14.5% moisture.

Plant and straw samples were ground to pass a 20 mesh screen in a Thomas moving blade mill (Thomas Scientific, 2008). Grain samples were ground with a coffee grinder. Total N was determined with a Kjeldahl procedure (American Association of Cereal Chemists, 1976). Dry matter yield was calculated in kg ha^{-1} by dividing the dry weight of plant material in kg by the area of plant row harvested in hectares. Nitrogen accumulation was converted to kg ha^{-1} by multiplying the concentrations of N in percent by dry matter yields in kg ha^{-1}. Total N accumulation at maturity represents the sum of N accumulation in the grain and straw.

3.3.5 Statistical Analysis

Data for each individual variable were originally analyzed as repeated measures experiments using the mixed model procedure of SAS with all effects and interactions included in the model (Littell et al.,1996). Individual crop data for each individual

variable were later analyzed separately for each individual year with management system being the only effect in the model. Least significant difference values were determined with SAS pdmix procedures. Single degree of freedom orthogonal contrasts were used to determine the significance of pre-determined treatment comparisons. Effects were considered significant at $P < 0.05$. Pearson correlation coefficients were calculated between selected crop and soil measurements using SAS Proc Corr procedures.

3.4 Results and Discussion

Only results from the wheat crop phase of the rotation are presented.

3.4.1 Inorganic Soil NO_3^- Content

The soil NO_3^- test provides a measure of inorganic soil NO_3^- at the time of sampling (Jowkin and Schoenau, 1995) and has proven relatively effective for fertilizer N recommendations under Manitoba conditions (Soper and Huang, 1963; Soper et al., 1971; Flaten, 2001b). When considered over time, changes in soil NO_3^- test values will indicate losses or gains of NO_3^- over the time interval (Jowkin and Schoenau, 1995).

For 2002, at the 0-15 cm soil depth there was no significant difference in the inorganic soil NO_3^- content among management systems at early spring or seeding (Table 3.3). Between early spring and seeding, soil NO_3^- increased in response to N mineralization in the absence of an actively growing crop. From seeding to early boot, soil NO_3^- remained constant in C, D and E systems but declined in A and B systems in response to crop uptake. Between early boot and anthesis soil NO_3^- declined in all systems in response to crop uptake.The pr esence of higher soil NO_3^- in C, D, and E systems in the middle of the growing season compared to the A and B systems resulted

from the application of synthetic urea fertilizer at the time of seeding.

For 2002, at the 15-60 cm soil depth, soil NO_3^- remained unchanged in A and B systems between early spring and late fall (Table 3.3). From seeding to late fall, soil NO_3^- was consistently higher in systems receiving synthetic urea fertilizer. In early spring, soil NO_3^- was significantly higher in the C management system compared to the D and E systems. The C system receives conventional tillage while the D and E systems are under zero-till management. The spring of 2002 was relatively cold and dry (Table 3.1) and the conventional tillage in the C system may have resulted in warmer soil temperatures, increased microbial activity and increased release of soil N through mineralization. This is consistent with findings from north-central Alberta where Nyborg and Malhi (1989) observed greater amounts of NO_3^- in tillage plots compared to zero-tillage plots. Soil NO_3^- increased in C, D, and E management systems from early spring to early boot and then declined to early spring levels. The constant concentrations of soil NO_3^- in A and B systems over the growing season suggests that the increase in soil NO_3^- in C, D, and E systems was, indeed, due to urea fertilization and not to N mineralization. Also, in each of the C, D, and E systems, the highest soil NO_3^- content occurred at the June 26 early boot crop stage. This date represented the first sampling after the seeding application of synthetic urea fertilizer. Although the month of June received normal amounts of precipitation, the application of a readily available form of N at seeding may have exceeded initial crop demand and moved lower in the soil profile during the early part of the growing season. Significantly higher soil NO_3^- in the conventional tilled C system compared to the zero-tilled D and E systems appeared again in late fall.

Table 3.3. Soil NO_3^- content of soil samples collected from 0-15 and 15-60 cm soil depths in plots seeded to durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		22	57	21	7	17	24
Organic with compost (B)		26	76	22	14	20	32
Nutrients no pesticides (C)		31	55	37	22	22	30
Pesticide Free Production (D)		23	34	44	13	13	19
Integrated Management (E)		25	47	49	16	22	36
LSD		-	-	-	9	7	11
SE		4.54	12.99	10.57	3.11	2.43	3.75
ANOVA	df			Pr>F			
Management system	4	0.6316	0.2681	0.2665	0.0338	0.0414	0.0302
Contrasts							
A vs. B		ns*	ns	ns	ns	ns	ns
A,B vs. C,D,E		ns	ns	0.0407	0.0270	ns	ns
A,B vs. C		ns	ns	ns	0.0063	ns	ns
C vs. D,E		ns	ns	ns	ns	ns	ns

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		22	21	31	18	14	19
Organic with compost (B)		22	26	33	17	14	19
Nutrients no pesticides (C)		26	37	78	53	23	35
Pesticide Free Production (D)		18	25	56	31	14	18
Integrated Management (E)		20	25	80	52	25	29
LSD		-	-	33	25	-	9
SE		2.47	5.03	12.33	8.31	3.40	3.05
ANOVA	df			Pr>F			
Management system	4	0.2428	0.2471	0.0150	0.0141	0.0698	0.0048
Contrasts							
A vs. B		ns	ns	ns	ns	ns	ns
A,B vs. C,D,E		ns	ns	0.0017	0.0023	ns	0.0076
A,B vs. C		ns	0.0414	0.0045	0.0034	0.0456	0.0008
C vs. D,E		0.0380	ns	ns	ns	ns	0.0085

*ns = not significant, $P>0.05$.

Soil NO_3^- in the 2003 0-15 cm soil depth was not affected by management system in early spring (Table 3.4). Between early spring and the May 14 sampling date, soil NO_3^- increased in all management systems except E. At the May 14 sampling, higher soil NO_3^- was observed in the conventional tilled C system compared to the zero-tilled D and E systems and in the B system compared to the A system. The effect of tillage treatment in the C system compared to the D and E systems was the same as previously described for the 2002 15-60 cm soil depth. The higher soil NO_3^- in B compared to A can be related to the application of composted beef cattle manure in the B system prior to seeding. In a study to determine N mineralization from composted beef cattle manure under field conditions, Eghball (2000) found about 4% of total compost N was immediately plant available after application. Being a fully phased study, the compost application in 2003 represented the second application to the respective plots with the first application being made in 2001. It is possible that the higher soil NO_3^- in the B systems in 2003 is partially attributed to a residual effect of the compost application made in 2001. In a field study to examine the N availability of composted beef cattle manure for corn, Paul and Beauchamp (1993) reported 2.9% N recovery in the first residual year and 5.5% in the second residual year. Soil NO_3^- content remained unchanged in the A, C, and D systems between May 14 and May 28 but increased in the B and E systems. From May 28 to the June 17 late tillering crop stage, soil NO_3^- declined in all systems in response to crop N demand. Higher soil NO_3^- contents were still observed in the compost treated B system compared to the untreated A system at both May 28 and June 17 sampling dates. Between June 17 and late fall, soil NO_3^- remained at levels equal to or below those in early spring in all management systems except B. In the B system, compost increased soil NO_3^- above

that of the A system at maturity and late fall resulting in late fall soil NO_3^- levels significantly above those in early spring. This reflects the slower release of N from the composted manure. The only significant effect of synthetic urea fertilizer on soil NO_3^- content was observed at the June 30 and July 3 sampling dates where soil NO_3^- was higher in the C, D, and E systems compared to the A and B systems. The duration of higher soil NO_3^- contents in the middle of the growing season in the C, D, and E systems compared to the A and B systems may reflect the readily available form of N supplied with synthetic fertilizer at seeding. In contrast to the May 14 sampling date, soil NO_3^- was higher in the D and E systems compared to the C system at the June 30 and July 3 sampling dates. According to weather data, June and July received below normal amounts of precipitation (Table 3.1). Although gravimetric soil moisture was not determined on soil samples collected on July 3, soil moisture was higher in zero-till managed systems on June 30 (Appendix F). According to Jowkin and Schoenau (1995), greater moisture content under no-till managed sites would be expected to enhance mineralization and bio-availability of NO_3^-.How ever, the increased moisture content of soils under zero-till management requires more heat to warm in early spring which may result in less mineralization earlier in the growing season.

Management system had no effect on early spring soil NO_3^- in the 2003 15-60 cm soil depth (Table 3.4). Between the June 17 late tillering crop stage and late fall, the soil NO_3^- content in all management systems was equal to or lower than early spring levels. Between the late tillering and July 12 anthesis crop stages, soil NO_3^- was higher in C, D, and E systems compared to A and B systems. Soil NO_3^- was also higher in the C, D, and E systems compared to the A and B systems in the 0-15 cm soil depth at this time.

Table 3.4. Soil NO_3^- content of soil samples collected from 0-15 and 15-60 cm soil depths in plots seeded to durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth										
		Sampling Date								
Mgmt Syst		May 1	May 14	May 28	Jun 17	Jun 30	Jul 3	Jul 12	Aug 19	Oct 29
		(kg ha^{-1})								
Org (A)		17	32	31	9	6	7	6	8	13
OrgC (B)		25	52	67	23	8	8	9	13	36
NNP (C)		17	46	55	16	9	7	8	12	17
PFP (D)		15	30	36	14	10	8	7	9	17
IM (E)		20	22	45	24	12	12	12	13	22
LSD		-	19	18	8	2	2	3	-	10
SE		3.77	3.28	2.94	3.58	0.80	0.34	1.08	1.60	3.45
ANOVA	df	Pr>F								
Mgmt Syst	4	0.4238	0.0305	0.0053	0.0128	0.0018	0.0003	0.0124	0.0925	0.0033
Contrasts										
A vs. B		ns*	0.0415	0.0008	0.0038	ns	ns	ns	0.0308	0.0003
A,B vs. C,D,E		ns	ns	ns	ns	0.0007	0.0111	ns	ns	ns
A,B vs. C		ns	ns	ns	ns	ns	ns	ns	ns	ns
C vs. D,E		ns	0.0225	ns	ns	0.0474	0.0030	ns	ns	ns

15-60 cm soil depth										
		Sampling Date								
Mgmt Syst		May 1	May 14	May 28	Jun 17	Jun 30	Jul 3	Jul 12	Aug 19	Oct 29
		(kg ha^{-1})								
Org (A)		26	n.d.†	n.d.	16	14	n.d.	12	9	6
OrgC (B)		37	n.d.	n.d.	21	13	n.d.	14	12	8
NNP (C)		49	n.d.	n.d.	27	16	n.d.	19	14	19
PFP (D)		35	n.d.	n.d.	40	30	n.d.	17	10	13
IM (E)		60	n.d.	n.d.	43	29	n.d.	24	10	13
LSD		-	-	-	11	11	-	-	-	-
SE		13.38	-	-	4.46	3.92	-	2.77	2.15	3.69
ANOVA	df	Pr>F								
Mgmt Syst	4	0.4361	-	-	0.0006	0.0085	-	0.0688	0.2091	0.1761
Contrasts										
A vs. B		ns	-	-	ns	ns	-	ns	ns	ns
A,B vs. C,D,E		ns	-	-	0.0001	0.0041	-	0.0167	ns	0.0336
A,B vs. C		ns	-	-	ns	ns	-	ns	ns	0.0215
C vs. D,E		ns	-	-	0.0067	0.0081	-	ns	ns	ns

*ns = not significant, $P>0.05$.

†n.d. = no data were collected.

Similar to the 15-60 cm soil depth in 2002, the relatively constant levels of soil NO_3^- in the 2003 15-60 cm soil depth over the growing season suggests that the contribution from mineralization was limited or that crop uptake was keeping up with mineralization. Therefore,some NO_3^- from the readily available synthetic urea fertilizer applied in the C, D, and E systems at seeding may have moved lower in the soil profile during the early to middle part of the growing season. Zero-tillage resulted in higher soil NO_3^- content in the D and E systems compared to the conventional tilled C system at the June 17 and June 30 sampling times. The effect of tillage treatment in the D and E systems compared to the C system was the same as previously described for the June 30 and July 3 sampling dates in the 2003 0-15 cm soil depth.

3.4.2 Wheat Dry Matter Yield

Crop dry matter production continued to maturity in most management systems and was significantly higher in the C, D, and E management systems compared to the A and B systems at all crop stages sampled in both years of study (Table 3.5). Similar findings were reported by Campbell et al. (1977b) in a field study with spring wheat grown in lysimeters at two moisture levels and seven rates of N fertilizer where dry matter production increased to maturity and the amount of dry matter produced increased with N applied, moisture, and time. In 2002, no difference was observed in crop dry matter yield between the A and B systems at the July 8 early boot and July 15 anthesis crop stages; however,d ry matter yield was significantly higher in the B system at maturity.

In 2003, crop dry matter yield was higher in the B system compared to A at the June 20 late tillering and June 27 early boot crop stages but no difference was observed at

anthesis. Crop dry matter yield was higher in the C management system compared to the A and B systems at each crop stage sampled in 2002 but no difference was observed between the C system and the A and B systems at any crop stage in 2003. The lack of a difference between crop dry matter yield in the C system compared to the A and B systems in 2003 may partly reflect the significantly higher amount of weed biomass in the C system in response to the readily available form of N supplied with the synthetic urea fertilizer and an absence of in-crop weed control. This is evidenced by the higher crop dry matter production at all crop stages in both 2002 and 2003 in the D and E systems which received synthetic fertilizer and pesticides compared to C which received synthetic fertilizer only.

Table 3.5. Crop dry matter yield of durum wheat (*Triticum durum*) at selected crop stages on a range of management systems during the 2002 and 2003 growing seasons.

		Sampling Date						
		2002			2003			
Mgmt Syst		Jul 8 (boot)	Jul 15 (anthesis)	Sep 1 (maturity)	Jun 20 (tillering)	Jun 27 (boot)	Jul 8 (anthesis)	Aug 14 (maturity)
		----------(kg ha^{-1})----------						
Org (A)		2109	2445	4717	474	734	1294	n.d.†
OrgC (B)		2576	3130	5891	1009	2023	2003	n.d.
NNP (C)		3223	4287	6838	957	1424	1411	n.d.
PFP (D)		4362	6095	8016	1378	2355	4096	6393
IM (E)		4033	5677	8114	1002	1816	4023	7488
LSD		643	1112	1171	370	674	1230	-
SE		211.54	362.57	393.74	130.99	220.86	455.27	965.16
ANOVA	df				Pr>F			
Mgmt Syst	4	<0.0001	<0.0001	0.0002	0.0034	0.0021	0.0004	0.2763
Contrasts								
A vs. B		ns*	ns	0.0495	0.0084	0.0013	ns	-
A,B vs. C,D,E		<0.0001	<0.0001	<0.0001	0.0054	0.0312	0.0012	-
A,B vs. C		0.0048	0.0053	0.0064	ns	ns	ns	-
C vs. D,E		0.0025	0.0035	0.0218	ns	0.0295	0.0002	-

*ns = not significant, $P>0.05$.

†n.d. = no data were collected.

3.4.3 Wheat Grain Yield and Protein Concentration

In 2002, final grain yield was significantly higher in C, D, and E systems receiving synthetic urea fertilizer compared to the organic A and B systems under legume and legume and composted manure based fertility, respectively and in D and E systems receiving pesticides compared to C which did not receive pesticides (Table 3.6). This is consistent with the higher dry matter production observed in response to an abundant source of plant available N and reduced weed competition. In a field trial with four spring wheat genotypes, McMullen et al. (1988) reported a highly positive correlation between grain yield and dry matter accumulation.

Table 3.6. Final grain yield and protein concentration of durum wheat (*Triticum durum*) on a range of management systems in the 2002 and 2003 growing seasons.

	Grain Yield		Grain Protein	
Management System	2002	2003	2002	2003
	---(kg ha^{-1})---		-----(%)-----	
Organic (A)	1717	n.d.†	11.5	n.d.†
Organic with compost (B)	1891	n.d.	13.4	n.d.
Nutrients no pesticides (C)	2088	n.d.	14.0	n.d.
Pesticide Free Production (D)	2849	2272	14.5	15.0
Integrated Management (E)	3426	3332	14.3	15.2
LSD	528	-	1.7	-
SE	175.15	378.61	0.57	0.22

ANOVA	df	Pr>F			
Management System	4	<0.0001	0.0519	0.0150	0.1817
Contrasts					
A vs. B		ns	-	0.0360	-
A,B vs. C,D,E		<0.0001	-	0.0037	-
A,B vs. C		ns	-	0.0485	-
C vs. D,E		0.0002	-	ns	-

*ns = not significant, $P>0.05$.
†n.d. = no data were collected.

The grain protein concentration (grain N concentration multiplied by a factor of 5.7) in 2002 was higher in systems receiving synthetic urea fertilizer compared to organic systems and in the B system receiving beef manure compost compared to the untreated A system (Table 3.6). According to Olsen and Kurtz (1982), N fertilization of cereal crops generally increases protein content of the grain when the N fertilizer rate exceeds a critical rate which increases yield at the expense of protein. Once N is no longer the main factor limiting grain yield, protein concentration will increase. It is possible that a release of N from composted manure later in the growing season increased N supply after grain yield was essentially fixed, thereby increasing protein concentration. In 2003, grain yields and protein comparisons across systems were not possible due to the harvest of treatments A, B, and C as silage.

3.4.4 Wheat Tissue Nitrogen Concentration

Crop tissue N concentration was significantly higher in the C, D, and E systems receiving synthetic urea fertilizer compared to the organic A and B systems at all crop stages sampled in 2002 and in the late tillering and anthesis crop stages in 2003 (Table 3.7). No effect of management system was observed on crop N concentration in the 2003 early boot crop stage. Although crop N concentration was higher in the C, D, and E systems compared to A and B at late tillering, the lack of management system response at early boot might reflect significantly higher dry matter yield in C, D, and E systems at the early boot crop stage which may have diluted plant N concentration to values similar to those observed in the A and B systems.

Table 3.7. Crop tissue and grain N concentration of durum wheat (*Triticum durum*) at selected crop stages on a range of management systems during the 2002 and 2003 growing seasons.

	Sampling Date and Crop Stage						
	2002			2003			
	plant tissue		grain	plant tissue			grain
Mgmt Syst	Jul 8 (boot)	Jul 15 (anthesis)	Sep 1 (maturity)	Jun 20 (tillering)	Jun 27 (boot)	Jul 8 (anthesis)	Aug 14 (maturity)
	----------			(%)			----------
Org (A)	2.60	2.18	2.03	2.93	1.88	1.25	n.d.†
OrgC (B)	2.65	1.78	2.35	2.93	2.48	1.28	n.d.
NNP (C)	3.13	2.13	2.45	3.83	2.55	2.15	n.d.
PFP (D)	3.25	2.28	2.55	3.98	2.60	1.90	2.18
IM (E)	3.25	2.45	2.50	4.35	2.55	2.25	2.28
LSD	0.29	-	0.30	0.69	-	0.58	-
SE	0.11	0.18	0.10	0.24	0.30	0.23	0.04
ANOVA	df			Pr>F			
Mgmt Syst	4	0.0004	0.088	0.015	0.0019	0.4422	0.0054	0.0917
Contrasts							
A vs. B		ns*	ns	0.036	ns	ns	ns	-
A,B vs. C,D,E		<0.0001	0.0482	0.0037	0.0001	ns	0.0004	-
A,B vs. C		0.001	ns	0.0485	0.0067	ns	0.0023	-
C vs. D,E		ns	ns	ns	ns	ns	ns	-

*ns = not significant, $P>0.05$.
†n.d. = no data were collected.

In general, crop N concentration was highest at the earliest crop stage sampled and then declined with later crop samplings. Similar results were reported from field studies with spring wheat (Boatwright and Haas, 1961) and winter wheat (Gregory et al., 1979; Darroch and Fowler, 1990) where the concentration of nutrients within the whole plant generally decreased throughout growth. Other researchers have used crop N concentration at a specific growth stage as an indicator of crop N sufficiency or deficiency (Baethgen and Alley, 1989). According to Baethgen and Alley (1989), a critical N concentration of 39.5 g N kg^{-1} (3.95%) at Zadoks 30 (pseudo stem erection)

was required in winter wheat to produce 90% of the maximum yield with no further N fertilizer application. The Manitoba Provincial Soil Testing Laboratory (MPSTL) (1982) reported a sufficiency N concentration for spring wheat of 2 to 3% in the whole plant prior to filling. The crop N concentrations we observed at the 2002 anthesis crop stage were all very near or within the sufficiency range reported by the MPSTL (1982); however,d ry matter yield at maturity increased in the order A < B = C < D = E. This difference in dry matter production may be related to increased plant available soil N in response to fertility and/or pesticide treatments and suggests that the thresholds determined by the MPSTL (1982) may need to be higher. Therefore,it appe ars that N was a limiting factor for dry matter production. In 2003, the significantly higher crop N concentrations in the C, D, and E systems compared to the A and B systems were very near or exceeding the critical level determined by Baethgen and Alley (1989) and very near or within the range of sufficiency reported by the MPSTL (1982) at the June 20 late tillering and July 8 anthesis crop stages respectively. Although the C system received synthetic urea fertilizer, the lower dry matter yield at boot and anthesis compared to D and E may be related to competition from much higher weed biomass. The crop N concentration in the A and B systems at anthesis was well below the sufficiency level of 2 to 3% and suggests that available N was a limiting factor in these systems.

3.4.5 Wheat Nitrogen Uptake

The pattern of crop N accumulation was similar to that of dry matter accumulation; however, crop N uptake reached a maximum near anthesis in most management systems (Table 3.8). Similar findings were reported by Darroch and Fowler

(1990) in a field study using winter wheat where 89% of total N had accumulated by anthesis compared to only 70% of total dry matter.

In 2002, crop N uptake was not influenced by compost application at any of the crop stages sampled. Similar results were observed at the July 8 early boot and July 15 anthesis crop stages where crop dry matter yield and tissue N concentration showed no significant response to compost application. However, at maturity, crop dry matter yield and tissue N concentration were significantly higher in the compost treated B system compared to the untreated A system. The loss of easily convertible N during the composting process (Eghball, 2000) may have limited mineralization of composted manure N early in the growing season, thereby reducing dry matter production, tissue N concentration, and crop N uptake. A release of compost N between anthesis and maturity may have increased crop dry matter yield and grain tissue N concentration at maturity relative to the untreated A system. Although not significant, soil NO_3^- content was numerically equal or higher in the compost treated B system compared to the untreated A system at all stages sampled. The fact that crop N uptake was not influenced by the compost application suggests that the formula used to apply compost based on available N (NO_3-N and NO_2-N + NH_4-N + 15% of organic N) was over estimating availability of the compost N.

At each crop sampling stage in 2002, crop N uptake was higher in systems receiving synthetic urea fertilizer compared to legume and legume and composted manure fertility based organic systems. On average, crop N uptake in systems receiving synthetic urea fertilizer was around 50% of that applied. Crop dry matter yield and tissue N concentration were also higher in response to synthetic fertilizer at all crop stages

sampled. Since N from synthetic fertilizer is assumed to be 100% plant available in the year of application (Eghball, 2000), the higher crop dry matter yield, tissue N concentration, and crop N uptake in response to synthetic urea fertilizer may be attributed to an increased supply of immediately plant available N. This was supported by higher soil NO_3^- contents in systems receiving synthetic urea fertilizer compared to organic systems at the early boot and anthesis crop stages in the 0-15 cm soil depth and between seeding and late fall in the 15-60 cm soil depth. Crop N uptake was also higher at all crop stages in the D and E systems which received pesticides compared to the C system which did not. The same effect of management was observed for crop dry matter yield; however,no si gnificant difference in crop tissue N concentration was observed between the D and E and C systems. The use of pesticides in the D and E systems resulted in significantly lower weed biomass determined post spraying compared to C (Appendix L). It is likely that a higher proportion of nutrients were accumulated in weed biomass in C compared to the D and E systems, thereby reducing the supply of N available in the C system for crop dry matter production.

Maximum crop N accumulation in 2002 had occurred by the July 8 early boot crop stage regardless of management system. Similar results were reported by Johnston and Fowler (1991) who found 100% of the final N in no-till winter wheat was present by Zadocks 45 (boot just swollen). The constant or declining accumulation of N between anthesis and maturity suggests that the majority of N accumulating in the growing grain would have been redistributed from within the plant. However, leaf loss may also have offset N uptake during this period. Other researchers have reported the cessation of N uptake at or shortly after anthesis in winter wheat (Gregory et al., 1979).

Table 3.8. Crop N uptake of durum wheat (*Triticum durum*) at selected crop stages on a range of management systems during the 2002 and 2003 growing seasons.

	Sampling Date and Crop Stage						
	2002			2003			
Mgmt Syst	Jul 8 (boot)	Jul 15 (anthesis)	Sep 1 (maturity)	Jun 20 (tillering)	Jun 27 (boot)	Jul 8 (anthesis)	Aug 14 (maturity)
	----------(kg ha^{-1})----------						
Org (A)	55	55	48	12	13	15	n.d.†
OrgC (B)	68	55	62	27	46	23	n.d.
NNP (C)	100	90	83	33	32	25	n.d.
PFP (D)	141	138	104	50	56	70	66
IM (E)	131	139	116	40	41	81	88
LSD	19	28	15	10	18	19	-
SE	6.43	9.25	5.45	4.19	5.95	6.66	10.69

ANOVA	df	Pr>F					
Mgmt Syst	4	<0.0001	<0.0001	<0.0001	<0.000 1	0.0016	<0.0001	0.0579
Contrasts								
A vs. B		ns*	ns	ns	0.0085	0.0012	ns	-
A,B vs. C,D,E		<0.0001	<0.0001	<0.0001	<0.000 1	0.0297	<0.0001	-
A,B vs. C		0.0002	0.0071	0.0008	0.0052	ns	ns	-
C vs. D,E		0.0004	0.0007	0.0009	0.0103	0.0370	<0.0001	-

*ns = not significant, $P>0.05$.
†n.d. = no data were collected.

Beef manure compost increased crop N uptake in the B system above that of the untreated A system in 2003 at the June 20 late tillering and June 27 early boot crop stages (Table 3.8). The same effect of compost was observed for crop dry matter yield; however,no effect of compost was observed for crop tissue N concentration. Higher soil NO_3^- content in the 0-15 cm soil depth between seeding and late tillering in the B system compared to the A system may have resulted in increased dry matter yield and crop N uptake. Although no effect of compost was observed on soil NO_3^- content at the early boot crop stage, it is possible that the limited amount of plant available N supplied by the compost had been accumulated in crop biomass by this time.

Higher crop N accumulation was observed in the C, D, and E systems receiving synthetic urea fertilizer compared to the organic A and B systems at all crop stages sampled in 2003. Crop dry matter yield and crop tissue N concentration were also higher in the C, D, and E systems compared to the A and B systems at all crop stages with the exception of the June 27 early boot crop stage where no management system effects were observed on crop tissue N concentration. This is consistent with the higher soil NO_3^- content in the C, D, and E systems compared to the A and B systems at the early boot and July 3 sampling dates and between late tillering and anthesis in the 0-15 and 15-60 cm soil depths respectively. However,at both ea rly boot and anthesis crop stages, there was no difference in crop N accumulation between the C system receiving synthetic fertilizer and no pesticides and the organic A and B systems. Although no difference in crop dry matter yield was observed between the C and the A and B systems at any crop stage sampled, crop tissue N concentration was significantly higher in the C system compared to the A and B systems at the June 20 late tillering and July 8 anthesis crop stages. At each crop stage sampled, the crop N tissue concentrations in the C system were within the range of sufficiency reported by the MPSTL (1982) suggesting that crop N uptake in the C system was limited by dry matter production. Although the C system received synthetic urea fertilizer, the significantly higher amount of weed biomass in the C system compared to the A and B systems (Appendix L) may have limited crop dry matter yield and crop N accumulation by effectively competing for available soil N or other resources such as available light and soil moisture. Higher crop N uptake was also observed in the D and E systems compared to the C system at all crop sampling stages. Crop dry matter yield was also significantly higher in the D and E systems compared to the C system at

the June 27 early boot and July 8 anthesis crop stages whereas no difference in crop N tissue concentration was observed between the D and E systems and the C system at any crop stage sampled. The D and E systems received synthetic urea fertilizer and pesticides while the C system received synthetic urea fertilizer only. This effect of pesticides was similar to that observed in 2002.

Based on the three crop stages sampled in the A, B, and C systems, maximum crop N accumulation had occurred by the late tillering crop stage in the A and C systems and by early boot in the B system. In the D and E systems, maximum crop N accumulation had occurred by the early boot and anthesis crop stages respectively. Between anthesis and maturity, the weight of nutrients accumulated in the crop remained almost constant or declined suggesting limited post anthesis accumulation of N.

3.5 Conclusions

The pattern of soil N release was similar in all management systems with the highest soil NO_3^- contents generally observed between seeding and the first crop stage sampled. Crop dry matter yield increased to maturity while the highest crop tissue N concentrations were observed at the first crop stage sampled. It appeared that increasing N supply increased dry matter yield to a greater extent than tissue N concentration. The responsiveness of dry matter to N indicated that N was deficient. Maximum crop N accumulation was realized between late tillering and anthesis. Soil NO_3^- content in the 15-60 cm soil depth was frequently higher in systems receiving synthetic fertilizer suggesting that an abundant source of readily available N is more likely to move lower in the profile unless closely matched to crop demand. No effect of composted manure on

soil and crop N dynamics was observed until the second year of the study indicating the effect of compost should be considered beyond the year of application and that the formula used to apply compost based on available N (NO_3-N and NO_2-N + NH_4-N + 15% of organic N) was over estimating availability of compost N in the year of application. The slow release of N from composted manure did not increase soil NO_3^- content in the 15-60 cm soil depth and the amount of N released was not adequate to meet crop N sufficiency requirements. The continued release of N from compost treated systems beyond maturity raises concerns about possible negative influences on the environment. Systems receiving synthetic urea fertilizer without pesticides also experienced N limitations in response to competition from significantly higher weed biomass. The PFP™ system was able to produce dry matter and final grain yields comparable to the integrated management system. In order to optimize crop production under Manitoba conditions, producers should ensure adequate N is available in the system to meet crop demand and practice an effective means of in-crop weed control.

4.0 EVALUATION OF THE PRS™-PROBE AND ILLINOIS SOIL NITROGEN TEST FOR PREDICTING NITROGEN RELEASE IN WHEAT CROPPING SYSTEMS IN MANITOBA, CANADA

4.1 Abstract

A reliable method of estimating the N supplying capacity of a soil is needed to improve predictions of crop fertilizer N requirements. Numerous soil N availability indices have been proposed to predict the amount of N that will be supplied by the soil to the growing crop. The effectiveness of Plant Root Simulator (PRS™) probes and the Illinois soil N test to predict soil N release through the growing season were evaluated on a Newdale clay loam soil in Manitoba, Canada. Spring wheat (*Triticum durum* Desf. cv. AC Avonlea) was grown on field pea (*Pisum sativa* L.) stubble in 2002 and 2003 on a range of cropping systems with N being supplied by decomposition of legume residues, composted beef cattle manure, and synthetic N fertilizers. Soil samples to a depth of 60 cm and whole above ground plant biomass samples were collected at selected crop development stages during the crop year and analyzed for inorganic soil NO_3^- and total plant N respectively. Plant Root Simulator probes were used at seeding and late tillering/early boot to measure soil NO_3^- release rates (PRS-NO_3^-). The Illinois soil N test was used to estimate the concentration of amino sugar N (ISNT-N) in soil samples collected at seeding, late tillering/early boot, and anthesis. The PRS-NO_3^- and ISNT-N values were used as an index of soil N release potential.

Management practices influenced inorganic soil NO_3^- content, crop N uptake, and the difference in recoverable N (RN) between sampling events. In general, measured soil and crop N variables were greatest in systems receiving synthetic fertilizer. A similar response to management was noted for PRS-NO_3^-. The highest ISNT-N values were

observed in systems receiving composted manure. Good relationships were found between mid season PRS-NO_3^- and crop N uptake (r = 0.51* and 0.64**) in 2002 and 2003,respectivel y. However, mid season soil NO_3^- content in the 0-15 cm depth was more highly correlated with crop N uptake (r = 0.59** and 0.68**) in 2002 and 2003, respectively than was PRS-NO_3^-. There was no significant correlation between early season ISNT-N and crop N uptake (r = -0.05 and 0.18) in 2002 and 2003 respectively. The ISNT was not a reliable indicator of potential N release under Manitoba conditions, based on the critical value of 300 mg kg^{-1} suggested for soil samples collected from a 0-15 cm depth from corn sites in Illinois. The lack of strong, consistent relationships between early season assessment of N release potential and crop N uptake make it difficult to use these indices for adjusting recommended fertilizer rates. A pre-plant soil NO_3^- test may still be the best option for predicting NO_3^- availability under Manitoba conditions.

4.2 Introduction

Nitrogen fertilizer is applied to make up the difference between the N that the crop requires for optimum growth and what can be provided by the soil. Therefore it is important to have an accurate assessment of the supply of N from the soil to the growing plant in order to accurately determine fertilizer requirements. Nitrogen supplied from the soil includes the reserves of inorganic N as well as the N released from mineralization of soil organic matter over the growing season. The majority of southern Manitoba, Canada is classified as a humid continental climate characterized by seasonal temperature extremes and moderate precipitation (Dunlop and Shaykewich, 1982). In Manitoba, as in

many other relatively dry locations, fertilizer N recommendations are commonly based on the level of extractable soil NO_3^- found in the soil prior to seeding (Flaten, 2001). Empirical relationships have been developed through regional field experimentation to determine the N additions required to meet specific yield goals across a range of soil NO_3^- levels (Soper and Huang, 1963; Soper et al., 1971). While the soil NO_3^- test has proven relatively effective under Manitoba conditions, it relies on a measurement of the stored soil NO_3^- at the time of sampling and does not provide a specific prediction of the NO_3^- that may become available to the crop over the growing season through mineralization. Inclusion of mineralizable N may provide a more accurate assessment of the season-long N supply to the crop and allow a closer prediction of fertilizer N needs. More closely matching N supply to crop demand would be beneficial, both economically and environmentally.

The development of the Illinois soil N test (ISNT) was stimulated by earlier reports that identified numerous sites throughout the north-central and northeastern USA where corn (*Zea mays* L.) did not respond to N fertilization (Mulvaney et al., 2001). In many such cases, large releases of NO_3^- were not predicted by soil testing for NO_3^- either before (pre-plant) or after (pre-sidedress) planting and overfertilization resulted (Mulvaney et al., 2001). The goal was to identify and measure a specific fraction of the soil organic N that supplies NO_3^- through mineralization and design a simple soil test procedure suitable for routine soil analysis (Mulvaney et al., 2001).

The ISNT uses microdiffusion techniques in a Mason jar to perform diffusion directly on the soil sample without the need for acid hydrolysis or chemical extraction (Khan et al., 2001). In Illinois, the resulting soil test values in mg N kg^{-1} (ppm) were

found to be highly correlated (r = 0.90) (P<0.001) with hydrolyzable amino sugar N (Khan et al., 2001). Amino sugar N is an organic fraction of soil N found in microbial cell walls and has been identified as a possible labile fraction of organic soil N that readily supplies plant available N through mineralization (Mulvaney et al., 2001). Based on a 30 cm soil sampling depth, a test value of 250 mg N kg^{-1} or higher indicates that corn will be nonresponsive to N fertilization in central or northern Illinois (^{15}N Analysis Service, 2002). A critical value of 300 mg N kg^{-1} would be appropriate for samples collected from a 15 cm depth (^{15}N Analysis Service, 2002). As designed, the ISNT does not account for variability in supplies of immediately available N nor does it account for reserves of available N from soil depths below 15 cm. Therefore, the ISNT does not eliminate the need for profile sampling (Khan et al., 2001). Using the ISNT, Khan et al. (2001) were able to correctly classify 25 soils in the north-central and northeastern USA on the basis of N fertilizer responsiveness by corn.

Other researchers have used ion-exchange resins (IERs) to measure soil NO_3^- release rates as an estimate of potentially available soil N (Adderley et al., 1998; Adderley et al., 2006; Flaten and Greer, 1998; Giblin et al., 1994; Greer et al., 1997; Jowkin and Schoenau, 1995; Jowkin and Schoenau, 1998; Kolberg et al., 1997; Qian and Schoenau, 1995; Qian and Schoenau, 2000; Qian and Schoenau, 2005; Qian et al., 1992; Subler et al., 1995; Ziadi et al., 1999). Resins are strong ion sinks and continually adsorb nutrient ions from the soil solution in a manner similar to adsorption by plant roots (Dobermann et al., 1994). The resulting nutrient measurement should therefore more closely represent the portion in the soil which is bio-available (Skogley, 1992). High correlations between IER NO_3^- adsorption and crop N uptake have been reported in

greenhouse studies with canola (*Brassica napus*) (Greer et al., 1997; Qian and Schoenau, 1995; Qian and Schoenau, 2000; Qian and Schoenau, 2005; Qian et al., 1992) and field trials with spring wheat (*Triticum aestivum* L.), (Jowkin and Schoenau, 1998), timothy (*Phleum pretense* L.), and orchardgrass (*Dactylis glomerata* L.) (Ziadi et al., 1999). The Plant Root Simulator (PRS™) probe is a diffusion-sensitive synthetic IER consisting of an ion-exchange membrane encapsulated in a plastic probe which is inserted into the soil (Western Ag Innovations Inc., 2001).

Although there has been research on both the ISNT and IERs, there has been limited information collected under Manitoba conditions. Therefore the objective of this study was to evaluate the effectiveness of the PRS™-probe and ISNT to predict soil N supplying capacity in a range of management systems in Manitoba, Canada.

4.3 Materials and Methods

The field site, experimental treatments, and soil and plant sampling and measurements were as described in chapter 3.0.

4.3.1 Recoverable Inorganic Soil Nitrogen

Inorganic soil NO_3^- and NH_4^+ content in kg ha^{-1} for each soil sample were added together to determine the inorganic soil N content. The inorganic soil N content of 0-15 cm depth soil samples were combined with the inorganic soil N content of corresponding 15-60 cm depth soil samples and the measure of crop N uptake at corresponding sampling dates to provide an estimate of the amount of recoverable N to a 60 cm soil depth.

4.3.2 Plant Root Simulator (PRS™) Probes

Plant Root Simulator (PRS™) probes supplied by Western Ag Innovations Inc. were buried for 2 week periods in each oat and wheat crop-management combination at two crop stages during the 2002 and 2003 growing seasons. Probes were buried at seeding (May 17) and early boot (June 28) and seeding (wheat: May 14, oats: May 23) and late tillering (wheat: June 19, oats: June 28) in 2002 and 2003 respectively.

In each burial, 4 cation (purple) and 4 anion (orange) probes were placed in each oat and wheat plot. A butter knife was used to make an insertion in the soil, and the probes were inserted vertically in the 0-15 cm soil layer to the depth of the membrane. Care was taken to ensure the probes were placed equal distance between the seed rows to avoid placing the probes in a fertilizer band. In the 2003 seeding burials, a measuring rule was used to estimate the location of seed rows in the A, B, and C systems based on the row spacing of the seeding tool by measuring from the edge of each subplot. This was necessary due to disruption and leveling of the soil from post seeding tillage and sweet clover seeding. The soil around each probe was packed to ensure good contact between the membrane and the soil. In the 2002 seeding burials, each cation and anion probe was buried randomly and separately from each other. In all subsequent burials, each cation probe was buried immediately beside an anion probe and the cation-anion pairs were randomly placed in each plot. In the burials at early boot (2002) and late tillering (2003), a 10 cm diameter by 25 cm long piece of PVC pipe was placed around each cation-anion pair and driven down to a depth of 20 cm to isolate the probes from plant root competition.

Once the probes were removed from the plots, all residual soil adhering to each probe was removed by washing with deionized/distilled water while scrubbing with a soft toothbrush. Excess water was shaken off each washed probe and the 4-cation and 4-anion probes from each plot were placed in a labeled 18 by 20 cm heavy-duty zip seal freezer bag. Any unused, recharged probes were also bagged and returned for analysis to account for ions that may not have been removed from the probes in the wash/recharge step. The washed and bagged probes were kept cool in a disposable styrofoam cooler packed with ice and returned to Western Ag Innovations Inc. for analysis.

As previously described in Western Ag Innovations Inc. (2001), once in the lab, the probes were eluted by adding 17.5 mL of 0.5 N HCl solution per PRS probe to each of the zip seal freezer bags (140 mL per 8 probes). As much air as possible was removed from each bag to ensure each PRS probe was completely immersed in the acid solution and the bags were sealed to eliminate leakage. Sealed bags were let stand for an hour, agitating every fifteen minutes, or alternatively placed on a side to side shaker at slow speed. The acid solution from each bag was transferred to a separate 20-dram vial and analyzed for NO_3-N and NH_4-N colormetrically using an autoanalyzer.

4.3.3 Illinois Soil Nitrogen Test

A 25-gram subsample of dried, ground soil from soil samples collected from the 0-15 cm depth in early spring, late tillering (2003 only), early boot (2002 only) and anthesis were sent to Agvise Laboratories to determine the concentration of (NH_4 + amino sugar)-N in ppm (mg kg^{-1}) using the Illinois Soil N Test (Agvise Laboratories, 2008).

4.4 Results and Discussion

Only results from the wheat crop phase of the rotation are presented.

4.4.1 Nitrogen Supplying Capacity as Assessed by the Pre-plant NO_3^- Test

In drier climates where leaching and denitrification are limited, the concentration of NO_3^- present in the soil in late fall or spring will usually be available for crop uptake (Flaten, 2001). Research in Manitoba, Canada has shown the amount of NO_3-N in the profile at the time of seeding provided a reasonably good indication of the supply of N available to a crop when the sampling was of sufficient depth (Soper et al., 1971). According to Soper et al. (1971), the amount of NO_3-N in the soil at the 61 cm depth provided the best correlation with uptake of N by barley. In more humid regions, a pre-plant soil test for residual NO_3-N is of limited value because NO_3-N may be lost through leaching and denitrification before crop uptake in these soils (Mulvaney et al., 2001).

No significant management system effect was observed in either year of study on pre-plant NO_3^- test values determined from soil samples collected in early spring (May 2 and May 1; 2002 and 2003 respectively) (Tables 4.1 and 4.2). Averaged across all management systems, the early spring pre-plant NO_3^- test values were 47.2 kg ha^{-1} and 60.0 kg ha^{-1} in 2002 and 2003 respectively. According to Manitoba Agriculture, Food and Rural Initiatives (2009), a 2695 kg ha^{-1} (40 bu ac^{-1}) spring wheat crop will uptake 85 to 104 kg N ha^{-1}.Bas ed on this estimate, our pre-plant NO_3^- test results would predict a response to added N fertilizer in all management systems for a 40 bu ac^{-1} yield goal. This was supported by the actual grain yields realized in 2002 where grain yields were significantly higher in C, D, and E systems receiving 80 kg N ha^{-1} from synthetic

fertilizer compared to organic A and B systems based strictly on legume and combinations of legume and composted manure fertility respectively (Table 3.6).

Although other researchers (Soper et al., 1971) have found good relationships between early season concentrations of NO_3^- in the soil and N uptake by a cereal crop, we observed no significant correlations in either year of study between early spring pre-plant NO_3^- values and crop N uptake at any of the stages sampled (Tables 4.6 and 4.9). The lack of a strong relationship with a reliable biological measure of N availability makes it difficult to use estimates of early season soil NO_3^- as a predictor of N release over the growing season.

Table 4.1. Soil NO_3^- content of soil samples collected from 0-60 cm soil depths in plots seeded to durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

	0-60 cm soil depth					
	Sampling Date					
Management System	May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
	----------(kg ha^{-1})----------					
Organic (A)	44	78	51	24	31	43
Organic with compost (B)	48	102	55	31	34	51
Nutrients no pesticides (C)	57	92	114	75	45	66
Pesticide Free Production (D)	41	59	100	44	26	37
Integrated Management (E)	46	72	129	68	47	65
LSD	-	-	53	27	13	18
SE	5.69	15.91	18.69	8.87	4.79	5.96

ANOVA	df	Pr>F					
Management System	4	0.3783	0.3479	0.0241	0.0037	0.0219	0.0124
Contrasts							
A vs. B		ns*	ns	ns	ns	ns	ns
A,B vs. C,D,E		ns	ns	0.0021	0.0007	ns	ns
A,B vs. C		ns	ns	0.0130	0.0006	0.0376	0.0210
C vs. D,E		ns	ns	ns	ns	ns	ns

*ns = not significant, $P>0.05$.

Table 4.2. Soil NO_3^- content of soil samples collected from 0-60 cm soil depths in plots seeded to durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

	0-60 cm soil depth					
	Sampling Date					
Management System	May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
	----------(kg ha^{-1})----------					
Organic (A)	42	25	20	18	17	19
Organic with compost (B)	61	44	22	22	26	43
Nutrients no pesticides (C)	66	43	25	27	26	36
Pesticide Free Production (D)	51	55	40	23	19	30
Integrated Management (E)	80	67	41	36	24	35
LSD	-	17	13	10	-	12
SE	15.44	7.53	4.50	3.19	3.19	4.07

ANOVA	df	Pr>F					
Management System	4	0.4765	0.0025	0.0058	0.0151	0.1200	0.0091
Contrasts							
A vs. B		ns*	0.0330	ns	ns	0.0430	0.0006
A,B vs. C,D,E		ns	0.0018	0.0022	0.0105	ns	ns
A,B vs. C		ns	ns	ns	ns	ns	ns
C vs. D,E		ns	0.0219	0.0083	ns	ns	ns

*ns = not significant, $P>0.05$.

4.4.2 Nitrogen Supplying Capacity as Assessed by the Difference in Recoverable Plant Available Nitrogen

Summing the inorganic soil N ($NO_3^- + NH_4^+$) content to a 60 cm depth with the measure of crop N uptake at corresponding sampling dates provides an estimate of the amount of recoverable plant available N (RPAN) (Tables 4.3 and 4.4). In 2002, RPAN was significantly greater in the C, D, and E systems which received synthetic urea fertilizer compared to the organic A and B systems based strictly on legume and combinations of legume and composted manure fertility respectively at the early boot, anthesis, and maturity crop stages (Table 4.3). The RPAN was also significantly greater in the C system compared to the A and B systems from early boot through maturity (Table 4.3). The early boot sampling time represents the first sampling following

application of the synthetic urea fertilizer and suggests the greater RPAN in the C, D and E systems compared to the A and B systems was the result of the synthetic urea fertilizer.

Table 4.3. Recoverable plant available N to a depth of 60 cm in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

		Sampling Date					
Mgmt Syst		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Org (A)		90	130	145	119	151	115
OrgC (B)		92	147	165	131	166	126
NNP (C)		112	149	252	215	182	125
PFP (D)		86	116	279	226	167	101
IM (E)		112	134	300	250	193	135
LSD		-	-	53	28	27	-
SE		8.36	18.00	19.97	9.38	9.02	8.95
ANOVA	df	Pr>F					
Mgmt Syst	4	0.1053	0.6863	<0.0001	<0.0001	0.0406	0.1244
Contrasts							
A vs. B		ns*	ns	ns	ns	ns	ns
A,B vs. C,D,E		ns	ns	<0.0001	<0.0001	0.0153	ns
A,B vs. C		ns	ns	0.0006	<0.0001	0.0479	ns
C vs. D,E		ns	ns	ns	ns	ns	ns

*ns = not significant, $P>0.05$.

In 2003, RPAN was significantly greater in the B system compared to the A system, in the C, D, and E systems compared to the A and B systems, in the C system compared to the A and B systems, and in the D and E systems compared to the C system at the late tillering crop stage (Table 4.4). This suggests RPAN was increased in response to compost application, application of synthetic urea fertilizer, and application of pesticides. From early boot to anthesis, RPAN was significantly greater in the C, D, and E systems compared to the A and B systems and in the D and E systems compared to the

C system; suggesting a greater proportion of RPAN was immobilized by weed biomass later in the growing season in systems which did not receive pesticides.

Table 4.4. Recoverable plant available N to a depth of 60 cm in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

		Sampling Date					
Mgmt Syst		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Org (A)		94	81	73	75	n.d.†	52
OrgC (B)		105	120	98	89	n.d.	69
NNP (C)		114	123	97	105	n.d.	77
PFP (D)		96	154	129	133	140	60
IM (E)		127	147	114	163	158	66
LSD		-	24	27	27	-	-
SE		17.60	8.91	9.02	9.52	17.05	7.95
ANOVA	df			Pr>F			
Mgmt Syst	4	0.6836	0.0002	0.0071	<0.0001	0.2308	0.3009
Contrasts							
A vs. B		ns*	0.0048	ns	ns	-	ns
A,B vs. C,D,E		ns	<0.0001	0.0045	<0.0001	-	ns
A,B vs. C		ns	0.0369	ns	ns	-	ns
C vs. D,E		ns	0.0139	0.0435	0.0018	-	ns

*ns = not significant, $P>0.05$.
†n.d. = no data were collected.

When considered over time, the difference in RPAN ($T_2 - T_1$) between sampling dates should provide an estimate of net N mineralization/immobilization (MIT). However, this estimate is not exact since inorganic soil N is subject to many possible N cycle processes and variability within the study was assumed to be relatively high. Between the May 14 to June 26 and May 14 to September 4 time intervals in 2002, the 80 kg N ha^{-1} supplied by synthetic fertilizer was subtracted from the difference in RPAN in C, D, and E systems since the synthetic fertilizer had not yet been applied at the May 14

soil sampling and would not be accounted for in the measure of inorganic soil N content at that time. In 2003, the 80 kg N ha^{-1} contribution from synthetic fertilizer in the C, D, and E systems and the 84 kg available N ha^{-1} (NO_3-N and NO_2-N + NH_4-N + 15% of organic N) estimated to be supplied by the compost in the B system was subtracted from the difference in RN value in the May 1 to June 17 and May 1 to July 12 time intervals.

In 2002, management system had a significant effect on MIT between the May 14 seeding date and the June 26 early boot crop stage, the July 17 anthesis and September 4 maturity crop stages, and over the entire growing season between May 14 and September 4 (Table 4.5); however, it must be considered that MIT is not the only process affecting RPAN. Between seeding and early boot, the amount of inorganic N in the soil plus N accumulated in the plant was greater than the amount of inorganic N in the soil at seeding in all management systems indicating a net mineralization of N. This net mineralization was higher in the C, D, and E management systems receiving synthetic urea fertilizer compared to the A and B organic systems and in the zero-tilled D and E systems receiving synthetic urea fertilizer and pesticides compared to the conventional tilled C system which received synthetic urea fertilizer only. The overall trend of N mineralization from May 14 to June 26 in all management systems was significantly correlated with crop N uptake ($r = 0.66^{**}$, 0.60^{**}, and 0.70^{***}) at the early boot, anthesis, and maturity crop stages respectively (Table 4.6). From July 17 to September 4 and May 14 to September 4, significant immobilization of N was observed in the C, D, and E systems receiving synthetic urea fertilizer compared to the organic A and B systems which experienced a net mineralization of N. Although it's possible that the smaller RPAN observed at maturity compared to the anthesis and seeding sampling times

reflects losses from denitrification or leaching it is unlikely given the below average temperature and precipitation experienced in 2002 (Table 3.1). A negative correlation was observed between the difference in RPAN and crop N uptake at all crop stages during the July 17 to September 4 and the May 14 to September 4 time intervals indicating lower crop N uptake with increasing immobilization and/or losses.

Table 4.5. Differen ce in recoverable plant available N between selected time intervals in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

		Time Interval				
Mgmt Syst		May 2 to May 14	May 14 to Jun 26	Jun 26 to Jul 17	Jul 17 to Sep 4	May 14 to Sep 4
		----------(kg ha^{-1})----------				
Org (A)		41	15	-26	32	21
OrgC (B)		55	17	-33	35	19
NNP (C)		37	23	-37	-33	-47
PFP (D)		30	83	-53	-59	-29
IM (E)		22	86	-50	-57	-20
LSD		-	49	-	47	-
SE		16.85	19.37	20.75	15.65	19.94
ANOVA	df			Pr>F		
Mgmt Syst	4	0.6928	0.0117	0.7471	0.0007	0.0967
Contrasts						
A vs. B		ns*	ns	ns	ns	ns
A,B vs. C,D,E		ns	0.0064	ns	<0.0001	0.0110
A,B vs. C		ns	ns	ns	0.0036	0.0137
C vs. D,E		ns	0.0087	ns	ns	ns

*ns = not significant, $P>0.05$.

Although significant correlations were observed between the difference in RPAN from May 14 to June 26 and crop N uptake at the early boot, anthesis, and maturity crop stages, there were no significant correlations between early season assessment of soil NO_3^- using the pre-plant NO_3^- test and crop N uptake at any crop stage sampled (Table

4.6). However, the goal of the pre-plant NO_3^- test is not to correlate with a biological measure of soil N availability but rather to indicate how much N is available and whether more is required to meet yield objectives. The lack of a relationship between early season pre-plant NO_3^- test results and crop N uptake is still of concern because significantly greater crop N accumulation in synthetically fertilized treatments is evidence that N was indeed limiting.

A significant effect of management on MIT was observed in 2003 between the May 1 early spring sampling and the June 17 late tillering crop stage and over the growing season from May 1 to the July 12 anthesis crop stage (Table 4.7). In both May 1 to June 17 and May 1 to July 12 time intervals there was a net immobilization of N in all management systems; however,imm obilization was significantly higher in the B system receiving composted manure compared to the untreated A system. The July 12 anthesis crop stage is being used for the estimate of MIT over the growing season since this was the last sampling date where crop biomass samples were available from all management systems. The overall trend of N immobilization from May 1 to June 17 in all management systems was significantly correlated with crop N uptake ($r = 0.46^*$, 0.61^{**}, and 0.47^*) at the late tillering, early boot, and anthesis crop stages respectively (Table 4.9). Other significant correlations were observed between the difference in RPAN from the June 30 to July 12 and the May 1 to July 12 time intervals and crop N uptake at anthesis ($r = 0.55^*$ and 0.70^{***} respectively) (Table 4.9). The much greater immobilization in 2003 compared to 2002 suggests that all systems were N limited.

Table 4.6. Correlations (r) between selected soil and crop measurements from plots seeded to durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season (n = 20)[a].

	Soil NO_3 (0-60 cm)		PRS-probe NO_3		ISNT-N		Crop N uptake			Difference in RPAN		
	May 2	Jun 26	May 17	Jun 28	May 2	Jun 26	Jul 8	Jul 15	Sep 1	May 14 to Jun 26	Jul 17 to Sep 4	May 14 to Sep 4
Soil NO_3 (0-60 cm)												
May 2	----											
Jun 26	0.47*	----										
PRS-probe NO_3												
May 17	0.04^{ns}	0.01^{ns}	----									
Jun 28	0.19^{ns}	0.50*	0.01^{ns}	----								
ISNT-N												
May 2	0.30^{ns}	0.04^{ns}	-0.05^{ns}	0.19^{ns}	----							
Jun 26	-0.34^{ns}	-0.28^{ns}	0.05^{ns}	0.35^{ns}	0.28^{ns}	----						
Crop N uptake												
Jul 8	-0.01^{ns}	0.57**	0.39^{ns}	0.42^{ns}	0.08^{ns}	0.09^{ns}	----					
Jul 15	-0.11^{ns}	0.56*	0.23^{ns}	0.32^{ns}	0.13^{ns}	0.09^{ns}	0.87****	----				
Sep 1	-0.04^{ns}	0.65**	0.33^{ns}	0.51*	-0.05^{ns}	0.21^{ns}	0.90****	0.83****	----			
Difference in RPAN†												
May 14 to Jun 26	-0.04^{ns}	0.62*	0.37^{ns}	0.24^{ns}	0.03^{ns}	-0.04^{ns}	0.66**	0.60**	0.70***	----		
Jul 17 to Sep 4	-0.04^{ns}	-0.57**	0.03^{ns}	-0.17^{ns}	-0.12^{ns}	0.17^{ns}	-0.74***	-0.87****	-0.64**	-0.68**	----	
May 14 to Sep 4	-0.39^{ns}	-0.60**	0.22^{ns}	-0.29^{ns}	-0.16^{ns}	0.30^{ns}	-0.45*	-0.51*	-0.33^{ns}	0.04^{ns}	0.16^{ns}	----

[a]ns, *, **, ***, **** = notsignificant, significant at P <0.05, 0.01, 0.001, and 0.0001, respectively.

†RPAN = Recoverable Plant Available N (Sum of soil NO_3^- and NH_4^+ to 60 cm plus crop N uptake).

Table 4.7. Differen ce in recoverable plant available N between selected time intervals in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

		Time Interval				
Mgmt Syst		May 1 to Jun 17	Jun 17 to Jun 30	Jun 30 to Jul 12	Jul 12 to Aug 19	May 1 to Jul 12
		----------(kg ha^{-1})----------				
Org (A)		-13	-8	2	n.d.†	-19
OrgC (B)		-70	-21	-9	n.d.	-100
NNP (C)		-71	-26	8	n.d.	-89
PFP (D)		-22	-26	4	7	-43
IM (E)		-59	-34	50	-5	-44
LSD		-	-	-	-	53
SE		16.53	11.09	13.67	19.58	18.14
ANOVA	df			Pr>F		
Mgmt Syst	4	0.0736	0.5894	0.0709	0.5046	0.0307
Contrasts						
A vs. B		0.0310	ns	ns	-	0.0064
A,B vs. C,D,E		ns*	ns	ns	-	ns
A,B vs. C		ns	ns	ns	-	ns
C vs. D,E		ns	ns	ns	-	ns

*ns = not significant, $P>0.05$.
†n.d. = no data were collected.

4.4.3 Nitrogen Supplying Capacity as Assessed by PRS™-Probe NO_3^- Supply Rate

Although the soil NO_3^- test provides a measure of soil NO_3^- at the time of sampling, it does not account for the soil N which may become available over the growing season through mineralization. This is different from an IEM which acts as a continuous sink for nutrient ions similar to a plant root (Jowkin and Schoenau, 1995). The NO_3^- adsorbed on an IEM integrates the initial soil NO_3^- content, plus mineralization/immobilization gains and losses as they affect bio-available NO_3^- over the burial period (Jowkin and Schoenau, 1995). Therefore,th e supply rates measured by 2

week PRS™-probe burials should provide some indication of a soil's capacity to release N.

The PRS™-probe measured NO_3^- supply rates (PRS-NO_3^-) were not affected by management system in the 2002 early spring burial (02ES) but were significantly higher in systems receiving synthetic urea fertilizer compared to organic systems in the 2002 mid-season burial (02MS), the 2003 early spring burial (03ES) and the 2003 mid-season burial (03MS) (Table 4.8). The effect of management system on PRS-NO_3^- in the 02ES and 02MS was consistent with the effect of management system on soil NO_3^- content at the time of the 02ES and 02MS (Tables 3.3 and 4.8). Other researchers have shown highly significant correlations between ion exchange membrane (IEM) bound NO_3^- and soil NO_3^- concentrations determined by chemical-based extractions (Qian et al., 1992; Subler et al., 1995). However, the significantly higher PRS-NO_3^- in systems receiving synthetic urea fertilizer compared to organic systems in the 03ES and 03MS was not detected in the soil NO_3^- contents at the time of the 03ES and 03MS. Although Wander et al. (1995) reported similar patterns of NO_3^- availability for chemical extracts and IEM methods, the total quantity of NO_3^- extracted from the IEMs was greater than the quantity extracted from the soil. Wander et al. (1995) found IEMs were more sensitive to agronomic treatments and considered IEMs superior to soil extracts as a means of soil NO_3^- assessment. The PRS™-probes also detected higher NO_3^- supply rates in the 03MS in D and E systems receiving zero-tillage, synthetic urea fertilizer and pesticides compared to C systems receiving conventional tillage, synthetic urea fertilizer, and no pesticides. The management systems that did not receive pesticides in 2003 experienced severe wild oat (*Avena fatua* L.) infestations which may have provided strong

competition for available soil nutrients. Jowkin and Schoenau (1995) attributed higher bio-available N in a no-till system compared to a conventional system over the fallow season to greater soil moisture content and lack of incorporation of crop residue into the soil.

Table 4.8.PR S™-probe measured NO_3^- supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems.

	Sampling Date			
	2002		2003	
Management System	May 17	Jun 28	May 14	Jun 19
	----------(μg/10cm^2/2 weeks)----------			
Organic (A)	221	112	128	74
Organic with compost (B)	215	133	156	89
Nutrients no pesticides (C)	217	145	216	77
Pesticide Free Production (D)	249	148	201	84
Integrated Management (E)	231	149	177	122
LSD	-	-	56	17
SE	18.82	12.54	18.48	5.68

ANOVA	df	Pr>F		Pr>F	
Management System	4	0.5898	0.2394	0.0296	0.0004
Contrasts					
A vs. B		ns*	ns	ns	ns
A,B vs. C,D,E		ns	0.0451	0.0046	0.0255
A,B vs. C		ns	ns	0.0052	ns
C vs. D,E		ns	ns	ns	0.0027

*ns = not significant, $P>0.05$.

The PRS-NO_3^- values were greater in the early season than the later season burials in both years of study regardless of management system (Table 4.8). The greater early season supply rates compared to mid-season supply rates may reflect greater soil moisture contents earlier in the growing season in most management systems (Appendix I). According to Sulewski et al. (2002), supply rates generally increase as soil moisture contents increase in response to increased microbial activity and reduced tortuousity in

the path the ions must travel to reach the PRS™ membrane. In regards to diffusion, soil moisture also affects the cross sectional area through which the ions diffuse and the proportion of pore space as water. The lower PRS-NO_3^- in mid-season burials may also suggest competing ion sinks. Since the PRS™-probe assesses nutrient supply rates by continuously adsorbing charged ionic species from the soil during the burial period, any factor responsible for removing ions from the available soil nutrient pool can compete with the probes for ions and result in reduced nutrient supply rate measurements (Sulewski et al., 2002). Early season burials occurred immediately after crop planting while mid-season burials occurred at plant growth stages associated with near maximum nutrient uptake rates. Since plant roots are effective ion sinks, probes were buried within a 10 cm diameter by 25 cm long piece of PVC pipe inserted in the soil to a depth of 20 cm to isolate the probes from plant root competition. It is also possible that lower mid-season PRS-NO_3^- could reflect ion immobilization from increased microbial activity in response to warmer mid-season temperatures.

As a form of IER, PRS™-probes are reported to continually adsorb nutrient ions from the plant available pool along with nutrients that are converted to the available form over the burial period in a manner similar to plant roots (Western Ag Innovations Inc., 2001). The greater PRS-NO_3^- values observed in the 02MS, 03ES, and 03MS in C, D, and E systems receiving synthetic urea fertilizer compared to the organic A and B systems and in D and E systems compared to C in the 03MS is consistent with the greater crop N accumulation in the C, D, and E systems compared to A and B and in D and E compared to C respectively.

Previous research has shown high correlations between IEM NO_3^- adsorption and crop N uptake in greenhouse studies with canola (*Brassica napus*) (Greer et al., 1997; Qian and Schoenau, 1995; Qian and Schoenau, 2000; Qian and Schoenau, 2005; Qian et al., 1992) and field trials with spring wheat (*Triticum aestivum* L.) (Jowkin and Schoenau, 1998), timothy (*Phleum pretense* L.), and orchardgrass (*Dactylis glomerata* L.) (Ziadi et al., 1999). This was in agreement with our data where a positive correlation between mid-season PRS-NO_3^- and the final measure of crop N uptake was observed in 2002 and 2003 (r = 0.51* and r = 0.64**) (Tables 4.6 and 4.9). A positive correlation between early season PRS-NO_3^- and early crop N uptake (r = 0.46*) was also observed in 2003. Compared to correlations between PRS-NO_3^- and the final measure of crop N uptake, greater correlations were observed between mid-season 0-60 cm soil NO_3^- contents in 2002 and 2003 (r = 0.65** and 0.76***) and the final measure of crop N uptake.Howev er, a positive correlation was observed in 2002 between the early season PRS-NO_3^- and the difference in RPAN from May 14 to September 4 (r = 0.46*). In 2003, a positive correlation between mid-season PRS-NO_3^- and the difference in RPAN from June 30 to July 12 (r = 0.46*) was observed.

4.4.4 Nitrogen Supplying Capacity as Assessed by the Illinois Soil N Test

Soil NO_3^- is subject to many N cycle processes including mineralization, immobilization, nitrification, denitrification, leaching, and plant uptake and can therefore demonstrate extensive spatial and temporal variability (Khan et al., 2001). Therefore, we cannot rely on MIT alone to explain all variations in soil N measures. An ideal soil test

Table 4.9. Correlation s between selected soil and crop measurements from plots seeded to durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season (n = 20)[a].

	Soil NO_3 (0-60 cm)		PRS-probe NO_3		ISNT-N		Crop N uptake			Difference in RPAN		
	May 1	Jun 30	May 14	Jun 19	May 1	Jul 12	Jun 20	Jun 27	Jul 8	May 1 to Jun 17	Jun 30 to Jul 12	May 1 to Jul 12
Soil NO_3 (0-60 cm)												
May 1	----											
Jun 17	0.43^{ns}											
Jun 30	0.14^{ns}	----										
PRS-probe NO_3												
May 14	0.19^{ns}	0.35^{ns}	----									
Jun 19	0.33^{ns}	0.66**	0.11^{ns}	----								
ISNT-N												
May 1	0.11^{ns}	0.47*	0.29^{ns}	0.27^{ns}	----							
Jul 12	0.22^{ns}	0.01^{ns}	-0.05^{ns}	0.32^{ns}		----						
Crop N uptake												
Jun 20	0.40^{ns}	0.63**	0.46*	0.30^{ns}	0.31^{ns}	0.11^{ns}	----					
Jun 27	0.04^{ns}	0.49*	0.34^{ns}	0.28^{ns}	0.22^{ns}	0.32^{ns}	0.71***	----				
Jul 8	0.21^{ns}	0.76***	0.29^{ns}	0.64**	0.18^{ns}	0.14^{ns}	0.72***	0.49*	----			
Difference in RPAN†												
May 1 to Jun 17	-0.49*	0.53*	0.38^{ns}	0.25^{ns}	0.45*	0.04^{ns}	0.46*	0.61**	0.47*	----		
Jun 30 to Jul 12	0.44^{ns}	0.10^{ns}	0.02^{ns}	0.46*	-0.16^{ns}	-0.02^{ns}	0.20^{ns}	-0.24^{ns}	0.55*	-0.19^{ns}	----	
May 1 to Jul 12	-0.45*	0.47*	0.16^{ns}	0.41^{ns}	0.06^{ns}	-0.07^{ns}	0.35^{ns}	0.40^{ns}	0.70***	0.75***	0.33^{ns}	----

[a]ns, *, **, ***, **** = notsignificant, significant at P <0.05, 0.01, 0.001, and 0.0001, respectively.

†RPAN = Recoverable Plant Available N (Sum of soil NO_3^- and NH_4^+ to 60 cm plus crop N uptake).

for predicting soil N supplying capacity would estimate a labile organic fraction that supplies NO_3^- through mineralization (Mulvaney et al., 2001). The ISNT was designed to be a relatively simple, routine procedure for estimating amino sugar N which has been identified as a possible fraction of labile soil organic N that mineralizes readily to provide plant available N (Khan et al., 2001).

The ISNT-N did not differ with management system in 2002 but significantly greater test values were observed in organic systems receiving beef manure compost compared to the unfertilized check in 2003 mid season samplings (Table 4.10). The lack of detectable differences in conventional systems receiving synthetic urea fertilizer is consistent with the findings of Ruffo et al. (2005) where N fertilizer did not have a significant effect ($p > 0.30$) on ISNT-N in any fields where samples were collected in the same year as N fertilization. Also, in a study conducted by Schlegel (1992) to determine the effect of composted manure on soil chemical properties, soil organic matter increased linearly with increased compost rates but was not affected by N fertilizer applications. Marriott and Wander (2006) report increased soil organic carbon and total N concentrations under organic management compared with conventional systems. Since the rotation started in 2001, the compost application in 2003 represented the second application to the respective plots and would be reflected in the mid season samplings. Addition of manure or compost will generally increase soil organic matter (Eghball and Power, 1994) and therefore should increase the potential of the soil to supply N. Eghball and Power (1999) estimated 8% N availability from compost in the first residual year after application while Paul and Beauchamp (1993) reported 2.9% N recovery in the first residual year and 5.5% in the second residual year. Klapwyk et al. (2006) found strong

relationships between annual changes in ISNT-N and annual changes in residual N credits from composted dairy manure in New York assuming N availability of 12% and 5% in the first and second residual year respectively. The greater ISNT-N we measured in 2003 may reflect the accumulation of organic N following repeated applications of composted manure.

Table 4.10. Illinois soil N test estimated amino sugar N in plots of durum wheat (*Triticum durum*) on a range of management systems.

		Sampling Date					
		2002			2003		
Mgmt Syst		May 2	Jun 26	Jul 17	May 1	Jun 17	Jul 12
		----------(mg kg^{-1})----------					
Org (A)		273	285	273	303	291	296
OrgC (B)		303	305	291	415	364	385
NNP (C)		270	284	266	371	277	298
PFP (D)		287	298	280	403	306	317
IM (E)		296	306	317	390	327	354
LSD		-	-	-	-	-	57
SE		28.73	19.43	20.20	78.44	25.55	18.99
ANOVA	df			Pr>F			
Mgmt Syst	4	0.9067	0.8661	0.3212	0.3976	0.0612	0.0185
Contrasts							
A vs. B		ns*	ns	ns	ns	0.0216	0.0046
A,B vs. C,D,E		ns	ns	ns	ns	ns	ns
A,B vs. C		ns	ns	ns	ns	ns	ns
C vs. D,E		ns	ns	ns	ns	ns	ns

*ns = not significant, $P>0.05$.

The ISNT estimates amino sugar N but also recovers exchangeable NH_4^+ and therefore may not provide a reliable prediction of soil N supplying capacity on sites that have received a recent input of NH_4^+ through application of ammoniacal fertilizer or manure (^{15}N Analysis Service, 2002). Klapwyk et al. (2006) suggest that when using the ISNT, soil sampling should not be performed for at least 2 weeks following manure

application assuming conditions are favorable for nitrification. Our mid season soil samples were collected well beyond 2 weeks after compost application. In addition, no detectable differences in exchangeable NH_4^+ were observed in our compost treated soils compared to the unfertilized check in 2003 (Appendix C). According to Eghball et al. (1997), composted manure contains little NH_4-N since up to 40% of the easily mineralizable N is lost during the composting process. In a similar study by Marriott and Wander (2006), no difference in exchangeable NH_4^+ concentrations were observed in a range of organic and conventional farming systems.

Although a source of N, manure also increases soil microbial activity (Praveen-Kumar et al., 2002). The increase in soil microbial activity following manure application is consistent with the findings of Praveen-Kumar et al. (2002) where maximum amino sugar N concentrations were observed under pearl millet (*Pennisetum glaucum*) cultivation after the incorporation of goat (*Capra hircus*) manure. Since amino sugars have been identified in the cell walls of bacteria and fungi and to a lesser extent in antibiotics produced by bacteria, actinomycetes and fungi (Parsons, 1981), Praveen-Kumar et al. (2002) concluded that the increase in amino sugar N following manure application may be due to an increase in the fungal and actinomycetes population. Therefore,it seems r easonable that the higher 2003 mid season ISNT-N in our system receiving manure compost does not reflect elevated exchangeable NH_4^+ levels from compost applied in early spring but rather indicates increased organic forms of N.

In most cases, the ISNT values we measured in both years were in the range reported for non-responsive sites regardless of management system (Table 4.10). When the ISNT was originally developed, a critical value of 225-235 mg kg^{-1} or higher based

on soil samples collected to a 30 cm depth in central or northern Illinois indicated corn would be non-responsive to N fertilization (Hoeft, 2002; Khan et al., 2001; Khan et al., 2002; Mulvaney et al., 2003). If the ISNT estimates a labile fraction of soil N associated with organic matter, test values should be higher in surface samples. This was confirmed by Khan et al. (2001) and Barker et al. (2006a) who found the highest ISNT values were obtained from 0-15 cm soil samples and that a decrease occurred with greater depth. Mulvaney et al. (2003) found a 15 cm soil depth was as equally effective as a 30 cm soil depth to detect non-responsive sites as long as the critical test value was increased by 30 mg kg^{-1}.

Assuming a critical test value of 300 mg kg^{-1}or higher for soil samples collected from a 15 cm soil depth (^{15}N Analysis Service, 2002), our ISNT values suggest that the majority of our sites should be non-responsive to N fertilization. This was not an accurate prediction since crop N uptake was significantly increased in systems receiving synthetic urea fertilizer in both years of study (Table 3.8). This suggests that the thresholds developed for Illinois crops and environmental conditions may not be appropriate for use in Manitoba. No relationship was found between ISNT-N and any other measured soil and crop variables in 2002 (Table 4.6). In 2003, there was no relationship between ISNT-N and crop N uptake; however, a good correlation between early season ISNT-N and mid season soil NO_3^- content ($r = 0.47^*$) was observed (Table 4.9). Torrie et al. (2004) also found a poor correlation between ISNT-N and N response in wheat growing in Saskatchewan, Canada. In Iowa, Barker et al. (2006b) found no positive correlation between ISNT-N and corn N responses, relative yield, yield response to applied N, or economically optimum N rate across a range of soil and climatic conditions. Research by

Barker et al. (2006b) and Klapwyk and Ketterings (2006) also showed that the ISNT was unable to differentiate responsive from non-responsive corn sites in Iowa and New York respectively. However, according to Klapwyk and Ketterings (2006), the predictive ability of the ISNT was improved when organic matter was included in the model since there tends to be a high correlation between ISNT-N and organic matter (Klapwyk et al., 2006). Similarly, Barker et al. (2006b) and Marriott and Wander (2006) found strong correlations between ISNT and total soil N which they used to explain the inability of the ISNT to estimate a labile fraction of soil N.

Other research has shown that sites having a high ISNT value sometimes respond to applied N fertilizer, particularly during a dry and/or cool spring (Khan et al., 2002) since soil temperature and moisture are the major environmental factors that control N mineralization (Sierra, 1997). According to weather data collected during our study, 2002 was a relatively cool and dry year while 2003 received above normal temperature and precipitation (Table 3.1). The crop fertilizer N response in 2002, despite relatively high ISNT-N, may have resulted from limited mineralization of amino sugar N under cold/dry weather conditions. Despite relatively high ISNT-N and favorable conditions for mineralization in 2003, significant crop responses to applied N fertilizer were observed. In comparison to Illinois, Manitoba has relatively young soils with higher soil organic matter, a shorter growing season, and cooler and drier overall soil conditions. This would affect our mineralization over the season and the index of soil N release potential estimated by the ISNT. The researchers that developed the Illinois test acknowledge that different critical values would likely be needed for other crops and/or climatic conditions (^{15}N Analysis Service, 2002). Thresholds may need to be increased for use in Manitoba.

The relatively high ISNT-N in our study may also have been influenced by the previous crop, tillage system, and type and amount of manure applied. The previous crop in our study was field pea, which is a legume and provides N through biological N fixation. Following three years of successive cultivation of the legumes mung bean (*Vigna aconitifolia*) and clusterbean (*Cyamopsis tetragonoloba*), researchers in India attributed increased soil amino sugar N from conversion of biologically fixed N (Praveen-Kumar et al., 2002). However, of the 25 sites that were used in the development of the ISNT, corn followed the legumes soybean (*Glycine max* L. Merr.) in 6 and 7 of the non-responsive and responsive sites respectively and alfalfa in 1 of the non-responsive sites (Khan et al., 2001). During ISNT development, there were examples of both responsive and non-responsive sites under either mulch tillage or no-till (Khan et al., 2001) suggesting a limited effect of tillage. We noted similar results where the only management system effects detected by the ISNT were based on the presence or absence of composted beef cattle manure in 2003 mid season samplings. Eight of the 12 sites identified as non-responsive during ISNT development had received manure at rates ranging from 85 to >2500 kg N ha^{-1} from either swine (*Sus scrofa domesticus*), poultry, beef or dairy cattle while all 13 sites identified as responsive received no manure (Khan et al., 2001). Marriott and Wander (2006) observed no difference in ISNT-N between organic systems receiving manure and organic systems whose fertility is based solely on legumes. According to Barker et al. (2006a), ISNT values were more variable at sites with high soil organic carbon or manure application history. Furthermore, Barker et al. (2006a) reported that differences between soils under corn production in Iowa had larger effects on ISNT-N than crop management practices.

If the ISNT is measuring a labile fraction of organic N, then test values should vary with time. In a study to compare the ISNT-N of soil samples before and after an 8 week incubation, Khan et al. (2002) found that ISNT-N consistently declined upon incubation. According to Mulvaney et al. (2003), ISNT-N would be expected to decline over the growing season in response to crop N uptake, followed by an increase associated with production of microbial biomass in the absence of plant competition for mineral N. This is consistent with our 2003 data where time of sampling had a significant effect on ISNT-N (Appendix E). In general, ISNT-N was highest in early spring followed by a decline by mid season. In a study conducted by Mulvaney et al. (2003), to compare the ISNT-N of soil samples collected in late November 2001 and early April 2002 from five sites under continuous corn, ISNT-N was found to be 3.5% to 12.6% higher for spring sampling presumably owing to microbial decomposition of crop residues over winter. The potential risk of identifying a responsive soil as non-responsive on the basis of an elevated ISNT value has led Mulvaney et al. (2003) to recommend that sampling for the ISNT is best done in the fall after harvest. If the ISNT had been performed on late fall soil samples in our study, we may have observed lower test values that might have more accurately predicted the responsiveness to N fertilization. If we correct our early spring ISNT values to reflect late fall values assuming ISNT values in late fall are approximately 10% lower, we can accurately predict a crop fertilizer N response in all management systems in 2002. Correcting the early spring ISNT values in 2003 would predict a crop fertilizer N response only in the organic A system. The ISNT values in all other management systems in 2003 would still be above the 300 mg kg^{-1} critical value, suggesting these sites would not respond to added fertilizer N.

Given the spatial and temporal variation observed in ISNT-N, and variability in environmental conditions, there will be years when the test will fail (Hoeft, 2002). Failure rates of 10% in detecting non-responsive sites and about 20% in detecting responsive sites have been reported, much of which has been related to field variability (Mulvaney, 2004). In a recent study to examine the spatial variability of ISNT-N in central and southern Illinois, Ruffo et al. (2005) observed ISNT-N was generally normally distributed with a relatively low coefficient of variation and skewness. Further, Ruffo et al. (2005) determined that on average 10 samples across a field were adequate to estimate the mean ISNT-N with a maximum error of 24 mg kg^{-1} based on soil sampling conducted on a 24 by 70 meter grid at 14 sites. However, as the level of precision was increased, the number of samples required increased (Ruffo et al., 2005). Our soil sampling consisted of a 3-hole composite sample on each of the 4 replicates. It is possible, that our sampling strategy was not adequate to accurately characterize the concentration of amino sugar-N in our study.

4.5 Conclusions

The PRS™-probe and the ISNT have been proposed as sampling techniques to improve predictions of fertilizer N requirements by estimating the contribution of N released through mineralization. In 2002, the effect of management system on PRS-NO_3^- was the same as that observed for soil NO_3^- content in the 0-15 cm soil depth at the time of the probe burials and similar to that for crop N uptake. In 2003, PRS-NO_3^- detected significant management system differences that were not detected by soil NO_3^- content but were consistent with crop N uptake. However, the effect of beef manure compost in

2003 was not predicted by PRS-NO_3^-. In each year, the mid-season PRS-NO_3^- were significantly correlated with the final measure of crop N uptake and the mid to later season soil NO_3^- content. However, soil NO_3^- content was more highly correlated with crop N uptake compared to PRS-NO_3^- suggesting soil NO_3^- content is a better index of NO_3^- availability under Manitoba conditions.

There was no correlation between ISNT-N and crop N uptake in either year of study regardless of management system. The ISNT was not a reliable indicator of potential N release based on the critical value of 300 mg kg^{-1} suggested for soil samples collected from a 0-15 cm depth from corn sites in Illinois. However, the ISNT did appear to be estimating an organic N fraction since test values in 2003 declined between early spring and mid season samplings in response to mineralization followed by an increase later in the growing season. Also, management system had no significant influence on exchangeable NH_4^+. Since the ISNT estimates amino sugar N but also recovers exchangeable NH_4^+, the lack of management system effect on exchangeable NH_4^+ suggests differences in ISNT test values were due to differences in organic N concentrations. The limited range in test values for sites under different management practices might be a result of high inherent organic matter levels in Manitoba. Further correlation and calibration of the ISNT under different cropping systems, soil classes, and crops is required. Temporal and spatial variability will need to be considered as soil sampling guidelines for the ISNT are developed. Different critical values will likely need to be established for different crops and/or climatic conditions. Based on these findings, use of the ISNT in Manitoba, Canada to predict soil N release under wheat production is not recommended, yet.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

When pioneer farmers began tilling the virgin soil they reaped bountiful harvests for many years. Each product sold from the farm saw vital plant nutrients being exported with it. Over time, crop yields declined and farmers began to realize the natural supply of plant food in many soils was being depleted. Management practices such as legume cropping, green manuring and incorporation of animal manures became common soil fertility improvement techniques. Nutrient deficiencies were further overcome by the use of synthetic fertilizers which provided a relatively available form of plant nutrients in the year of application.

Despite the availability of synthetic fertilizers, many farmers believed synthetic fertilizers injured the soil and that once used their use must be continued. However, it was not because the soil had developed a "bad habit" that farmers continued to use synthetic fertilizer, but because of profitable returns. In times when synthetic fertilizers were relatively inexpensive, they were often applied in excess of crop requirements as a means of insuring sufficient plant available nutrients were present for maximum yields. Synthetic fertilizers also held the promise of providing an abundance of economically produced food for a growing population. The finite nature of the natural resources used to produce synthetic fertilizers, increasing costs, and the growing awareness of the possible negative influence of excess nutrients on the environment has made farmers and environmental regulators more cognizant of the need for efficient nutrient management.

Today it is widely recognized that sustainable crop production requires nutrient supply be in balance with crop demand. If nutrients are limiting, crop production will decline. If nutrients are in excess or not in synchrony with crop demand, nutrients may be

lost from the system, resulting in environmental degradation. In order to match crop demand with nutrient supply, it is important to be able to predict the pattern of nutrient release from and its relationship to nutrient uptake by the crop. Nutrient additions can then be used to compensate for deficiencies between soil supply and crop demand. Furthermore, factors such as soil characteristics, environmental conditions, and crop management practices will affect the amount and timing of nutrient release by soils.

The primary objective of this study was to evaluate the pattern of soil N release and crop N uptake by durum wheat grown on field pea stubble in 2002 and 2003 under a range of management systems including (i) organic (A), (ii) organic with composted beef cattle manure (B), (iii) synthetic fertilizer, no pesticides (C), (iv) Pesticide Free Production™ (PFP) (D) and (v) integrated management (E). Our null hypothesis was one of no difference in soil and crop N dynamics between management systems. The general patterns of soil N release and crop N uptake were similar regardless of management, with the greatest soil NO_3^- contents observed between seeding and the first crop stage sampled and maximum crop N accumulation occurring by anthesis. Since the majority of N is accumulated early in the growing season, it is important to have sufficient N available in the soil to meet crop N demand.

However, notable differences were observed in nutrient dynamics between the management systems. Application of synthetic urea fertilizer at seeding in C, D, and E systems resulted in higher soil NO_3^- contents compared to organic A and B systems receiving strictly legume or legume and composted beef cattle manure fertility treatments respectively. Other researchers have generally assumed synthetic urea fertilizer to be immediately plant available in the year of application, although the amount actually

accumulated in crop biomass will depend on the many environmental and management factors that influence N cycle processes. When applied, the urea was subsurface banded with the seeding operation which would have minimized potential losses due to volatilization and minimized residence in soil prior to crop demand. Also, moisture and temperature conditions should not have inhibited urease activity. So it is likely that the majority of N supplied by the synthetic urea fertilizer was available for crop uptake.

The increased soil NO_3^- contents resulting from synthetic urea fertilizer were reflected in increased dry matter production, grain yield, tissue N concentration, and crop N accumulation in C, D, and E systems compared to organic A and B systems. These results indicate the strictly legume and legume and composted manure based fertility treatments were not able to supply sufficient N for optimum crop production. Although measured soil and crop N variables in the B system receiving composted manure were lower than those of the systems receiving synthetic urea fertilizer, it appeared that the compost applications were increasing the capacity of the soil under B management to supply N. The compost application in 2002, representing the first to those respective plots, resulted in little difference in soil NO_3^- contents between the A and B systems. Application of compost in 2003 represented the second application to those respective plots (fully phased rotation; first application made in 2001) and resulted in higher soil NO_3^- contents in the B system compared to A. This is consistent with other reports where the residual N benefit of composted manure is measurable at least two years beyond the year of application. There was also evidence that N from composted manure was becoming available later in the growing season. Although, no difference in soil NO_3^- contents between A and B systems was observed in 2002, crop dry matter yield at

maturity and grain protein concentration were higher under B management suggesting a later release of N. In 2003, soil NO_3^- contents in the B system were significantly higher at maturity and late fall than early spring levels. Although applications of composted manure can greatly improve the ability of a soil to supply N, the pattern of N release is not always in synchrony with the N demand of annual cropping systems, resulting in reduced N efficiency and greater potential for environmental pollution.

Furthermore, crop dry matter yield, grain yield, and crop N accumulation were higher in the D and E systems which received synthetic urea fertilizer and pesticides compared to the C management system which received synthetic urea fertilizer only. Although crop tissue N concentrations were similar between the C, D, and E systems, the lower dry matter yield of the C system indicates that N was limited by competition from significantly higher weed biomass. It is apparent that optimum crop production must include a successful means of weed control, especially when supplying a readily available form of N. However, the similar crop dry matter and final grain yields produced under the PFP managed D system were comparable to those of the E system which suggests that reduced pesticide systems may be sustainable.

Although a previous legume and combinations of a previous legume and composted manure did not provide sufficient N for profitable production, the practices themselves should not be discounted. Legumes do provide a residual benefit to succeeding crops and applications of manure or compost are well known to increase the soil's capacity to supply nutrients. The relative infancy of the management systems used in this study at the time soil and plant measurements were collected must also be considered. Though it may be good business sense to apply synthetic fertilizers to a crop

to increase profits in the year of application, it may be better still to improve fertility in such a way that it will benefit several crops in succeeding seasons. At the time of this writing, the management systems used in this study are now in their eighth year. Although pesticides had to be introduced into the strictly organic A and B systems to control increasing weed pressure, the compost amended B system is now producing yields similar to the C, D, and E systems receiving synthetic urea fertilizer. Regardless of the soil fertility improvement plan, the challenge remains as to how to estimate soil N release through the growing season so that nutrient additions do not result in over or under fertilization.

The second objective of the this study was to assess the effectiveness of Plant Root Simulator™ (PRS) probes and the Illinois soil N test (ISNT) as means of predicting N release through the growing season in systems with N being produced by decomposition of legume residues, composted manure, and mineral N fertilizers. Since PRS-probes were designed to continuously absorb nutrient ions over the burial period similar to a plant root and the INST was designed to measure a fraction of soil organic N that potentially supplies plant available N through mineralization, it was thought that the estimate of soil N release potential provided by these indices could improve predictions of fertilizer N requirements.

The PRS-probe measured soil NO_3^- supply rates (PRS-NO_3^-) were higher in early season burials compared to mid season burials which was consistent with the higher soil moisture contents observed earlier in the growing season. Since the PRS-probe is a diffusion sensitive system, it requires soil moisture to move nutrient ions to the membrane for adsorption. It is also possible that the presence of an actively growing crop

at the time of the mid season probe burials provided increased competition for nutrient ions, resulting in a lower PRS-NO_3^-. The effect of management system on PRS-NO_3^- in 2002 was the same as that observed for soil NO_3^- contents at the time of the probe burials. However, in 2003, the higher PRS-NO_3^- in C, D, and E systems compared to A and B systems was not reflected in soil NO_3^- contents at the time of the probe burials. By adsorbing nutrient ions over the burial period, it is possible that the higher PRS-NO_3^- compared to soil NO_3^- contents at the time of the probe burials reflects a greater contribution from N that became available through mineralization. Also, the effect of beef manure compost in 2003 was not predicted by PRS-NO_3^-.More importantl y, the usefulness of any soil N availability index generally depends on how well it correlates with some biological measure of N availability such as crop uptake. Although the effect of management on PRS-NO_3^- was the same as that observed for crop N uptake, good relationships between crop N uptake and PRS-NO_3^- were only observed with the mid season PRS-probe assessment of soil N availability. The lack of strong, consistent relationships between early season PRS-probe assessment of N release potential and crop N uptake make it difficult to use PRS-NO_3^- for adjusting recommended fertilizer rates unless using the mid season PRS-probe assessment in combination with a split application fertility regime.Howeve r, the mid season PRS-probe index based on a 2 week probe burial at late tillering or early boot is already past the most active period of crop N uptake. Furthermore, mid season soil NO_3^- content was more highly correlated with crop N uptake than PRS-NO_3^- suggesting soil NO_3^- content may still provide a better index of NO_3^- availability under Manitoba conditions.

The only effect of management system on ISNT-N was observed in the 2003 mid season samplings where ISNT-N was significantly higher in the compost treated B system compared to the unfertilized control. This seems reasonable since the ISNT was designed to measure an organic fraction of soil N and manure and composted manure are generally reported to increase soil organic matter and soil microbial activity. However, based on a critical value of 300 mg kg^{-1} for soil samples collected from a 0-15 cm depth from corn sites in Illinois, the ISNT values we measured in each year of the study were within the range reported for non-responsive soils regardless of management. This was not an accurate prediction since crop N uptake was significantly increased in systems receiving synthetic urea fertilizer. Furthermore, there was no correlation between ISNT-N and crop N uptake in either year of study regardless of management system which makes it difficult to use this index for adjusting recommended fertilizer rates.Th e overall inability of the ISNT to correctly classify soils in Manitoba on the basis of fertilizer N responsiveness may be related to differences in soil and climatic conditions in Manitoba compared to Illinois which would influence mineralization and the index of soil N release potential estimated by the ISNT. Further testing of the ISNT under different cropping systems, soil classes, and crops is required. Different critical values may need to be established for different crops and/or climatic conditions. Based on these findings, use of the ISNT in Manitoba, Canada to predict soil N release under wheat production is not yet recommended.

Although shortcomings were identified with the use of both the PRS probes and the ISNT to assess N release under Manitoba conditions, deficiencies were also uncovered in the use of the pre-plant NO_3^- test. The objective of the pre-plant NO_3^- test is

to provide an indication of how much N is available so that a producer can determine whether more is required to obtain a specific yield goal. Though the pre-plant NO_3^- test was not designed to correlate with a biological measure of soil N availability, the lack of correlation we observed between early season pre-plant NO_3^- test results and crop N uptake is still of concern because significantly greater crop N accumulation in synthetically fertilized treatments is evidence that N was indeed limiting. Many researchers have suggested that estimates of soil N release over the growing season could be improved by combining the pre-plant NO_3^- test with an index of soil organic N availability. The best means of combining a static measurement of N availability with one based on N release over the growing season will require further investigation. Although the pre-plant NO_3^- test is still considered an effective monitoring tool, results may be best interpreted based on producer experience.

The dynamic nature of N in soils continues to provide challenges for farmers and environmentalists as to how to balance N availability with crop demand. Soils differ widely in their inherent ability to mineralize N but actual N release is further influenced by many environmental and management factors. Methods of estimating soil N release over the growing season such as the PRS-probes and the ISNT have shown promise; however, the lack of consistent relationships between early season assessment of N release and biological measures of N availability make it difficult to use these indices for adjusting fertilizer rates. Also of concern, is the fact that the standard method of assessing N availability using the pre-plant NO_3^- test may not always prove reliable. Based on these findings, it appears that the need for better N management is greater than ever.

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7.0 APPENDICES

7.1. APPENDIX A – MANAGEMENT AND SAMPLING INFORMATION.

Table A.1. Management systems and corresponding crop rotations used during the study at AAFC's BRC field operations site.

	Crop Rotation Phase			
Management System	1	2	3	4
Organic (A)	field pea	wheat u/s sweet clover	sweet clover	oats
Organic with compost (B)	field pea	wheat u/s sweet clover	sweet clover	oats
Nutrients no pesticides (C)	field pea	wheat u/s sweet clover	sweet clover	oats
Pesticide Free Production (D)	field pea	wheat	flax	oats
Integrated Management (E)	field pea	wheat	flax	oats

Table A.2. Sampling dates and cor responding growing season stages of plots of durum wheat (*Triticum durum*) and oats (*Avena sativa*) during the 2002 growing season on a range of management systems at AAFC's BRC field operations site.

Sampling Date	Crop	Sample Type	Depth (cm)	Growing Season Stage
May 2	wheat, oat	soil	0-15, 15-60	early spring
May 14	wheat, oat	soil	0-15, 15-60	seeding
May 17	wheat, oat	PRS	0-15	seeding
-[†]	wheat, oat	weed		post spraying
Jun 26	wheat, oat	soil	0-15, 15-60	early boot
Jun 28	wheat, oat	PRS	0-15	early boot
Jul 8	wheat, oat	crop		early boot
Jul 15	wheat, oat	crop		anthesis
Jul 17	wheat, oat	soil	0-15, 15-60	anthesis
Sep 1	wheat, oat	crop		maturity
Sep 4	wheat, oat	soil	0-15, 15-60	maturity
Oct 28	wheat, oat	soil	0-15, 15-60	late fall

[†]Date not recorded.

Table A.3. Sampling dates and corresponding growing season stages of plots of durum wheat (*Triticum durum*) and oats (*Avena sativa*) during the 2003 growing season on a range of management systems at AAFC's BRC field operations site.

Sampling Date	Crop	Sample Type	Depth (cm)	Growing Season Stage
May 1	wheat, oat	soil	0-15, 15-60	early spring
May 14	oat	soil	0-15, 15-60	seeding
May 14	wheat	PRS	0-15	seeding
May 14	wheat	soil	0-15	PRS burial
May 23	oat	PRS	0-15	seeding
May 23	oat	soil	0-15	PRS burial
May 28	wheat	soil	0-15	PRS removal
Jun 7	oats	soil	0-15	PRS removal
-[†]	wheat, oat	weed		post spraying
Jun 17	wheat	soil	0-15, 15-60	late tillering
Jun 17	wheat	soil	0-15	PRS burial
Jun 19	wheat	PRS	0-15	late tillering
Jun 20	wheat	crop		late tillering
Jun 27	oat	soil	0-15, 15-60	late tillering
Jun 27	oat	soil	0-15	PRS burial
Jun 27	oat	crop		late tillering
Jun 27	wheat	crop		early boot
Jun 28	oat	PRS	0-15	late tillering
Jun 30	wheat	soil	0-15, 15-60	early boot
Jul 3	wheat	soil	0-15	PRS removal
Jul 4	oat	crop		early boot
Jul 6	oat	soil	0-15, 15-60	early boot
Jul 8	wheat	crop		anthesis
Jul 11	oat	crop		anthesis
Jul 12	wheat	soil	0-15, 15-60	anthesis
Jul 13	oat	soil	0-15, 15-60	anthesis
Jul 13	oat	soil	0-15	PRS removal
Aug 13	oat	crop		maturity
Aug 14	wheat	crop		maturity
Aug 19	wheat, oat	soil	0-15, 15-60	maturity
Oct 29	wheat, oat	soil	0-15, 15-60	late fall

[†]Date not recorded.

Table A.4. Sampling dates and cor responding growing season stages of plots of durum wheat (*Triticum durum*) and oats (*Avena sativa*) during the 2004 growing season on a range of management systems at AAFC's BRC field operations site.

Sampling Date	Crop	Sample Type	Depth (cm)	Growing Season Stage
Apr 26	wheat, oat	soil	0-15, 15-60	early spring
Jun 6	wheat, oat	soil	0-15, 15-60	seeding
Jul 16	wheat, oat	crop		late tillering
Jul 16	wheat, oat	weed		late tillering
Aug 5	wheat, oat	crop		anthesis
Aug 5	wheat, oat	weed		anthesis
Aug 5	wheat, oat	soil	0-15, 15-60	anthesis
Sep 29	oat	crop		maturity
Sep 29	oat	soil	0-15, 15-60	maturity
Oct 7	wheat	crop		maturity
Oct 7	wheat	soil	0-15, 15-60	maturity
Oct 25	wheat, oat	soil	0-15, 15-60	late fall

7.2.AP PENDIX B – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON SOIL NITRATE CONTENT DURING THE GROWING SEASON.

Table B.1. So il NO_3^- content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		22	57	21	7	17	24
Organic with compost (B)		26	76	22	14	20	32
Nutrients no pesticides (C)		31	55	37	22	22	30
Pesticide Free Production (D)		23	34	44	13	13	19
Integrated Management (E)		25	47	49	16	22	36
LSD		14	39	32	9	7	11
ANOVA	df			Pr>F			
Management System	4	0.6316	0.2681	0.2665	0.0338	0.0414	0.0302
Contrasts							
A vs. B		0.5183	0.2980	0.9116	0.0846	0.3129	0.1277
A,B vs. C,D,E		0.4794	0.0940	0.0407	0.0270	0.7517	0.9398
A,B vs. C		0.1907	0.4864	0.2501	0.0063	0.2107	0.6065
C vs. D,E		0.2324	0.3580	0.4676	0.0541	0.1308	0.4930

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		22	21	31	18	14	19
Organic with compost (B)		22	26	33	17	14	19
Nutrients no pesticides (C)		26	37	78	53	23	35
Pesticide Free Production (D)		18	25	56	31	14	18
Integrated Management (E)		20	25	80	52	25	29
LSD		7	15	33	25	10	9
ANOVA	df			Pr>F			
Management System	4	0.2428	0.2471	0.0150	0.0141	0.0698	0.0048
Contrasts							
A vs. B		0.9276	0.4750	0.9002	0.9700	0.9755	0.9726
A,B vs. C,D,E		0.6240	0.2385	0.0017	0.0023	0.0543	0.0076
A,B vs. C		0.2614	0.0414	0.0045	0.0034	0.0456	0.0008
C vs. D,E		0.0380	0.0641	0.4803	0.2863	0.3636	0.0085

Table B.2. So il NO_3^- content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Organic (A)		17	9	6	6	8	13
Organic with compost (B)		25	23	8	9	13	36
Nutrients no pesticides (C)		17	16	9	8	12	17
Pesticide Free Production (D)		15	14	10	7	9	17
Integrated Management (E)		20	24	12	12	13	22
LSD		11	8	2	3	5	10
ANOVA	df	Pr>F					
Management System	4	0.4238	0.0128	0.0018	0.0124	0.0925	0.0033
Contrasts							
A vs. B		0.1471	0.0038	0.1067	0.1253	0.0308	0.0003
A,B vs. C,D,E		0.3639	0.4800	0.0007	0.0975	0.5772	0.0909
A,B vs. C		0.4242	0.9068	0.1000	0.5097	0.4712	0.1156
C vs. D,E		0.8558	0.3396	0.0474	0.3416	0.6441	0.6342

15-60 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Organic (A)		26	16	14	12	9	6
Organic with compost (B)		37	21	13	14	12	8
Nutrients no pesticides (C)		49	27	16	19	14	19
Pesticide Free Production (D)		35	40	30	17	10	13
Integrated Management (E)		60	43	29	24	10	13
LSD		41	11	11	8	5	11
ANOVA	df	Pr>F					
Management System	4	0.4361	0.0006	0.0085	0.0688	0.2091	0.1761
Contrasts							
A vs. B		0.5685	0.3321	0.8593	0.7067	0.1751	0.6737
A,B vs. C,D,E		0.1857	0.0001	0.0041	0.0167	0.5869	0.0336
A,B vs. C		0.2934	0.0748	0.6107	0.0968	0.0921	0.0215
C vs. D,E		0.9385	0.0067	0.0081	0.7280	0.0553	0.2251

Table B.3. So il NO_3^- content to 15 cm depth in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

		Sampling Date								
Management System		May 1	May 14	May 28	Jun 17	Jun 30	Jul 3	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------								
Organic (A)		17	32	31	9	6	7	6	8	13
Organic with compost (B)		25	52	67	23	8	8	9	13	36
Nutrients no pesticides (C)		17	46	55	16	9	7	8	12	17
Pesticide Free Production (D)		15	30	36	14	10	8	7	9	17
Integrated Management (E)		20	22	45	24	12	12	12	13	22
LSD		11	19	18	8	2	2	3	5	10
ANOVA	df	Pr>F								
Management System	4	0.4238	0.0305	0.0053	0.0128	0.0018	0.0003	0.0124	0.0925	0.0033
Contrasts										
A vs. B		0.1471	0.0415	0.0008	0.0038	0.1067	0.2937	0.1253	0.0308	0.0003
A,B vs. C,D,E		0.3639	0.1255	0.5199	0.4800	0.0007	0.0111	0.0975	0.5772	0.0909
A,B vs. C		0.4242	0.6148	0.3884	0.9068	0.1000	0.8193	0.5097	0.4712	0.1156
C vs. D,E		0.8558	0.0225	0.0592	0.3396	0.0474	0.0030	0.3416	0.6441	0.6342

Table B.4. So il NO_3^- content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 crop year.

0-15 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		19	12	5	2	2
Organic with compost (B)		22	17	6	4	4
Nutrients no pesticides (C)		19	11	8	3	4
Pesticide Free Production (D)		21	7	6	4	6
Integrated Management (E)		19	8	9	4	5
LSD		6	3	2	3	2
ANOVA	df			Pr>F		
Management System	4	0.6402	<0.0001	0.0039	0.5370	0.0947
Contrasts						
A vs. B		0.2266	0.0020	0.1582	0.2211	0.1143
A,B vs. C,D,E		0.6716	<0.0001	0.0053	0.2734	0.0680
A,B vs. C		0.5312	0.0033	0.0080	0.6283	0.6449
C vs. D,E		0.6395	0.0071	0.3632	0.6003	0.1560

15-60 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		23	46	8	2	3
Organic with compost (B)		27	38	5	1	2
Nutrients no pesticides (C)		25	42	9	3	3
Pesticide Free Production (D)		32	19	9	5	8
Integrated Management (E)		36	17	15	3	3
LSD		10	39	8	5	5
ANOVA	df			Pr>F		
Management System	4	0.1097	0.3905	0.1845	0.6281	0.1658
Contrasts						
A vs. B		0.4657	0.6782	0.3567	0.7358	0.4893
A,B vs. C,D,E		0.0662	0.1939	0.0882	0.1947	0.2196
A,B vs. C		0.8874	0.9887	0.5023	0.5106	0.9708
C vs. D,E		0.0641	0.1439	0.3199	0.6135	0.1888

Table B.5. So il NO_3^- content in plots of oats (*Avena sativa*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		19	36	18	8	13	19
Organic with compost (B)		19	87	21	14	25	24
Nutrients no pesticides (C)		21	28	33	14	24	24
Pesticide Free Production (D)		29	38	62	18	25	15
Integrated Management (E)		25	60	43	14	25	34
LSD		10	30	26	5	8	6
ANOVA	df	Pr>F					
Management System	4	0.2244	0.0046	0.0205	0.0191	0.0261	0.0003
Contrasts							
A vs. B		0.9184	0.0023	0.7827	0.0400	0.0082	0.1327
A,B vs. C,D,E		0.0868	0.0421	0.0051	0.0140	0.0325	0.1653
A,B vs. C		0.7057	0.0134	0.2084	0.2378	0.1663	0.3899
C vs. D,E		0.1582	0.1066	0.0933	0.2256	0.6575	0.7591

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		8	15	30	14	15	18
Organic with compost (B)		9	15	31	16	20	17
Nutrients no pesticides (C)		23	20	50	27	20	24
Pesticide Free Production (D)		24	28	62	29	26	26
Integrated Management (E)		23	23	66	46	39	47
LSD		17	10	31	29	17	15
ANOVA	df	Pr>F					
Management System	4	0.1283	0.0742	0.0866	0.1793	0.0650	0.0048
Contrasts							
A vs. B		0.9088	0.9748	0.9511	0.8708	0.5014	0.9672
A,B vs. C,D,E		0.0117	0.0145	0.0102	0.0423	0.0516	0.0057
A,B vs. C		0.0537	0.2331	0.1515	0.3099	0.7286	0.2840
C vs. D,E		0.9123	0.2398	0.2914	0.3800	0.0865	0.0724

Table B.6. So il NO_3^- content in plots of oats (*Avena sativa*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth								
		Sampling Date						
Management System		May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		----------(kg ha^{-1})----------						
Organic (A)		15	20	7	7	7	8	19
Organic with compost (B)		15	50	21	10	8	11	34
Nutrients no pesticides (C)		20	19	24	13	15	21	34
Pesticide Free Production (D)		16	14	14	8	9	11	19
Integrated Management (E)		16	16	16	12	10	15	18
LSD		9	6	7	2	3	6	15
ANOVA	df				Pr>F			
Management System	4	0.7807	<0.0001	0.0026	0.0013	0.0071	0.0033	0.0695
Contrasts								
A vs. B		0.8919	<0.0001	0.0016	0.0259	0.5827	0.2576	0.0540
A,B vs. C,D,E		0.4380	<0.0001	0.0793	0.0029	0.0069	0.0047	0.5775
A,B vs. C		0.2167	<0.0001	0.0041	0.0007	0.0004	0.0003	0.2370
C vs. D,E		0.3131	0.1504	0.0081	0.0238	0.0037	0.0048	0.0253

15-60 cm soil depth								
		Sampling Date						
Management System		May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		----------(kg ha^{-1})----------						
Organic (A)		14	13	15	14	15	9	5
Organic with compost (B)		21	28	17	18	14	7	5
Nutrients no pesticides (C)		9	14	19	19	28	13	16
Pesticide Free Production (D)		45	39	38	30	29	23	15
Integrated Management (E)		41	36	38	38	30	16	18
LSD		16	19	11	13	9	8	10
ANOVA	df				Pr>F			
Management System	4	0.0011	0.0275	0.0009	0.0088	0.0023	0.0100	0.0421
Contrasts								
A vs. B		0.3618	0.1135	0.7750	0.4717	0.7526	0.5634	0.9242
A,B vs. C,D,E		0.0121	0.1393	0.0005	0.0056	<0.0001	0.0035	0.0032
A,B vs. C		0.2128	0.3533	0.5124	0.5782	0.0022	0.2031	0.0176
C vs. D,E		0.0002	0.0074	0.0012	0.0147	0.7464	0.0650	0.9854

Table B.7. So il NO_3^- content to 15 cm depth in plots of oats (*Avena sativa*) on a range of management systems during the 2003 crop year.

Management System		Sampling Date								
		May 1	May 14	May 23	Jun 7	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		----------(kg ha^{-1})----------								
Organic (A)		15	20	24	29	7	7	7	8	19
Organic with compost (B)		15	50	63	71	21	10	8	11	34
Nutrients no pesticides (C)		20	19	59	49	24	13	15	21	34
Pesticide Free Production (D)		16	14	24	37	14	8	9	11	19
Integrated Management (E)		16	16	22	38	16	12	10	15	18
LSD		9	6	11	14	7	2	3	6	15
ANOVA	df	Pr>F								
Management System	4	0.7807	<0.0001	<0.0001	0.0002	0.0026	0.0013	0.0071	0.0033	0.0695
Contrasts										
A vs. B		0.8919	<0.0001	<0.0001	<0.0001	0.0016	0.0259	0.5827	0.2576	0.0540
A,B vs. C,D,E		0.4380	<0.0001	0.0189	0.0522	0.0793	0.0029	0.0069	0.0047	0.5775
A,B vs. C		0.2167	<0.0001	0.0042	0.8342	0.0041	0.0007	0.0004	0.0003	0.2370
C vs. D,E		0.3131	0.1504	<0.0001	0.0588	0.0081	0.0238	0.0037	0.0048	0.0253

Table B.8. So il NO_3^- content in plots of oats (*Avena sativa*) on a range of management systems during the 2004 crop year.

0-15 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		10	13	5	3	3
Organic with compost (B)		11	18	6	5	7
Nutrients no pesticides (C)		14	12	12	6	9
Pesticide Free Production (D)		17	7	5	6	8
Integrated Management (E)		21	9	6	5	4
LSD		9	2	3	3	3
ANOVA	df			Pr>F		
Management System	4	0.1161	<0.0001	0.0036	0.3065	0.0108
Contrasts						
A vs. B		0.8231	<0.0001	0.2890	0.2718	0.0286
A,B vs. C,D,E		0.0270	<0.0001	0.0583	0.1142	0.1629
A,B vs. C		0.3670	0.0002	0.0005	0.1202	0.0174
C vs. D,E		0.1840	<0.0001	0.0005	0.5567	0.0293

15-60 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		11	10	5	2	3
Organic with compost (B)		8	16	4	4	3
Nutrients no pesticides (C)		14	17	11	9	10
Pesticide Free Production (D)		34	23	6	5	7
Integrated Management (E)		40	19	8	4	4
LSD		24	12	9	10	10
ANOVA	df			Pr>F		
Management system	4	0.0419	0.2389	0.5901	0.6347	0.5051
Contrasts						
A vs. B		0.8164	0.3099	0.8353	0.7174	1.0000
A,B vs. C,D,E		0.0161	0.0730	0.1953	0.2983	0.1771
A,B vs. C		0.6241	0.3690	0.1367	0.1504	0.0975
C vs. D,E		0.0375	0.4553	0.4073	0.2975	0.3025

7.3. APPENDIX C – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON SOIL AMMONIUM CONTENT DURING THE GROWING SEASON.

Table C.1. Soil NH_4^+ content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		12	14	12	11	15	10
Organic with compost (B)		11	10	10	13	16	9
Nutrients no pesticides (C)		14	14	11	15	15	12
Pesticide Free Production (D)		10	13	11	11	14	13
Integrated Management (E)		12	15	10	12	16	11
LSD		4	5	2	2	2	5
ANOVA	df	Pr>F					
Management System	4	0.2836	0.1984	0.1605	0.0023	0.2604	0.4116
Contrasts							
A vs. B		0.5944	0.1086	0.0561	0.0209	0.2941	0.5245
A,B vs. C,D,E		0.4523	0.1267	0.5247	0.4080	0.6664	0.0929
A,B vs. C		0.0824	0.1865	1.0000	0.0024	0.5384	0.1880
C vs. D,E		0.0719	0.7941	0.4779	0.0004	0.6565	0.9508

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		35	39	26	29	45	53
Organic with compost (B)		33	35	31	32	43	56
Nutrients no pesticides (C)		41	43	26	36	31	41
Pesticide Free Production (D)		35	45	27	33	34	46
Integrated Management (E)		54	47	30	32	38	52
LSD		23	26	7	10	14	15
ANOVA	df	Pr>F					
Management System	4	0.3271	0.8777	0.4740	0.6624	0.2269	0.2843
Contrasts							
A vs. B		0.8933	0.7599	0.1789	0.5118	0.7710	0.6695
A,B vs. C,D,E		0.2005	0.3441	0.7189	0.3559	0.0414	0.1019
A,B vs. C		0.4430	0.5980	0.4259	0.1969	0.0379	0.0495
C vs. D,E		0.7570	0.7776	0.4259	0.3484	0.3715	0.2280

Table C.2. Soil NH_4^+ content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Organic (A)		12	13	9	14	14	8
Organic with compost (B)		13	11	9	15	13	5
Nutrients no pesticides (C)		12	11	10	13	13	9
Pesticide Free Production (D)		11	13	9	10	12	7
Integrated Management (E)		14	10	9	13	13	7
LSD		4	5	2	7	3	3
ANOVA	df	Pr>F					
Management System	4	0.4836	0.5373	0.7779	0.5622	0.7058	0.1475
Contrasts							
A vs. B		0.4666	0.2665	0.7625	0.6520	0.4744	0.0793
A,B vs. C,D,E		0.8992	0.8789	0.3972	0.2408	0.3592	0.1427
A,B vs. C		1.0000	0.4364	0.2354	0.6642	0.6774	0.0556
C vs. D,E		0.8873	0.1900	0.3898	0.4900	0.6774	0.1868

15-60 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Organic (A)		41	31	31	29	39	26
Organic with compost (B)		31	38	22	29	32	21
Nutrients no pesticides (C)		35	37	31	40	39	32
Pesticide Free Production (D)		35	36	24	29	44	23
Integrated Management (E)		32	28	23	34	34	25
LSD		17	10	10	13	14	19
ANOVA	df	Pr>F					
Management System	4	0.7642	0.1468	0.1929	0.3028	0.4731	0.7616
Contrasts							
A vs. B		0.2338	0.1114	0.0792	1.0000	0.3269	0.5603
A,B vs. C,D,E		0.7517	0.7288	0.8716	0.1571	0.4776	0.5909
A,B vs. C		0.9565	0.5627	0.2898	0.0481	0.5661	0.2763
C vs. D,E		0.7855	0.2214	0.0897	0.1325	0.9488	0.2969

Table C.3. Soi l NH_4^+ content to 15 cm depth in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

		Sampling Date								
Management System		May 1	May 14	May 28	Jun 17	Jun 30	Jul 3	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------								
Organic (A)		12	24	14	13	9	10	14	14	8
Organic with compost (B)		13	28	14	11	9	9	15	13	5
Nutrients no pesticides (C)		12	46	17	11	10	12	13	13	9
Pesticide Free Production (D)		11	23	12	13	9	13	10	12	7
Integrated Management (E)		14	22	19	10	9	11	13	13	7
LSD		4	12	9	5	2	5	7	3	3
ANOVA	df	Pr>F								
Management System	4	0.4836	0.0035	0.5649	0.5373	0.7779	0.4116	0.5622	0.7058	0.1475
Contrasts										
A vs. B		0.4666	0.5230	0.9525	0.2665	0.7625	0.5245	0.6520	0.4744	0.0793
A,B vs. C,D,E		0.8992	0.1846	0.5125	0.8789	0.3972	0.0929	0.2408	0.3592	0.1427
A,B vs. C		1.0000	0.0008	0.4752	0.4364	0.2354	0.1880	0.6642	0.6774	0.0556
C vs. D,E		0.8873	0.0003	0.7317	0.1900	0.3898	0.9508	0.4900	0.6774	0.1868

Table C.4. Soil NH_4^+ content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 crop year.

0-15 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		26	15	10	11	15
Organic with compost (B)		18	14	10	13	12
Nutrients no pesticides (C)		24	14	10	12	14
Pesticide Free Production (D)		20	13	9	13	14
Integrated Management (E)		25	17	9	10	16
LSD		16	4	4	6	3
ANOVA	df			Pr>F		
Management System	4	0.7990	0.4471	0.9348	0.8066	0.0594
Contrasts						
A vs. B		0.3053	0.7960	0.8871	0.4183	0.0438
A,B vs. C,D,E		0.7869	0.7389	0.5363	0.9813	0.1089
A,B vs. C		0.7114	0.8813	0.9346	0.8749	0.6779
C vs. D,E		0.7998	0.5530	0.5686	0.8338	0.2232

15-60 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		78	48	36	43	32
Organic with compost (B)		47	53	36	36	29
Nutrients no pesticides (C)		49	41	35	39	21
Pesticide Free Production (D)		50	50	30	42	32
Integrated Management (E)		70	44	25	37	23
LSD		39	11	11	15	8
ANOVA	df			Pr>F		
Management System	4	0.3562	0.2053	0.1576	0.8327	0.0421
Contrasts						
A vs. B		0.1156	0.3863	1.0000	0.3589	0.4403
A,B vs. C,D,E		0.5958	0.1144	0.0692	0.9787	0.0709
A,B vs. C		0.3941	0.0440	0.7274	0.9524	0.0150
C vs. D,E		0.4873	0.1671	0.1158	0.9524	0.0708

Table C.5. Soil NH_4^+ content in plots of oats (*Avena sativa*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		13	20	14	13	15	20
Organic with compost (B)		11	9	13	13	15	18
Nutrients no pesticides (C)		15	18	11	13	18	18
Pesticide Free Production (D)		12	15	10	13	16	19
Integrated Management (E)		13	14	15	12	16	17
LSD		5	7	7	4	4	3
ANOVA	df	Pr>F					
Management System	4	0.4639	0.0506	0.5218	0.9264	0.5614	0.5033
Contrasts							
A vs. B		0.4153	0.0057	0.7759	0.6530	0.7815	0.2616
A,B vs. C,D,E		0.3205	0.5457	0.4668	0.5627	0.2449	0.4757
A,B vs. C		0.1112	0.2338	0.4171	0.7946	0.1045	0.4001
C vs. D,E		0.1847	0.2604	0.6818	0.7946	0.2344	0.6374

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		33	40	34	36	47	46
Organic with compost (B)		41	35	30	38	42	44
Nutrients no pesticides (C)		40	51	31	36	37	48
Pesticide Free Production (D)		32	55	30	36	46	53
Integrated Management (E)		32	37	26	35	29	43
LSD		11	18	8	21	13	11
ANOVA	df	Pr>F					
Management System	4	0.2582	0.1076	0.4400	0.9995	0.0732	0.3606
Contrasts							
A vs. B		0.1593	0.5343	0.3383	0.8784	0.4702	0.7826
A,B vs. C,D,E		0.5018	0.0738	0.2591	0.8745	0.0975	0.3977
A,B vs. C		0.5044	0.0746	0.7357	0.9296	0.1768	0.5262
C vs. D,E		0.0927	0.4742	0.4358	0.9648	0.8883	1.0000

Table C.6. Soil NH_4^+ content in plots of oats (*Avena sativa*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth								
		Sampling Date						
Management System		May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		----------(kg ha^{-1})----------						
Organic (A)		14	18	10	9	11	12	7
Organic with compost (B)		15	21	12	5	12	12	6
Nutrients no pesticides (C)		18	16	10	9	14	15	8
Pesticide Free Production (D)		11	14	9	8	12	12	7
Integrated Management (E)		12	15	11	11	12	17	7
LSD		6	3	2	3	2	5	1
ANOVA	df				Pr>F			
Management System	4	0.1531	0.0014	0.1622	0.0286	0.0959	0.1336	0.0301
Contrasts								
A vs. B		0.5919	0.0392	0.0554	0.0386	0.3600	1.0000	0.0463
A,B vs. C,D,E		0.5799	0.0002	0.2701	0.0631	0.0587	0.0841	0.1060
A,B vs. C		0.1934	0.0162	0.5092	0.2795	0.0106	0.1719	0.0088
C vs. D,E		0.0192	0.1404	0.7901	0.5831	0.0483	0.9344	0.0204

15-60 cm soil depth								
		Sampling Date						
Management System		May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		----------(kg ha^{-1})----------						
Organic (A)		37	45	38	24	31	46	23
Organic with compost (B)		33	44	22	23	30	35	19
Nutrients no pesticides (C)		42	41	25	29	27	41	27
Pesticide Free Production (D)		35	51	27	23	29	38	23
Integrated Management (E)		35	49	32	33	27	31	20
LSD		17	19	12	9	11	15	9
ANOVA	df				Pr>F			
Management System	4	0.8087	0.7522	0.1146	0.0964	0.9121	0.2830	0.3130
Contrasts								
A vs. B		0.6390	0.8637	0.0165	0.7165	0.8816	0.1459	0.2875
A,B vs. C,D,E		0.6453	0.6587	0.6258	0.0753	0.3827	0.4065	0.4594
A,B vs. C		0.3118	0.6218	0.3500	0.1554	0.4436	0.9001	0.1102
C vs. D,E		0.3118	0.2296	0.3873	0.9163	0.8635	0.2709	0.1102

Table C.7. Soi l NH_4^+ content to 15 cm depth in plots of oats (*Avena sativa*) on a range of management systems during the 2003 crop year.

Management System		Sampling Date								
		May 1	May 14	May 23	Jun 7	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		(kg ha^{-1})								
Organic (A)		14	18	21	16	10	9	11	12	7
Organic with compost (B)		15	21	27	18	12	5	12	12	6
Nutrients no pesticides (C)		18	16	126	15	10	9	14	15	8
Pesticide Free Production (D)		11	14	22	13	9	8	12	12	7
Integrated Management (E)		12	15	22	14	11	11	12	17	7
LSD		6	3	38	4	2	3	2	5	1
ANOVA	df	Pr>F								
Management System	4	0.1531	0.0014	0.0002	0.1704	0.1622	0.0286	0.0959	0.1336	0.0301
Contrasts										
A vs. B		0.5919	0.0392	0.7688	0.3127	0.0554	0.0386	0.3600	1.0000	0.0463
A,B vs. C,D,E		0.5799	0.0002	0.0139	0.0369	0.2701	0.0631	0.0587	0.0841	0.1060
A,B vs. C		0.1934	0.0162	<0.0001	0.2204	0.5092	0.2795	0.0106	0.1719	0.0088
C vs. D,E		0.0192	0.1404	<0.0001	0.5067	0.7901	0.5831	0.0483	0.9344	0.0204

Table C.8. Soil NH_4^+ content in plots of oats (*Avena sativa*) on a range of management systems during the 2004 crop year.

0-15 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		25	18	9	13	16
Organic with compost (B)		17	21	8	8	12
Nutrients no pesticides (C)		26	17	10	10	17
Pesticide Free Production (D)		21	14	9	11	14
Integrated Management (E)		28	18	10	11	16
LSD		11	5	2	6	6
ANOVA	df			Pr>F		
Management System	4	0.2791	0.1460	0.3427	0.3909	0.4144
Contrasts						
A vs. B		0.1329	0.2288	0.3085	0.0580	0.1932
A,B vs. C,D,E		0.3025	0.1063	0.1233	0.9819	0.4488
A,B vs. C		0.3187	0.4097	0.0879	0.8002	0.2458
C vs. D,E		0.7281	0.5148	0.3757	0.6861	0.3584

15-60 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		87	41	32	32	32
Organic with compost (B)		50	44	39	35	29
Nutrients no pesticides (C)		73	43	27	24	32
Pesticide Free Production (D)		56	47	32	30	25
Integrated Management (E)		71	47	29	35	26
LSD		41	18	14	12	15
ANOVA	df			Pr>F		
Management System	4	0.3429	0.9570	0.4397	0.3820	0.7739
Contrasts						
A vs. B		0.0716	0.7913	0.2701	0.7043	0.6098
A,B vs. C,D,E		0.8625	0.6016	0.1600	0.3183	0.5112
A,B vs. C		0.8022	0.9593	0.1664	0.0824	0.8591
C vs. D,E		0.5714	0.6117	0.6046	0.1222	0.3224

7.4. APPENDIX D – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON INORGANIC SOIL NITROGEN CONTENT DURING THE GROWING SEASON.

Table D.1. Inorganic soil N (NO_3^- + NH_4^+) content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		33	70	33	18	31	43
Organic with compost (B)		37	86	33	27	35	51
Nutrients no pesticides (C)		46	70	48	36	36	48
Pesticide Free Production (D)		34	47	55	24	26	36
Integrated Management (E)		37	62	59	28	38	54
LSD		14	40	31	9	8	12
ANOVA	df			Pr>F			
Management System	4	0.3737	0.3556	0.2843	0.0082	0.0389	0.0415
Contrasts							
A vs. B		0.6279	0.4090	0.9811	0.0347	0.2395	0.1611
A,B vs. C,D,E		0.3692	0.1408	0.0426	0.0201	0.8981	0.8106
A,B vs. C		0.0814	0.6027	0.2466	0.0017	0.3810	0.7949
C vs. D,E		0.0976	0.3554	0.4924	0.0103	0.2466	0.5140

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		57	60	57	47	59	71
Organic with compost (B)		55	61	63	50	57	74
Nutrients no pesticides (C)		67	80	104	89	54	77
Pesticide Free Production (D)		52	70	83	64	48	64
Integrated Management (E)		74	72	110	84	63	81
LSD		28	30	31	25	19	19
ANOVA	df			Pr>F			
Management System	4	0.4489	0.6414	0.0099	0.0074	0.4990	0.4213
Contrasts							
A vs. B		0.9285	0.9337	0.6608	0.8316	0.8428	0.7211
A,B vs. C,D,E		0.3351	0.1761	0.0012	0.0011	0.6099	0.8500
A,B vs. C		0.3578	0.1447	0.0042	0.0012	0.6210	0.6176
C vs. D,E		0.7611	0.4823	0.5648	0.1623	0.8636	0.5907

Table D.2. Inorganic soil N (NO_3^- + NH_4^+) content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Organic (A)		28	23	15	20	22	21
Organic with compost (B)		38	34	17	24	26	40
Nutrients no pesticides (C)		29	26	18	21	25	26
Pesticide Free Production (D)		26	27	19	17	21	24
Integrated Management (E)		34	37	21	25	26	28
LSD		11	11	3	7	5	11
ANOVA	df	Pr>F					
Management System	4	0.1911	0.0762	0.0140	0.1644	0.1478	0.0208
Contrasts							
A vs. B		0.0819	0.0421	0.2860	0.2645	0.0974	0.0020
A,B vs. C,D,E		0.3800	0.5381	0.0025	0.7005	1.0000	0.2334
A,B vs. C		0.4155	0.6667	0.0696	0.9000	0.6620	0.3477
C vs. D,E		0.8098	0.1955	0.2774	0.8083	0.5141	0.9485

15-60 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Organic (A)		66	46	45	41	48	32
Organic with compost (B)		68	59	35	42	45	29
Nutrients no pesticides (C)		84	64	47	59	53	51
Pesticide Free Production (D)		70	76	54	46	54	36
Integrated Management (E)		92	71	52	57	44	38
LSD		48	16	15	16	13	21
ANOVA	df	Pr>F					
Management System	4	0.7177	0.0096	0.1357	0.0780	0.4031	0.2690
Contrasts							
A vs. B		0.9585	0.1024	0.1923	0.8438	0.5537	0.7681
A,B vs. C,D,E		0.3122	0.0021	0.0350	0.0202	0.3487	0.1029
A,B vs. C		0.3893	0.1028	0.2994	0.0178	0.2344	0.0313
C vs. D,E		0.8746	0.1424	0.3430	0.2938	0.4460	0.1258

Table D.3. Inorganic soil N ($NO_3^- + NH_4^+$) content to 15 cm depth in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 crop year.

		Sampling Date								
Management System		May 1	May 14	May 28	Jun 17	Jun 30	Jul 3	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------								
Organic (A)		28	56	45	23	15	17	20	22	21
Organic with compost (B)		38	79	81	34	17	16	24	26	40
Nutrients no pesticides (C)		29	92	72	26	18	19	21	25	26
Pesticide Free Production (D)		26	53	48	27	19	21	17	21	24
Integrated Management (E)		34	45	64	37	21	23	25	26	28
LSD		11	28	19	11	3	6	7	5	11
ANOVA	df	Pr>F								
Management System	4	0.1911	0.0144	0.0055	0.0762	0.0140	0.1886	0.1644	0.1478	0.0208
Contrasts										
A vs. B		0.0819	0.0906	0.0012	0.0421	0.2860	0.8555	0.2645	0.0974	0.0020
A,B vs. C,D,E		0.3800	0.5990	0.7616	0.5381	0.0025	0.0387	0.7005	1.0000	0.2334
A,B vs. C		0.4155	0.0468	0.2537	0.6667	0.0696	0.3325	0.9000	0.6620	0.3477
C vs. D,E		0.8098	0.0020	0.0531	0.1955	0.2774	0.3190	0.8083	0.5141	0.9485

Table D.4. Inorganic soil N ($NO_3^- + NH_4^+$) content in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 crop year.

0-15 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		40	27	15	12	17
Organic with compost (B)		40	31	16	17	16
Nutrients no pesticides (C)		43	25	18	15	17
Pesticide Free Production (D)		41	20	15	17	20
Integrated Management (E)		43	25	18	14	21
LSD		21	5	5	8	3
ANOVA	df			Pr>F		
Management System	4	0.9941	0.0111	0.3335	0.8033	0.0460
Contrasts						
A vs. B		0.9596	0.1043	0.5357	0.3195	0.4390
A,B vs. C,D,E		0.6978	0.0034	0.2748	0.6780	0.0160
A,B vs. C		0.7446	0.0742	0.1602	0.7786	0.5070
C vs. D,E		0.9529	0.2821	0.3577	0.9655	0.0568

15-60 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		101	94	44	45	35
Organic with compost (B)		74	91	41	37	30
Nutrients no pesticides (C)		74	83	43	42	24
Pesticide Free Production (D)		82	69	39	47	39
Integrated Management (E)		105	62	39	40	27
LSD		42	38	11	16	9
ANOVA	df			Pr>F		
Management System	4	0.3615	0.3398	0.7991	0.7462	0.0180
Contrasts						
A vs. B		0.1854	0.8627	0.4756	0.3348	0.2980
A,B vs. C,D,E		0.9859	0.0842	0.5893	0.7162	0.3263
A,B vs. C		0.4431	0.5483	0.8623	0.8920	0.0304
C vs. D,E		0.2649	0.2696	0.3931	0.8387	0.0271

Table D.5. Inorganic soil N (NO_3^- + NH_4^+) content in plots of oats (*Avena sativa*) on a range of management systems during the 2002 crop year.

0-15 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		32	56	32	20	28	39
Organic with compost (B)		30	96	34	27	39	42
Nutrients no pesticides (C)		36	46	44	26	41	41
Pesticide Free Production (D)		41	53	71	31	41	34
Integrated Management (E)		37	74	58	26	41	52
LSD		12	33	30	8	10	8
ANOVA	df			Pr>F			
Management System	4	0.3222	0.0322	0.0665	0.1321	0.0612	0.0027
Contrasts							
A vs. B		0.7909	0.0188	0.8653	0.0881	0.0302	0.4216
A,B vs. C,D,E		0.0625	0.0786	0.0160	0.1056	0.0300	0.3844
A,B vs. C		0.3081	0.0376	0.3601	0.4547	0.0815	0.7197
C vs. D,E		0.4977	0.2098	0.1143	0.4406	0.9206	0.6569

15-60 cm soil depth							
		Sampling Date					
Management System		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Organic (A)		41	55	64	50	61	63
Organic with compost (B)		50	50	61	53	62	62
Nutrients no pesticides (C)		63	71	81	63	57	72
Pesticide Free Production (D)		56	83	92	65	71	79
Integrated Management (E)		56	59	92	81	68	90
LSD		23	20	32	42	22	20
ANOVA	df			Pr>F			
Management System	4	0.3748	0.0222	0.1699	0.5435	0.6274	0.0486
Contrasts							
A vs. B		0.4395	0.5867	0.8514	0.8504	0.9311	0.8468
A,B vs. C,D,E		0.0901	0.0080	0.0218	0.1636	0.5842	0.0102
A,B vs. C		0.0823	0.0341	0.1897	0.5025	0.5741	0.2337
C vs. D,E		0.4487	0.9704	0.4061	0.5527	0.1606	0.1544

Table D.6. Inorganic soil N (NO_3^- + NH_4^+) content in plots of oats (*Avena sativa*) on a range of management systems during the 2003 crop year.

0-15 cm soil depth								
		Sampling Date						
Management System		May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		(kg ha^{-1})						
Organic (A)		36	43	29	17	19	29	30
Organic with compost (B)		26	36	30	16	20	29	25
Nutrients no pesticides (C)		28	35	20	17	20	24	26
Pesticide Free Production (D)		33	45	31	21	25	28	39
Integrated Management (E)		28	44	23	18	25	23	38
LSD		11	27	11	7	7	13	16
ANOVA	df	Pr>F						
Management System	4	0.2962	0.8664	0.1751	0.5658	0.1409	0.8314	0.2249
Contrasts								
A vs. B		0.0633	0.5680	0.9622	0.7438	0.9230	0.9938	0.4785
A,B vs. C,D,E		0.7716	0.8144	0.1770	0.3245	0.0643	0.4022	0.1783
A,B vs. C		0.5117	0.6709	0.0440	0.8354	0.8964	0.4053	0.7937
C vs. D,E		0.5082	0.3735	0.1070	0.4226	0.0600	0.7530	0.0687

15-60 cm soil depth								
		Sampling Date						
Management System		May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		(kg ha^{-1})						
Organic (A)		59	61	53	49	47	59	39
Organic with compost (B)		73	77	67	61	52	66	35
Nutrients no pesticides (C)		59	81	54	45	50	63	31
Pesticide Free Production (D)		71	84	48	48	55	36	37
Integrated Management (E)		48	56	47	47	56	36	27
LSD		30	40	25	23	16	18	17
ANOVA	df	Pr>F						
Management System	4	0.4091	0.5027	0.4639	0.6436	0.7627	0.0047	0.5208
Contrasts								
A vs. B		0.3323	0.4078	0.2589	0.3052	0.5173	0.3685	0.5814
A,B vs. C,D,E		0.4561	0.7211	0.1886	0.2626	0.4228	0.0059	0.2867
A,B vs. C		0.5797	0.4927	0.5740	0.3208	0.9544	0.9587	0.3789
C vs. D,E		0.9952	0.5268	0.5022	0.8145	0.4172	0.0025	0.9033

Table D.7. Inorganic soil N ($NO_3^- + NH_4^+$) content to 15 cm depth in plots of oats (*Avena sativa*) on a range of management systems during the 2003 crop year.

Management System		Sampling Date								
		May 1	May 14	May 23	Jun 7	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
		(kg ha^{-1})								
Organic (A)		36	43	45	45	29	17	19	29	30
Organic with compost (B)		26	36	90	88	30	16	20	29	25
Nutrients no pesticides (C)		28	35	184	63	20	17	20	24	26
Pesticide Free Production (D)		33	45	46	50	31	21	25	28	39
Integrated Management (E)		28	44	43	52	23	18	25	23	38
LSD		11	27	41	12	11	7	7	13	16
ANOVA	df	Pr>F								
Management System	4	0.2962	0.8664	<0.0001	<0.0001	0.1751	0.5658	0.1409	0.8314	0.2249
Contrasts										
A vs. B		0.0633	0.5680	0.0358	<0.0001	0.9622	0.7438	0.9230	0.9938	0.4785
A,B vs. C,D,E		0.7716	0.8144	0.0753	0.0080	0.1770	0.3245	0.0643	0.4022	0.1783
A,B vs. C		0.5117	0.6709	<0.0001	0.5267	0.0440	0.8354	0.8964	0.4053	0.7937
C vs. D,E		0.5082	0.3735	<0.0001	0.0274	0.1070	0.4226	0.0600	0.7530	0.0687

Table D.8. Inorganic soil N (NO_3^- + NH_4^+) content in plots of oats (*Avena sativa*) on a range of management systems during the 2004 crop year.

0-15 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		35	30	14	16	19
Organic with compost (B)		28	39	14	12	20
Nutrients no pesticides (C)		40	29	22	16	26
Pesticide Free Production (D)		37	20	14	17	21
Integrated Management (E)		49	27	16	15	20
LSD		16	6	3	7	8
ANOVA	df			Pr>F		
Management System	4	0.1527	0.0003	0.0008	0.6599	0.3543
Contrasts						
A vs. B		0.3342	0.0060	0.6292	0.2308	0.9891
A,B vs. C,D,E		0.0524	0.0002	0.0086	0.4573	0.2417
A,B vs. C		0.2350	0.0455	<0.0001	0.6174	0.0568
C vs. D,E		0.6052	0.0254	0.0002	0.9311	0.0996

15-60 cm soil depth						
		Sampling Date				
Management System		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Organic (A)		98	51	37	34	35
Organic with compost (B)		58	59	43	38	31
Nutrients no pesticides (C)		87	60	38	33	42
Pesticide Free Production (D)		89	70	38	35	32
Integrated Management (E)		112	65	37	38	30
LSD		55	18	15	14	12
ANOVA	df			Pr>F		
Management system	4	0.3610	0.2990	0.8820	0.8807	0.3111
Contrasts						
A vs. B		0.1445	0.3595	0.3736	0.5552	0.5234
A,B vs. C,D,E		0.2947	0.0965	0.5984	0.8595	0.7552
A,B vs. C		0.6857	0.5263	0.7056	0.5469	0.1178
C vs. D,E		0.5576	0.3289	0.9811	0.4807	0.0507

7.5. APPENDIX E – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON PRS™-PROBE ESTIMATED SOIL NITRATE SUPPLY RATE DURING THE GROWING SEASON.

Table E.1. PRS™-probe estimated NO_3^- supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date	
Management System		May 17	Jun 28
		---(μg/10cm^2/2 weeks)---	
Organic (A)		221	112
Organic with compost (B)		215	133
Nutrients no pesticides (C)		217	145
Pesticide Free Production (D)		249	148
Integrated Management (E)		231	149
LSD		50	38
ANOVA	df	Pr>F	
Management System	4	0.5898	0.2394
Contrasts			
A vs. B		0.8131	0.2647
A,B vs. C,D,E		0.3528	0.0451
A,B vs. C		0.9723	0.1640
C vs. D,E		0.2789	0.8067

Table E.2. PRS™-probe estimated NO_3^- supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date	
Management System		May 14	Jun 19
		---(µg/10cm^2/2 weeks)---	
Organic (A)		128	74
Organic with compost (B)		156	89
Nutrients no pesticides (C)		216	77
Pesticide Free Production (D)		201	84
Integrated Management (E)		177	122
LSD		56	17
ANOVA	df	Pr>F	
Management System	4	0.0296	0.0004
Contrasts			
A vs. B		0.2977	0.0906
A,B vs. C,D,E		0.0046	0.0255
A,B vs. C		0.0052	0.5534
C vs. D,E		0.2553	0.0027

Table E.3. PRS™-probe estimated NO_3^- supply rates in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date	
Management System		May 17	Jun 28
		---(μg/10cm^2/2 weeks)---	
Organic (A)		135	145
Organic with compost (B)		159	130
Nutrients no pesticides (C)		185	140
Pesticide Free Production (D)		222	148
Integrated Management (E)		257	174
LSD		28	42
ANOVA	df	Pr>F	
Management System	4	<0.0001	0.3081
Contrasts			
A vs. B		0.0777	0.4809
A,B vs. C,D,E		<0.0001	0.2198
A,B vs. C		0.0050	0.8784
C vs. D,E		0.0003	0.2494

Table E.4. PRS™-probe estimated NO_3^- supply rates in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date	
Management System		May 23	Jun 28
		---(μg/10cm²/2 weeks)---	
Organic (A)		186	1
Organic with compost (B)		143	10
Nutrients no pesticides (C)		220	9
Pesticide Free Production (D)		201	3
Integrated Management (E)		206	9
LSD		36	6
ANOVA	df	Pr>F	
Management System	4	0.0055	0.0242
Contrasts			
A vs. B		0.0240	0.0091
A,B vs. C,D,E		0.0013	0.3480
A,B vs. C		0.0022	0.1203
C vs. D,E		0.2730	0.1855

7.6. APPENDIX F – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON PRS™-PROBE ESTIMATED SOIL AMMONIUM SUPPLY RATE DURING THE GROWING SEASON.

Table F.1. PRS™-probe estimated NH_4^+ supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date	
Management System		May 17	Jun 28
		---(μg/10cm^2/2 weeks)---	
Organic (A)		1	2
Organic with compost (B)		2	2
Nutrients no pesticides (C)		1	1
Pesticide Free Production (D)		1	2
Integrated Management (E)		2	1
LSD		1	1
ANOVA	df	Pr>F	
Management System	4	0.0255	0.9449
Contrasts			
A vs. B		0.0730	0.6068
A,B vs. C,D,E		0.4038	0.5321
A,B vs. C		0.2788	0.6402
C vs. D,E		0.4771	1.0000

Table F.2. PRS™-probe estimated NH_4^+ supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date	
Management System		May 14	Jun 19
		---(μg/10cm^2/2 weeks)---	
Organic (A)		1	2
Organic with compost (B)		2	4
Nutrients no pesticides (C)		3	3
Pesticide Free Production (D)		1	3
Integrated Management (E)		2	4
LSD		3	1
ANOVA	df	Pr>F	
Management System	4	0.5472	0.0556
Contrasts			
A vs. B		0.5050	0.0078
A,B vs. C,D,E		0.7989	0.3555
A,B vs. C		0.2215	0.4577
C vs. D,E		0.1253	0.9401

Table F.3. PRS™-probe estimated NH_4^+ supply rates in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date	
Management System		May 17	Jun 28
		---(μg/10cm²/2 weeks)---	
Organic (A)		1	2
Organic with compost (B)		3	2
Nutrients no pesticides (C)		2	1
Pesticide Free Production (D)		3	1
Integrated Management (E)		2	2
LSD		1	1
ANOVA	df	Pr>F	
Management System	4	0.1618	0.4703
Contrasts			
A vs. B		0.0801	0.6641
A,B vs. C,D,E		0.6602	0.8513
A,B vs. C		0.3798	0.4555
C vs. D,E		0.0858	0.3645

Table F.4. PRS™-probe estimated NH_4^+ supply rates in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date	
Management System		May 23	Jun 28
		---(μg/10cm²/2 weeks)---	
Organic (A)		3	2
Organic with compost (B)		3	4
Nutrients no pesticides (C)		4	3
Pesticide Free Production (D)		2	2
Integrated Management (E)		2	2
LSD		1	1
ANOVA	df	Pr>F	
Management System	4	0.0049	0.0411
Contrasts			
A vs. B		0.2483	0.0036
A,B vs. C,D,E		0.0968	0.6873
A,B vs. C		0.1054	0.8124
C vs. D,E		0.0006	0.4255

7.7. APPENDIX G – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON PRS™-PROBE MEASURED INORGANIC SOIL NITROGEN SUPPLY RATE DURING THE GROWING SEASON.

Table G.1. PRS™-probe estimated inorganic soil N (NO_3^- + NH_4^+) supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date	
Management System		May 17	Jun 28
		---(μg/10cm^2/2 weeks)---	
Organic (A)		222	114
Organic with compost (B)		217	134
Nutrients no pesticides (C)		219	147
Pesticide Free Production (D)		250	150
Integrated Management (E)		232	151
LSD		50	38
ANOVA	df	Pr>F	
Management System	4	0.5992	0.2305
Contrasts			
A vs. B		0.8299	0.2575
A,B vs. C,D,E		0.3596	0.0432
A,B vs. C		0.9604	0.1590
C vs. D,E		0.2761	0.8093

Table G.2. PRS™-probe estimated inorganic soil N ($NO_3^- + NH_4^+$) supply rates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date	
Management System		May 14	Jun 19
		---(μg/10cm^2/2 weeks)---	
Organic (A)		129	76
Organic with compost (B)		158	92
Nutrients no pesticides (C)		219	80
Pesticide Free Production (D)		202	86
Integrated Management (E)		178	125
LSD		57	17
ANOVA	df	Pr>F	
Management System	4	0.0314	0.0003
Contrasts			
A vs. B		0.2964	0.0691
A,B vs. C,D,E		0.0052	0.0223
A,B vs. C		0.0053	0.5545
C vs. D,E		0.2390	0.0023

Table G.3. PRS™-probe estimated inorganic soil N (NO_3^- + NH_4^+) supply rates in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date	
Management System		May 17	Jun 28
		---(μg/10cm^2/2 weeks)---	
Organic (A)		136	146
Organic with compost (B)		161	132
Nutrients no pesticides (C)		186	141
Pesticide Free Production (D)		225	149
Integrated Management (E)		259	175
LSD		28	42
ANOVA	df	Pr>F	
Management System	4	<0.0001	0.3048
Contrasts			
A vs. B		0.0754	0.4828
A,B vs. C,D,E		<0.0001	0.2264
A,B vs. C		0.0053	0.8917
C vs. D,E		0.0003	0.2477

Table G.4. PRS™-probe estimated inorganic soil N (NO_3^- + NH_4^+) supply rates in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date	
Management System		May 23	Jun 28
		---(μg/10cm²/2 weeks)---	
Organic (A)		188	2
Organic with compost (B)		145	12
Nutrients no pesticides (C)		223	11
Pesticide Free Production (D)		202	5
Integrated Management (E)		208	10
LSD		37	6
ANOVA	df	Pr>F	
Management System	4	0.0060	0.0053
Contrasts			
A vs. B		0.0261	0.0014
A,B vs. C,D,E		0.0015	0.3700
A,B vs. C		0.0022	0.0963
C vs. D,E		0.2484	0.1243

7.8. APPENDIX H – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON SOIL AMINO SUGAR NITROGEN CONCENTRATION DURING THE GROWING SEASON.

Table H.1. Illinois soil N test estimated amino sugar N concentrations in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date		
Management System		May 2	Jun 26	Jul 17
		----------($mg\ kg^{-1}$)----------		
Organic (A)		273	285	273
Organic with compost (B)		303	305	291
Nutrients no pesticides (C)		270	284	266
Pesticide Free Production (D)		287	298	280
Integrated Management (E)		296	306	317
LSD		87	59	53
ANOVA	df		Pr>F	
Management System	4	0.9067	0.8661	0.3212
Contrasts				
A vs. B		0.4753	0.4887	0.4881
A,B vs. C,D,E		0.8870	0.9607	0.7183
A,B vs. C		0.6091	0.6348	0.4716
C vs. D,E		0.5434	0.4464	0.1524

Table H.2. Illinois soil N test estimated amino sugar N concentrations in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date		
Management System		May 1	Jun 17	Jul 12
		----------(mg kg^{-1})----------		
Organic (A)		303	291	296
Organic with compost (B)		415	364	385
Nutrients no pesticides (C)		371	277	298
Pesticide Free Production (D)		403	306	317
Integrated Management (E)		390	327	354
LSD		129	61	57
ANOVA	df		Pr>F	
Management System	4	0.3976	0.0612	0.0185
Contrasts				
A vs. B		0.0836	0.0216	0.0046
A,B vs. C,D,E		0.4611	0.2080	0.321
A,B vs. C		0.8156	0.0571	0.0851
C vs. D,E		0.6304	0.1209	0.1265

Table H.3. Illinois soil N test estimated amino sugar N concentrations in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date		
Management System		May 2	Jun 26	Jul 17
		----------(mg kg^{-1})----------		
Organic (A)		261	303	249
Organic with compost (B)		326	333	296
Nutrients no pesticides (C)		275	306	229
Pesticide Free Production (D)		296	308	280
Integrated Management (E)		294	305	296
LSD		64	45	66
ANOVA	df		Pr>F	
Management System	4	0.2932	0.6094	0.1689
Contrasts				
A vs. B		0.0472	0.1751	0.1445
A,B vs. C,D,E		0.7976	0.4124	0.8494
A,B vs. C		0.4828	0.5392	0.1278
C vs. D,E		0.4430	1.0000	0.0451

Table H.4. Illinois soil N test estimated amino sugar N concentrations in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date		
Management System		May 1	Jun 27	Jul 12
		----------(mg kg^{-1})----------		
Organic (A)		403	289	305
Organic with compost (B)		401	333	364
Nutrients no pesticides (C)		394	284	320
Pesticide Free Production (D)		376	303	327
Integrated Management (E)		338	326	331
LSD		102	36	37
ANOVA	df		Pr>F	
Management System	4	0.6280	0.0415	0.0439
Contrasts				
A vs. B		0.9707	0.0211	0.0039
A,B vs. C,D,E		0.3038	0.5405	0.459
A,B vs. C		0.8488	0.0819	0.3505
C vs. D,E		0.3813	0.0533	0.5585

7.9. APPENDIX I – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON SOIL MOISTURE CONTENT DURING THE GROWING SEASON.

Table I.1. Gravimetric soil moisture content in pl ots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

0-15 cm soil depth						
		Sampling Date				
Management System		May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(%)----------				
Organic (A)		13	13	11	16	19
Organic with compost (B)		14	13	13	18	20
Nutrients no pesticides (C)		14	13	12	16	19
Pesticide Free Production (D)		15	13	12	16	19
Integrated Management (E)		16	13	13	16	21
LSD		2	2	2	2	2
ANOVA	df			Pr>F		
Management System	4	0.0583	0.9561	0.3525	0.3960	0.1116
Contrasts						
A vs. B		0.1425	0.8030	0.0823	0.1042	0.1592
A,B vs. C,D,E		0.0210	0.7012	0.6992	0.4103	0.4486
A,B vs. C		0.3675	0.9634	0.8929	0.5628	0.1177
C vs. D,E		0.1574	0.7185	0.5287	0.9431	0.1243

15-60 cm soil depth						
		Sampling Date				
Management System		May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(%)----------				
Organic (A)		16	13	13	12	15
Organic with compost (B)		17	12	11	12	16
Nutrients no pesticides (C)		16	13	13	14	15
Pesticide Free Production (D)		15	13	11	11	14
Integrated Management (E)		15	13	13	12	15
LSD		5	2	2	5	2
ANOVA	df			Pr>F		
Management System	4	0.7981	0.5559	0.0318	0.7697	0.2675
Contrasts						
A vs. B		0.6163	0.1586	0.0261	0.8752	0.3225
A,B vs. C,D,E		0.4769	0.3665	0.7484	0.6569	0.0851
A,B vs. C		0.9548	0.5181	0.7137	0.3066	0.4350
C vs. D,E		0.3813	0.9606	0.3690	0.2912	0.4045

Table I.2. Gravimetric soil moisture content in pl ots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

0-15 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		(%)					
Organic (A)		17	12	9	6	5	18
Organic with compost (B)		18	15	11	8	6	18
Nutrients no pesticides (C)		17	16	9	7	5	17
Pesticide Free Production (D)		18	13	10	7	6	18
Integrated Management (E)		19	11	11	7	6	18
LSD		2	7	1	1	1	2
ANOVA	df	Pr>F					
Management system	4	0.3253	0.6672	0.0071	0.0908	0.1111	0.7763
Contrasts							
A vs. B		0.2739	0.4244	0.0036	0.0109	0.0497	0.5894
A,B vs. C,D,E		0.9709	0.9984	0.7728	0.4124	0.5056	0.4884
A,B vs. C		0.3329	0.4491	0.0521	0.3977	0.0849	0.2635
C vs. D,E		0.1459	0.2610	0.0125	0.7215	0.0634	0.3557

15-60 cm soil depth							
		Sampling Date					
Management System		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		(%)					
Organic (A)		16	13	12	8	7	11
Organic with compost (B)		18	15	11	9	8	12
Nutrients no pesticides (C)		17	13	11	8	6	11
Pesticide Free Production (D)		18	14	10	7	7	12
Integrated Management (E)		17	14	11	9	6	12
LSD		3	3	3	3	3	3
ANOVA	df	Pr>F					
Management system	4	0.8367	0.7629	0.5422	0.4861	0.4861	0.8249
Contrasts							
A vs. B		0.4068	0.3278	0.3519	0.2923	0.2923	0.3635
A,B vs. C,D,E		0.6803	0.6706	0.1596	0.2741	0.2741	0.9600
A,B vs. C		0.9539	0.4133	0.3291	0.3453	0.3453	0.6787
C vs. D,E		0.7080	0.4483	0.8830	0.8509	0.8509	0.5009

Table I.3. Gravimetric soil moisture content in pl ots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

0-15 cm soil depth						
		Sampling Date				
Management System		May 14	Jun 26	Jul 17	Sep 4	Oct 28
		(%)				
Organic (A)		12	11	11	16	16
Organic with compost (B)		14	12	12	17	16
Nutrients no pesticides (C)		14	12	12	16	17
Pesticide Free Production (D)		16	12	12	17	18
Integrated Management (E)		15	13	12	17	19
LSD		2	2	2	3	2
ANOVA	df	Pr>F				
Management System	4	0.0099	0.3133	0.6222	0.6568	0.0238
Contrasts						
A vs. B		0.0261	0.3417	0.2291	0.3850	0.4962
A,B vs. C,D,E		0.0137	0.3118	0.6081	0.5477	0.0106
A,B vs. C		0.6308	0.8964	0.8354	0.8133	0.4131
C vs. D,E		0.0286	0.1927	0.3809	0.3239	0.0568

15-60 cm soil depth						
		Sampling Date				
Management System		May 14	Jun 26	Jul 17	Sep 4	Oct 28
		(%)				
Organic (A)		11	12	12	13	15
Organic with compost (B)		14	12	13	13	15
Nutrients no pesticides (C)		15	11	12	15	16
Pesticide Free Production (D)		15	12	12	11	15
Integrated Management (E)		15	13	12	13	13
LSD		4	3	3	6	3
ANOVA	df	Pr>F				
Management System	4	0.1730	0.7607	0.9032	0.6556	0.5879
Contrasts						
A vs. B		0.1287	0.9609	0.4395	0.8933	0.9905
A,B vs. C,D,E		0.0477	0.9364	0.6054	0.9971	0.7544
A,B vs. C		0.0961	0.4381	0.6124	0.3992	0.5439
C vs. D,E		0.8038	0.2181	0.8548	0.2244	0.2174

Table I.4. Gravimetric soil moisture content in pl ots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

	0-15 cm soil depth						
	Sampling Date						
Management System	May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
	(%)						
Organic (A)	17	15	11	8	n.d.†	6	17
Organic with compost (B)	18	18	13	10	n.d.	7	18
Nutrients no pesticides (C)	18	16	11	8	n.d.	6	17
Pesticide Free Production (D)	18	16	12	9	n.d.	6	18
Integrated Management (E)	18	17	12	9	n.d.	6	18
LSD	2	1	1	1	-	1	1
ANOVA	df	Pr>F					
Management system	4	0.6212	0.0017	0.0140	0.0311	-	0.0099	0.7558
Contrasts							
A vs. B		0.1478	0.0002	0.0038	0.0052	-	0.0046	0.3857
A,B vs. C,D,E		0.7186	0.6716	0.7181	0.4979	-	0.0094	0.9197
A,B vs. C		0.7503	0.1845	0.0875	0.1231	-	0.0258	0.5980
C vs. D,E		0.9407	0.1298	0.0349	0.1148	-	0.7243	0.3720

	15-60 cm soil depth						
	Sampling Date						
Management System	May 1	May 14	Jun 27	Jul 6	Jul 13	Aug 19	Oct 29
	(%)						
Organic (A)	16	14	12	10	8	11	8
Organic with compost (B)	19	17	13	8	9	12	9
Nutrients no pesticides (C)	17	16	10	9	7	10	7
Pesticide Free Production (D)	18	17	12	9	7	11	7
Integrated Management (E)	17	16	11	10	7	11	7
LSD	4	3	3	2	2	3	2
ANOVA	df	Pr>F					
Management system	4	0.5416	0.1691	0.5290	0.5088	0.3624	0.7621	0.0473
Contrasts							
A vs. B		0.1151	0.0353	0.7902	0.1290	0.5942	0.5012	0.1167
A,B vs. C,D,E		0.6397	0.2499	0.2092	0.8599	0.0592	0.7385	0.0079
A,B vs. C		0.5665	0.3502	0.0978	0.7470	0.2226	0.3436	0.0196
C vs. D,E		0.7344	0.9172	0.2559	0.4985	0.7139	0.2943	0.6380

†n.d. = no data were collected.

7.10. APPENDIX J – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON WEED DRY MATTER YIELD DURING THE GROWING SEASON.

Table J.1. Weed dr y matter yield determined post spraying in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

Management System		Weed Dry Matter
		---(kg ha^{-1})---
Organic (A)		751
Organic with compost (B)		1527
Nutrients no pesticides (C)		1005
Pesticide Free Production (D)		177
Integrated Management (E)		138
LSD		856
ANOVA	df	Pr>F
Management System	4	0.0172
Contrasts		
A vs. B		0.0725
A,B vs. C,D,E		0.0166
A,B vs. C		0.7059
C vs. D,E		0.0277

Table J.2. Weed dr y matter yield determined post spraying in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

Management System		Weed Dry Matter
		---(kg ha^{-1})---
Organic (A)		717
Organic with compost (B)		2312
Nutrients no pesticides (C)		2728
Pesticide Free Production (D)		668
Integrated Management (E)		25
LSD		691
ANOVA	df	Pr>F
Management System	4	<0.0001
Contrasts		
A vs. B		0.0003
A,B vs. C,D,E		0.0929
A,B vs. C		0.0008
C vs. D,E		<0.0001

Table J.3. Weed dr y matter yield determined post spraying in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

Management System	Sampling Time	
	Late tillering	Anthesis
	-----(kg ha^{-1})-----	
Organic (A)	1011	740
Organic with compost (B)	1882	2069
Nutrients no pesticides (C)	2013	3530
Pesticide Free Production (D)	2646	7526
Integrated Management (E)	1077	380
LSD	1923	1810

ANOVA	df	Pr>F	
Management System	4	0.3564	<0.0001
Contrasts			
A vs. B		0.3428	0.1385
A,B vs. C,D,E		0.4301	0.0005
A,B vs. C		0.4730	0.0112
C vs. D,E		0.8461	0.5740

Table J.4. Weed dr y matter yield determined post spraying in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

Management System		Weed Dry Matter
		---(kg ha^{-1})---
Organic (A)		913
Organic with compost (B)		1016
Nutrients no pesticides (C)		1292
Pesticide Free Production (D)		263
Integrated Management (E)		223
LSD		718
ANOVA	df	Pr>F
Management System	4	0.0212
Contrasts		
A vs. B		0.7632
A,B vs. C,D,E		0.1078
A,B vs. C		0.2796
C vs. D,E		0.0027

Table J.5. Weed dr y matter yield determined post spraying in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

Management System		Weed Dry Matter
		---(kg ha^{-1})---
Organic (A)		676
Organic with compost (B)		1024
Nutrients no pesticides (C)		713
Pesticide Free Production (D)		186
Integrated Management (E)		34
LSD		253
ANOVA	df	Pr>F
Management System	4	<0.0001
Contrasts		
A vs. B		0.0111
A,B vs. C,D,E		<0.0001
A,B vs. C		0.1972
C vs. D,E		<0.0001

Table J.6. Weed dr y matter yield determined post spraying in plots of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

Management System		Sampling Time	
		Late tillering	Anthesis
		-----(kg ha^{-1})-----	
Organic (A)		1550	781
Organic with compost (B)		3221	2382
Nutrients no pesticides (C)		2839	2495
Pesticide Free Production (D)		4914	5231
Integrated Management (E)		1380	2533
LSD		1893	1891
ANOVA	df	Pr>F	
Management System	4	0.0078	0.0042
Contrasts			
A vs. B		0.0794	0.0897
A,B vs. C,D,E		0.2682	0.0066
A,B vs. C		0.5641	0.2477
C vs. D,E		0.6943	0.0897

7.11. APPENDIX K – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON CROP DRY MATTER YIELD DURING THE GROWING SEASON.

Table K.1. Crop dry matter accumulation in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date		
Management System		Jul 8	Jul 15	Sep 1
		----------(kg ha^{-1})----------		
Organic (A)		2109	2445	4717
Organic with compost (B)		2576	3130	5891
Nutrients no pesticides (C)		3223	4287	6838
Pesticide Free Production (D)		4362	6095	8016
Integrated Management (E)		4033	5677	8114
LSD		643	1112	1171
ANOVA	df		Pr>F	
Management System	4	<0.0001	<0.0001	0.0002
Contrasts				
A vs. B		0.1393	0.2045	0.0495
A,B vs. C,D,E		<0.0001	<0.0001	<0.0001
A,B vs. C		0.0048	0.0053	0.0064
C vs. D,E		0.0025	0.0035	0.0218

Table K.2. Crop dr y matter accumulation in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date			
Management System		Jun 20	Jun 27	Jul 8	Aug 14
		----------(kg ha^{-1})----------			
Organic (A)		474	734	1294	n.d.†
Organic with compost (B)		1009	2023	2003	n.d.
Nutrients no pesticides (C)		957	1424	1411	n.d.
Pesticide Free Production (D)		1378	2355	4096	6393
Integrated Management (E)		1002	1816	4023	7488
LSD		370	674	1230	2624
ANOVA	df		Pr>F		
Management System	4	0.0034	0.0021	0.0004	0.2763
Contrasts					
A vs. B		0.0084	0.0013	0.2329	-
A,B vs. C,D,E		0.0054	0.0312	0.0012	-
A,B vs. C		0.1689	0.8671	0.6356	-
C vs. D,E		0.1384	0.0295	0.0002	-

†n.d. = no data were collected.

Table K.3. Crop dr y matter accumulation in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

		Sampling Date		
Management System		Jul 16	Aug 5	Oct 7
		----------(kg ha^{-1})----------		
Organic (A)		607	2278	2505
Organic with compost (B)		933	3952	6032
Nutrients no pesticides (C)		1230	4449	5184
Pesticide Free Production (D)		1544	4185	3829
Integrated Management (E)		1130	5552	4024
LSD		344	1612	14671
ANOVA	df		Pr>F	
Management System	4	0.0010	0.0124	0.4218
Contrasts				
A vs. B		0.0613	0.0430	0.2014
A,B vs. C,D,E		0.0002	0.0055	0.9346
A,B vs. C		0.0056	0.0594	0.5280
C vs. D,E		0.4503	0.5242	0.4275

Table K.4. Crop dr y matter accumulation in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date		
Management System		Jul 8	Jul 15	Sep 1
		----------(kg ha^{-1})----------		
Organic (A)		1670	1982	4763
Organic with compost (B)		2615	2610	4628
Nutrients no pesticides (C)		2422	3362	5838
Pesticide Free Production (D)4825			5988	8488
Integrated Management (E)		4361	5541	7518
LSD		1100	872	1598
ANOVA	df		Pr>F	
Management System	4	0.0002	<0.0001	0.0003
Contrasts				
A vs. B		0.0859	0.1459	0.8596
A,B vs. C,D,E		0.0002	<0.0001	<0.0001
A,B vs. C		0.5339	0.0088	0.0989
C vs. D,E		0.0003	<0.0001	0.0045

Table K.5. Crop dr y matter accumulation in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

Management System		Sampling Date			
		Jun 27	Jul 4	Jul 11	Aug 13
		----------(kg ha^{-1})----------			
Organic (A)		464	957	1813	n.d.†
Organic with compost (B)		741	1544	2019	n.d.
Nutrients no pesticides (C)		966	1950	2215	n.d.
Pesticide Free Production (D)		1935	3589	3444	4815
Integrated Management (E)		1555	3131	3052	5299
LSD		278	622	598	1195
ANOVA	df		Pr>F		
Management System	4	<0.0001	<0.0001	0.0002	0.3604
Contrasts					
A vs. B		0.0503	0.0627	0.4681	-
A,B vs. C,D,E		<0.0001	<0.0001	0.0001	-
A,B vs. C		0.0058	0.0144	0.2336	-
C vs. D,E		<0.0001	<0.0001	0.0010	-

†n.d. = no data were collected.

Table K.6. Crop dr y matter accumulation in plots of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

Management System		Sampling Date		
		Jul 16	Aug 5	Sep 29
		----------(kg ha^{-1})----------		
Organic (A)		418	2096	2151
Organic with compost (B)		876	3062	5110
Nutrients no pesticides (C)		1108	3882	5703
Pesticide Free Production (D)		1907	6128	6318
Integrated Management (E)		1818	6858	9196
LSD		193	1342	15288
ANOVA	df		Pr>F	
Management System	4	<0.0001	<0.0001	0.2467
Contrasts				
A vs. B		0.0002	0.1455	0.2458
A,B vs. C,D,E		<0.0001	<0.0001	0.1413
A,B vs. C		<0.0001	0.0305	0.2965
C vs. D,E		<0.0001	0.0002	0.2989

7.12. APPENDIX L – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON GRAIN YIELD DURING THE GROWING SEASON.

Table L.1. Final grain yield of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date
Management System		Sep 1
		---(kg ha^{-1})---
Organic (A)		1717
Organic with compost (B)		1891
Nutrients no pesticides (C)		2088
Pesticide Free Production (D)		2849
Integrated Management (E)		3426
LSD		528
ANOVA	df	Pr>F
Management System	4	<0.0001
Contrasts		
A vs. B		0.4932
A,B vs. C,D,E		<0.0001
A,B vs. C		0.2053
C vs. D,E		0.0002

Table L.2. Final grain yield of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date
Management System		Aug 14
		---(kg ha^{-1})---
Organic (A)		n.d.†
Organic with compost (B)		n.d.
Nutrients no pesticides (C)		n.d.
Pesticide Free Production (D)		2272
Integrated Management (E)		3332
LSD		1077
ANOVA	df	Pr>F
Management System	4	0.0519
Contrasts		
A vs. B		-
A,B vs. C,D,E		-
A,B vs. C		-
C vs. D,E		-

†n.d. = no data were collected.

Table L.3. Final grain yield of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

		Sampling Date
Management System		Oct 7
		---(kg ha^{-1})---
Organic (A)		862
Organic with compost (B)		1429
Nutrients no pesticides (C)		1443
Pesticide Free Production (D)		1310
Integrated Management (E)		1696
LSD		759
ANOVA	df	Pr>F
Management System	4	0.2587
Contrasts		
A vs. B		0.1320
A,B vs. C,D,E		0.1626
A,B vs. C		0.3495
C vs. D,E		0.8494

Table L.4. Final grain yield of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date
Management System		Sep 1
		---(kg ha^{-1})---
Organic (A)		1576
Organic with compost (B)		2024
Nutrients no pesticides (C)		2151
Pesticide Free Production (D)		3759
Integrated Management (E)		3747
LSD		616
ANOVA	df	Pr>F
Management System	4	<0.0001
Contrasts		
A vs. B		0.1387
A,B vs. C,D,E		<0.0001
A,B vs. C		0.1777
C vs. D,E		<0.0001

Table L.5. Final grain yield of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date
Management System		Aug 13
		---(kg ha^{-1})---
Organic (A)		n.d.†
Organic with compost (B)		n.d.
Nutrients no pesticides (C)		n.d.
Pesticide Free Production (D)		2632
Integrated Management (E)		2930
LSD		556
ANOVA	df	Pr>F
Management System	4	0.1862
Contrasts		
A vs. B		-
A,B vs. C,D,E		-
A,B vs. C		-
C vs. D,E		-

†n.d. = no data were collected.

Table L.6. Final grain yield of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

		Sampling Date
Management System		Sep 29
		---(kg ha^{-1})---
Organic (A)		919
Organic with compost (B)		1801
Nutrients no pesticides (C)		2047
Pesticide Free Production (D)		2235
Integrated Management (E)		3474
LSD		971
ANOVA	df	Pr>F
Management System	4	0.0010
Contrasts		
A vs. B		0.0719
A,B vs. C,D,E		0.0008
A,B vs. C		0.1017
C vs. D,E		0.0588

7.13. APPENDIX M – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON GRAIN PROTEIN CONCENTRATION DURING THE GROWING SEASON.

Table M.1. Grain protei n concentration of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date
Management System		Sep 1
		---(%)---
Organic (A)		11.5
Organic with compost (B)		13.4
Nutrients no pesticides (C)		14.0
Pesticide Free Production (D)		14.5
Integrated Management (E)		14.3
LSD		1.7
ANOVA	df	Pr>F
Management System	4	0.0150
Contrasts		
A vs. B		0.0360
A,B vs. C,D,E		0.0037
A,B vs. C		0.0485
C vs. D,E		0.5486

Table M.2. Grai n protein concentration of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date
Management System		Aug 14
		---(%)---
Organic (A)		n.d.†
Organic with compost (B)		n.d.
Nutrients no pesticides (C)		n.d.
Pesticide Free Production (D)		15.0
Integrated Management (E)		15.2
LSD		0.5
ANOVA	df	Pr>F
Management System	4	0.1817
Contrasts		
A vs. B		-
A,B vs. C,D,E		-
A,B vs. C		-
C vs. D,E		-

†n.d. = no data were collected.

Table M.3. Grain protei n concentration of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

		Sampling Date
Management System		Oct 7
		---(%)---
Organic (A)		11.4
Organic with compost (B)		12.3
Nutrients no pesticides (C)		12.7
Pesticide Free Production (D)		13.1
Integrated Management (E)		13.6
LSD		0.7
ANOVA	df	Pr>F
Management System	4	<0.0001
Contrasts		
A vs. B		0.0075
A,B vs. C,D,E		<0.0001
A,B vs. C		0.0074
C vs. D,E		0.0230

Table M.4. Grain protei n concentration of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date
Management System		Sep 1
		---(%)---
Organic (A)		9.1
Organic with compost (B)		9.3
Nutrients no pesticides (C)		10.8
Pesticide Free Production (D)		11.1
Integrated Management (E)		10.3
LSD		1.5
ANOVA	df	Pr>F
Management System	4	0.0352
Contrasts		
A vs. B		0.8388
A,B vs. C,D,E		0.0034
A,B vs. C		0.0149
C vs. D,E		0.8143

Table M.5. Grain protei n concentration of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date
Management System		Aug 13
		---(%)---
Organic (A)		n.d.†
Organic with compost (B)		n.d.
Nutrients no pesticides (C)		n.d.
Pesticide Free Production (D)		15.2
Integrated Management (E)		15.7
LSD		2.6
ANOVA	df	Pr>F
Management System	4	0.7015
Contrasts		
A vs. B		-
A,B vs. C,D,E		-
A,B vs. C		-
C vs. D,E		-

†n.d. = no data were collected.

Table M.6. Grain protei n concentration of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

		Sampling Date
Management System		Sep 29
		---(%)---
Organic (A)		7.7
Organic with compost (B)		8.1
Nutrients no pesticides (C)		9.8
Pesticide Free Production (D)		10.5
Integrated Management (E)		10.0
LSD		0.9
ANOVA	df	Pr>F
Management System	4	<0.0001
Contrasts		
A vs. B		0.3027
A,B vs. C,D,E		<0.0001
A,B vs. C		<0.0001
C vs. D,E		0.1710

7.14. APPENDIX N – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON CROP NITROGEN UPTAKE DURING THE GROWING SEASON.

Table N.1. Crop nitroge n uptake in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date		
Management System		Jul 8	Jul 15	Sep 1
		--------(kg ha^{-1})--------		
Organic (A)		55	55	48
Organic with compost (B)		68	55	62
Nutrients no pesticides (C)		100	90	83
Pesticide Free Production (D)		141	138	104
Integrated Management (E)		131	139	116
LSD		19	28	15
ANOVA	df		Pr>F	
Management System	4	<0.0001	<0.0001	<0.0001
Contrasts				
A vs. B		0.1604	0.9951	0.0672
A,B vs. C,D,E		<0.0001	<0.0001	<0.0001
A,B vs. C		0.0002	0.0071	0.0008
C vs. D,E		0.0004	0.0007	0.0009

Table N.2. Cro p nitrogen uptake in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

Management System		Sampling Date			
		Jun 20	Jun 27	Jul 8	Aug 14
		----------(kg ha^{-1})----------			
Organic (A)		12	13	15	n.d.†
Organic with compost (B)		27	46	23	n.d.
Nutrients no pesticides (C)		33	32	25	n.d.
Pesticide Free Production (D)		50	56	70	66
Integrated Management (E)		40	41	81	88
LSD		10	18	19	24
ANOVA	df		Pr>F		
Management System	4	<0.0001	0.0016	<0.0001	0.0579
Contrasts					
A vs. B		0.0085	0.0012	0.3374	-
A,B vs. C,D,E		<0.0001	0.0297	<0.0001	-
A,B vs. C		0.0052	0.7951	0.4458	-
C vs. D,E		0.0103	0.0370	<0.0001	-

†n.d. = no data were collected.

Table N.3. Crop nitroge n uptake in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

		Sampling Date		
Management System		Jul 16	Aug 5	Oct 7
		----------(kg ha^{-1})----------		
Organic (A)		17	28	24
Organic with compost (B)		29	62	52
Nutrients no pesticides (C)		49	74	53
Pesticide Free Production (D)		57	68	44
Integrated Management (E)		45	96	52
LSD		12	33	24
ANOVA	df		Pr>F	
Management System	4	<0.0001	0.0106	0.0880
Contrasts				
A vs. B		0.0433	0.0423	0.0241
A,B vs. C,D,E		<0.0001	0.0042	0.1124
A,B vs. C		0.0001	0.0474	0.1335
C vs. D,E		0.7423	0.5444	0.6284

Table N.4. Crop nitroge n uptake in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

Management System		Sampling Date		
		Jul 8	Jul 15	Sep 1
		----------(kg ha^{-1})----------		
Organic (A)		34	32	39
Organic with compost (B)		55	41	42
Nutrients no pesticides (C)		66	71	60
Pesticide Free Production (D)		133	122	101
Integrated Management (E)		122	122	89
LSD		24	19	16
ANOVA	df		Pr>F	
Management System	4	<0.0001	<0.0001	<0.0001
Contrasts				
A vs. B		0.0713	0.3290	0.7175
A,B vs. C,D,E		<0.0001	<0.0001	<0.0001
A,B vs. C		0.0415	0.0004	0.0101
C vs. D,E		<0.0001	<0.0001	0.0001

Table N.5. Crop nitroge n uptake in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

Management System		Sampling Date			
		Jun 27	Jul 4	Jul 11	Aug 13
		----------(kg ha^{-1})----------			
Organic (A)		8	12	18	n.d.†
Organic with compost (B)		14	19	25	n.d.
Nutrients no pesticides (C)		28	38	44	n.d.
Pesticide Free Production (D)		54	71	58	66
Integrated Management (E)		48	64	60	75
LSD		9	12	13	22
ANOVA	df		Pr>F		
Management System	4	<0.0001	<0.0001	<0.0001	0.3701
Contrasts					
A vs. B		0.1948	0.2107	0.2902	-
A,B vs. C,D,E		<0.0001	<0.0001	<0.0001	-
A,B vs. C		0.0006	0.0004	0.0009	-
C vs. D,E		<0.0001	<0.0001	0.0146	-

†n.d. = no data were collected.

Table N.6. Crop nitroge n uptake in plots of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

Management System		Sampling Date		
		Jul 16	Aug 5	Sep 29
		----------(kg ha^{-1})----------		
Organic (A)		10	22	17
Organic with compost (B)		21	33	37
Nutrients no pesticides (C)		40	61	55
Pesticide Free Production (D)		55	85	59
Integrated Management (E)		61	106	90
LSD		10	27	25
ANOVA	df		Pr>F	
Management System	4	<0.0001	<0.0001	0.0005
Contrasts				
A vs. B		0.0344	0.4025	0.0970
A,B vs. C,D,E		<0.0001	<0.0001	0.0001
A,B vs. C		<0.0001	0.0087	0.0148
C vs. D,E		0.0006	0.0064	0.0736

7.15. APPENDIX O – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON RECOVERABLE PLANT AVAILABLE NITROGEN DURING THE GROWING SEASON.

Table O.1. Recov erable plant available N in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

		Sampling Date					
Mgmt Syst		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Org (A)		90	130	145	119	151	115
OrgC (B)		92	147	165	131	166	126
NNP (C)		112	149	252	215	182	125
PFP (D)		86	116	279	226	167	101
IM (E)		112	134	300	250	193	135
LSD		25	55	53	28	27	27
ANOVA	df	Pr>F					
Mgmt Syst	4	0.1053	0.6863	<0.0001	<0.0001	0.0406	0.1244
Contrasts							
A vs. B		0.8619	0.5132	0.4403	0.3757	0.2571	0.3944
A,B vs. C,D,E		0.1224	0.7279	<0.0001	<0.0001	0.0153	0.9776
A,B vs. C		0.0532	0.6442	0.0006	<0.0001	0.0479	0.6517
C vs. D,E		0.1992	0.2893	0.1047	0.0651	0.8665	0.5199

Table O.2. Recov erable plant available N in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Sampling Date					
Mgmt Syst		May 1	Jun 17	Jun 30	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------					
Org (A)		94	81	73	75	n.d.†	52
OrgC (B)		105	120	98	89	n.d.	69
NNP (C)		114	123	97	105	n.d.	77
PFP (D)		96	154	129	133	140	60
IM (E)		127	147	114	163	158	66
LSD		53	24	27	27	38	24
ANOVA	df	Pr>F					
Mgmt Syst	4	0.6836	0.0002	0.0071	<0.0001	0.2308	0.3009
Contrasts							
A vs. B		0.6748	0.0048	0.0659	0.2810	-	0.1596
A,B vs. C,D,E		0.4543	<0.0001	0.0045	<0.0001	-	0.3520
A,B vs. C		0.5339	0.0369	0.3233	0.0567	-	0.1187
C vs. D,E		0.9246	0.0139	0.0435	0.0018	-	0.1793

†n.d. = no data were collected.

Table O.3. Recov erable plant available N in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

		Sampling Date				
Mgmt Syst		Apr 26	Jun 6	Aug 5	Oct 7	Oct 25
		----------(kg ha^{-1})----------				
Org (A)		145	121	87	81	52
OrgC (B)		113	122	119	105	46
NNP (C)		117	108	135	110	41
PFP (D)		123	89	122	107	59
IM (E)		149	86	153	107	47
LSD		58	41	33	35	9
ANOVA	df			Pr>F		
Mgmt Syst	4	0.5708	0.2333	0.0125	0.4102	0.0082
Contrasts						
A vs. B		0.2563	0.9608	0.0590	0.1585	0.1626
A,B vs. C,D,E		0.9851	0.0451	0.0049	0.1795	1.0000
A,B vs. C		0.5991	0.4263	0.0315	0.2481	0.0381
C vs. D,E		0.4221	0.2425	0.8460	0.8224	0.0044

Table O.4. Recov erable plant available N in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

		Sampling Date					
Mgmt Syst		May 2	May 14	Jun 26	Jul 17	Sep 4	Oct 28
		----------(kg ha^{-1})----------					
Org (A)		73	111	130	102	126	102
OrgC (B)		80	146	151	121	135	103
NNP (C)		99	117	192	160	145	114
PFP (D)		97	136	296	218	172	112
IM (E)		93	133	272	230	158	142
LSD		30	40	56	47	28	21
ANOVA	df	Pr>F					
Mgmt Syst	4	0.3186	0.3742	<0.0001	<0.0001	0.0276	0.0101
Contrasts							
A vs. B		0.6302	0.0824	0.4176	0.3985	0.4862	0.9046
A,B vs. C,D,E		0.0481	0.9936	<0.0001	<0.0001	0.0060	0.0082
A,B vs. C		0.0894	0.5015	0.0399	0.0224	0.2236	0.2175
C vs. D,E		0.7603	0.3137	0.0013	0.0042	0.0969	0.1398

Table O.5. Recov erable plant available N in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Sampling Date						
Mgmt Syst		May 1	May 14	Jun 27	Jul 6	Jul 12	Aug 19	Oct 29
		----------(kg ha^{-1})----------						
Org (A)		80	96	78	66	82	n.d.†	55
OrgC (B)		84	142	85	75	88	n.d.	63
NNP (C)		88	89	105	106	128	n.d.	85
PFP (D)		107	119	142	140	136	150	63
IM (E)		103	115	143	157	138	153	62
LSD		27	32	22	20	18	45	28
ANOVA	df				Pr>F			
Mgmt Syst	4	0.1832	0.0247	<0.0001	<0.0001	<0.0001	0.8329	0.2512
Contrasts								
A vs. B		0.7424	0.0080	0.5215	0.3183	0.4412	-	0.5487
A,B vs. C,D,E		0.0476	0.2494	<0.0001	<0.0001	<0.0001	-	0.2091
A,B vs. C		0.5442	0.0346	0.0194	0.0007	<0.0001	-	0.0365
C vs. D,E		0.1518	0.0463	0.0011	0.0002	0.1868	-	0.0667

†n.d. = no data were collected.

Table O.6. Recov erable plant available N in plots of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

		Sampling Date				
Mgmt Syst		Apr 26	Jun 6	Aug 5	Sep 29	Oct 25
		----------(kg ha^{-1})----------				
Org (A)		133	82	72	68	55
OrgC (B)		86	98	90	88	51
NNP (C)		127	90	120	104	68
PFP (D)		127	90	137	111	53
IM (E)		160	92	158	143	50
LSD		67	19	30	26	18
ANOVA	df			Pr>F		
Mgmt Syst	4	0.2614	0.4964	0.0003	0.0005	0.2368
Contrasts						
A vs. B		0.1502	0.0864	0.2093	0.1152	0.6542
A,B vs. C,D,E		0.1772	0.9018	<0.0001	0.0002	0.4547
A,B vs. C		0.5282	0.9671	0.0066	0.0272	0.0547
C vs. D,E		0.5413	0.8417	0.0358	0.0411	0.0381

7.16. APPENDIX P – ANALYSIS OF VARIANCE AND CONTRASTS FOR THE INTERACTION OF YEAR AND CROP PHASE ON DIFFERENCE IN RECOVERABLE PLANT AVAILABLE NITROGEN DURING THE GROWING SEASON.

Table P.1. Diff erence in recoverable plant available N between sampling dates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2002 growing season.

	Time Interval				
Mgmt Syst	May 2 to May 14	May 14 to Jun 26	Jun 26 to Jul 17	Jul 17 to Sep 4	May 14 to Sep 4
	----------(kg ha-1)----------				
Org (A)	41	15	-26	32	21
OrgC (B)	55	17	-33	35	19
NNP (C)	37	103	-37	-33	33
PFP (D)	30	163	-53	-59	51
IM (E)	22	166	-50	-57	60
LSD	51	49	51	47	58
ANOVA	df		Pr>F		
Mgmt Syst	4	0.6928	<0.0001	0.7471	0.0007	0.4741
Contrasts					
A vs. B		0.5347	0.9130	0.7537	0.8917	0.9423
A,B vs. C,D,E		0.2519	<0.0001	0.2737	<0.0001	0.1254
A,B vs. C		0.5946	0.0008	0.7057	0.0036	0.5709
C vs. D,E		0.6086	0.0087	0.4959	0.2160	0.3522

Table P.2. Diff erence in recoverable plant available N between sampling dates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2003 growing season.

		Time Interval				
Mgmt Syst		May 1 to Jun 17	Jun 17 to Jun 30	Jun 30 to Jul 12	Jul 12 to Aug 19	May 1 to Jul 12
		----------(kg ha^{-1})----------				
Org (A)		-13	-8	2	n.d.†	-19
OrgC (B)		14	-21	-9	n.d.	-16
NNP (C)		9	-26	8	n.d.	-9
PFP (D)		58	-26	4	7	37
IM (E)		21	-34	50	-5	36
LSD		50	33	41	53	53
ANOVA	df			Pr>F		
Mgmt Syst	4	0.0940	0.5894	0.0709	0.5046	0.0829
Contrasts						
A vs. B		0.2486	0.4122	0.5627	-	0.8909
A,B vs. C,D,E		0.0751	0.1946	0.0719	-	0.0288
A,B vs. C		0.6602	0.4137	0.4947	-	0.6768
C vs. D,E		0.1588	0.8007	0.2726	-	0.0541

†n.d. = no data were collected.

Table P.3. Diff erence in recoverable plant available N between sampling dates in plots of durum wheat (*Triticum durum*) on a range of management systems during the 2004 growing season.

		Time Interval			
Mgmt Syst		Apr 26 to Jun 6	Jun 6 to Aug 5	Aug 5 to Oct 7	Jun 6 to Oct 7
		----------(kg ha^{-1})----------			
Org (A)		-24	-34	-6	-40
OrgC (B)		8	-3	-13	-16
NNP (C)		-9	27	-25	3
PFP (D)		-34	33	-15	18
IM (E)		-64	67	-46	20
LSD		67	62	39	53
ANOVA	df		Pr>F		
Mgmt Syst	4	0.2667	0.0360	0.2508	0.1369
Contrasts					
A vs. B		0.3128	0.2941	0.6834	0.3605
A,B vs. C,D,E		0.1974	0.0059	0.1244	0.0202
A,B vs. C		0.9678	0.0861	0.3479	0.1765
C vs. D,E		0.1689	0.3721	0.7093	0.4493

Table P.4. Diff erence in recoverable plant available N between sampling dates in plots of oats (*Avena sativa*) on a range of management systems during the 2002 growing season.

	Time Interval				
Mgmt Syst	May 2 to May 14	May 14 to Jun 26	Jun 26 to Jul 17	Jul 17 to Sep 4	May 14 to Sep 4
	----------(kg ha^{-1})----------				
Org (A)	38	19	-28	24	15
OrgC (B)	66	5	-30	14	-11
NNP (C)	19	74	-32	-15	28
PFP (D)	39	160	-78	-46	37
IM (E)	40	139	-42	-71	26
LSD	44	71	65	45	33

ANOVA	df	Pr>F				
Mgmt Syst	4	0.2968	0.0013	0.4623	0.0019	0.0734
Contrasts						
A vs. B		0.1923	0.6842	0.9356	0.6520	0.1196
A,B vs. C,D,E		0.1600	0.0002	0.2874	0.0003	0.0157
A,B vs. C		0.0816	0.0479	0.9149	0.0831	0.0774
C vs. D,E		0.2621	0.0211	0.3009	0.0298	0.8105

Table P.5. Diff erence in recoverable plant available N between sampling dates in plots of oats (*Avena sativa*) on a range of management systems during the 2003 growing season.

		Time Interval					
Mgmt Syst		May 1 to May 14	May 14 to Jun 27	Jun 27 to Jul 6	Jul 6 to Jul 12	Jul 12 to Aug 19	May 14 to Jul 12
		----------(kg ha^{-1})----------					
Org (A)		16	-18	-12	16	n.d.†	-14
OrgC (B)		59	-57	-10	13	n.d.	-54
NNP (C)		0	17	1	21	n.d.	39
PFP (D)		12	24	-2	-3	14	18
IM (E)		12	28	14	-19	15	23
LSD		45	44	26	33	56	41
ANOVA	df			Pr>F			
Mgmt Syst	4	0.1105	0.0057	0.2589	0.1107	0.9456	0.0027
Contrasts							
A vs. B		0.0630	0.0742	0.8195	0.8412	-	0.0548
A,B vs. C,D,E		0.0482	0.0006	0.0698	0.1482	-	0.0003
A,B vs. C		0.0609	0.0098	0.2644	0.6361	-	0.0008
C vs. D,E		0.5348	0.6064	0.6636	0.0303	-	0.2821

†n.d. = no data were collected.

Table P.6. Difference in recoverable plant available N between sampling dates in plots of oats (*Avena sativa*) on a range of management systems during the 2004 growing season.

	Time Interval			
Mgmt Syst	Apr 26 to Jun 6	Jun 6 to Aug 5	Aug 5 to Sep 29	Jun 6 to Sep 29
	----------(kg ha^{-1})----------			
Org (A)	-51	-9	-4	-14
OrgC (B)	12	-8	-2	-10
NNP (C)	-37	30	-16	14
PFP (D)	-36	47	-26	21
IM (E)	-68	66	-15	51
LSD	68	35	35	26

ANOVA	df	Pr>F			
Mgmt Syst	4	0.1813	0.0010	0.6143	0.0009
Contrasts					
A vs. B		0.0631	0.9353	0.9027	0.7793
A,B vs. C,D,E		0.1943	<0.0001	0.1617	0.0002
A,B vs. C		0.5272	0.0153	0.3857	0.0266
C vs. D,E		0.5857	0.0847	0.7640	0.0558