This is to certify that the
thesis entitled

NITROGEN RECOVERY AND NITROGEN BALANCE WITH ^{15}N IN POTATO SYSTEMS AMENDED WITH COVER CROPS AND MANURE

presented by

Judith Nyiraneza

has been accepted towards fulfillment
of the requirements for the

M.S degree in Department of Crop and Soil Sciences

Major Professor's Signature

Sept 29, 2003

Date

NITROGEN RECOVERY AND NITROGEN BALANCE WITH ^{15}N IN POTATO SYSTEMS AMENDED WITH COVER CROPS AND MANURE.

By

Judith Nyiraneza

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

2003

ABSTRACT

NITROGEN RECOVERY AND NITROGEN BALANCE WITH ^{15}N IN POTATO SYSTEMS AMENDED WITH COVER CROPS AND MANURE.

By

Judith Nyiraneza

Potato yield response to the combination of fertilizer, with cover crop and/or manure was assessed and nitrogen partitioning determined using ^{15}N. In the first field based experiment, benefits of growing a pure stand of a winter cereal cover crop (rye) versus growing a mixture of legume (hairy vetch) and cereal were compared in terms of biomass produced, nitrogen returned to the soil and yield of the following crop (potatoes). At two sites, the mixture significantly increased yield biomass of cover crop and nitrogen incorporated. In the second experiment, manure was applied in a split plot field study and in a large container study to evaluate cover crop and manure effects and their interactions, on potato yield, N use efficiency and N recovery. N partitioning by using ^{15}N was carried out in the complementary container experiment and nitrates released from different sources were monitored using anion exchange membranes. Net nitrogen recovery by ^{15}N ranged from 71 to 76%, with the main allocation in tubers. Rye and manure application significantly increased potato yield and nutrient uptake. Nitrate on anion exchange membranes followed the same trend, as nutrient uptake and potato total yield, indicating that, the anion exchange membranes are good tools in assessing nutrient release capacity from different sources. Organic sources rapidly improved the soil productivity.

AKNOWLEDGMENTS

I would like to express appreciation to Dr. Sieglinde Snapp, my major Professor, for her guidance, her understanding and for her permanent support during this period.

Sincere gratitude is also extended to Dr. Carrie Laboski and Dr. David Douches for their advice, their time, and for serving on the guidance committee.

I especially thank Dr. Adrien N'Dayegamiye and his technician Anne Drapeau for assistance in light fraction analysis and sample preparation for ^{15}N analysis.

I am also grateful to my family: my mother, my sister (Cécile), and my two brothers (Zeff and Justin) for the emotional support and encouragement.

Several other people helped in this study and I am thankful to them.

Thanks to my coworkers in Dr. Snapp laboratory for help and cooperation.

I recognize the help in multiple occasion of Dr. Sasha Kravchenko for statistical analysis, John Dahl of soil test lab for conducting part of analysis, and David Harris of Davis University (California) for ^{15}N analysis.

Debts of gratitude go to "Partnership for Enhancing Agriculture in Rwanda through Linkages" (PEARL) project, for the financial support that made this study possible.

Finally I thank many friends especially Geraldine, Costanza, Gaudence, Jean Claude, Shinsuke for the moral support and friendship.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIXES

Chapter 1. Literature review

Nitrogen effects on plant growth

Nitrogen (N) is often the most limiting nutrient for many crops because it is required at high levels. Crops obtain N mainly from mineralization of soil organic matter but also from added inorganic N from fertilizer, manures, and from N fixation by legumes. The nitrogen present in soil can generally be classified as inorganic or organic. Ninety-five percent or more of the N usually occurs in organic form in surface soils (Tisdale et al.1985). The inorganic forms of soil nitrogen include ammonium (NH_4^+), nitrate (NO_3^-), nitrous oxide (N_2O), nitric oxide (NO) and, elemental nitrogen (N_2). From the standpoint of soil fertility, the NH_4^+, N_2O, and NO_3^- forms are of greatest importance; N_2O and NO are also important in a negative way, they represent forms of nitrogen that are vulnerable to gaseous loss through denitrification (Tisdale et al. 1985).

The application of N fertilizer to grow crops is generally cost-effective. The cost of fertilizer is minimal compared to the extra value obtained. For this reason, farmers are encouraged to apply relatively high levels of N to optimize yields, which may be close to the maximum potential yield (Kitchen and Goulding 2001). Application of N fertilizer generally increases crop biomass and protein yield as well as nitrogen concentration in plant tissue. Nitrogen is important not only for the quantity of the crop produced, but also for the quality of the crop. Nitrogen fertilization has a big impact on potato quality for processing. It also influences potato size in regard to the fresh marketable yield. Nitrogen fertilization affects potato tuber size but also starch content and sugar content (Blumenthal et al. 2001). Low nitrogen fertilizer rate will cause particular problems in potatoes, as it is related to small tubers with low dry matter content and high reducing sugar levels. On the other hand, excessive nitrogen fertilizer rate delays tuber initiation while promoting excessive vine growth. It is therefore important to manage nitrogen properly to achieve optimum crop quality and quantity. In addition, nitrogen merits particular attention, more than any other nutrient because of environmental issues.

Of all the nutrients required for plant growth, N is by far the most mobile; losses of as much as half of the applied amount are frequent (Stevenson 1999). Five main processes for N loss include: bacterial denitrification, chemodenitrification, NH_3 volatilization, leaching and erosion (Stevenson 1999). From the standpoint of groundwater quality, leaching of NO_3^--N is the primary concern, and for that it requires careful consideration.

Nitrogen losses from soil by leaching

Modern farming practices that rely on N fertilizer rate in excess of use are often presumed to be responsible for the non-point source pollution of drinking water. The transfer of N from soil to lakes and streams occurs primarily through leaching and surface flow. Nitrogen is mainly leached as NO_3^--N, although NH_4^+ may be lost from sandy soils and from soils where excessive amount of NH_4^+ are applied.

Historically, the NO_3^--N content of surface waters has been increased by clearing native vegetation, practicing excessive tillage, increasing livestock numbers and recently by increasing N fertilization rate (Stevenson 1999). A study conducted in Sierra Polona Valley in Los Angeles County showed that anthropogenic sources contributed more than half of the NO_3^--N found in the basin and almost 40% of water wells routinely or occasionally exceeded the public drinking water standard of 10 mg L^{-1} (Williams et al. 1998). Studies have shown that the level of NO^{3-}-N leached and/or lost in subsurface tile drainage increases as N fertilization rate increases (Angle et al. 1993, Baker and Johnson 1981; Gast et al 1978). Concerns about NO_3^--N in drinking water and food arise from the fact that when consumed in large amounts, NO_3^--N has the potential to cause methemoglobinemia and stomach cancer (Stevenson 1999). Leaching losses occur when three conditions are met (Stevenson 1999): i) soil NO_3^--N levels are high; ii) plant uptake and microbial immobilization cannot remove all of the NO_3^--N from solution before it reaches greater depths in the soil profile where there are few roots and decreased microbial activity; and, iii) downward movement of water is sufficient to move NO_3^--N below the rooting depth.

From this, it is clear that crops, which have high nitrogen and water requirement and prefer deep and well-drained soils, are at risk for allowing a downward movement of NO_3^--N in groundwater. As potatoes meet all those conditions, it is not surprising that the potato producing area in Montcalm County in central Michigan has N leaching problems. In 1984, a survey of 178 wells in Montcalm County (Michigan) found that 7% of the water samples exceeded the standard of 10 mg L^{-1} of NO_3^--N in drinking water (Vitosh 1990). Most probably this is caused by the fact that this region represents an intensive agricultural area, high in irrigated potato production combined with sandy soils (Vitosh 1990).

Management practices that minimize NO_3^--N levels include (Stevenson 1999): i) modifying cropping systems, integrating cover crops and legume to reduce the need for N fertilizers; ii) using slow release fertilizers; iii) developing better models for predicting available soil N and reducing N fertilizer appropriately, iv) growing a winter cover crop which assimilates residual NO_3^--N into plant organic N, which is then returned to the soil in the spring when the plant is killed. If well managed, simple soil management practices which consist in combining fertilizer with an organic source such as cover crop and/or manure could help to avoid excessive N losses to the environment by decreasing N fertilizer rate.

Managing organic sources to reduce the need of N fertilizers

The main organic sources include animal manure, crop residues, green manure and cover crops. Also, logging and wood manufacturing residues, industrial organic wastes, and residues from the food processing industry are good sources for nutrients in agriculture. In the USA, estimates of organic residues are at about 694 metric ton per year (Rajendra and Power 1997).

An estimated 175 million tons of manure is excreted each year by all domestic livestock and poultry (Rajendra and Power 1997). N content in animal manure (dry weight basis) varies from 3 to 4% in poultry and 1 to 2% in beef cattle (Rajendra and Power 1997). Animal agriculture produces half of Michigan's agriculture income and animal nutrients represent 18%, 37%, and 25% of the crops needs for N, P, K, respectively in the State (Bickert 2002).

The main problem associated with organic sources (manure, cover crops or green manures) respect to fertilizer is that their N content is mostly under organic form and need to be mineralized, before being available to the following crop. The mineralization rate also depends on environmental conditions. Another constraint is that, there is also a high variability of manure nutrient, both in space and in time, depending on how they are treated and stored, and the related variability during application to the soil. A challenge associated with cover crops and manure is the poor synchronization or delays in nitrogen mineralization, which can reduce plant available nitrogen during a time of high demand (Malpassi et al. 2000).

Organic sources help to build the soil over the long-term by increasing soil quality, through increases in cation exchange capacity, water holding capacity, and organic matter. For example, approximately 20% greater water-stable aggregates were formed under crop residue treatments, compared to fertilizer alone (Ordan et al. 1996). Organic sources are important during transition from conventional to low input agriculture. Transitional changes were studied by Scow et al. (1994); after four years, soil pH and percent N levels were consistently greater in organic and low input systems than in conventional plots for all crops. Levels of the soil organic matter, phosphorus and potassium were also significantly greater in the organic than conventional plots.

The use of chemical fertilizer along with organic fertilizer is probably the best way to maintain satisfactory yields, to build the soil, and avoid environmental problems. Combining composts with reduced amount of mineral fertilizer to satisfy crop requirements presents several benefits. Sikora and Enkiri (2000) compared compost and fertilizer alone using ^{15}N analysis and observed that NH_4NO_3 fertilizer stimulated soil and/or compost mineralization, producing more N than predicted from incubation studies on compost N mineralization. The same increase of N use efficiency was observed by Jensen et al. (1999), who combined ^{15}N labeled ruminant manure with fertilizer.

To avoid the decline in soil organic matter concentration as well as the decline in aggregate stability observed in potatoes systems (Saini and Grant 1980), it is important to incorporate manure and cover crops.

Cover crop effects

A cover crop is a crop grown as a complementary plant to a cash crop to benefit the soil in many ways: it reduces erosion, weed pressure, insects, nematodes, other pest problems, and improves soil quality (Mutch and Martin 2000). Cover crops seeded in fall may reduce NO_3--N leaching by uptake of residual NO_3^- after fall crop harvest. Meisinger et al. (1991) and Power and Doran (1988) reported that the reduction of NO_3^--N leaching by non legumes ranged from 29 to 94%, compared with –6 to 48% by legumes in the southeast and northeast (Sainju and Singh 1997). McCraken et al. (1994) found that rye reduced NO_3^--N leaching by 94% compared with 48% for hairy vetch. Rye has been shown to be an effective recycler of soil NO_3^--N in the early growing season presumably due to high root density (Upendra et al. (1998).

Cover crops used as green manure can increase soil carbon content (Bolton et al. 1985; Muller and Sundman 1998; Wagger et al.1998). Increasing soil labile organic C by green manure results in increased microbial number and activity, improved soil structural stability, and increased water-holding capacity (Kuo et al. 1997; Muller and Sundman 1998; Abdallahi and N'Dayegamiye 2000). Several studies have demonstrated that green manures increase soil biological and enzymatic activity more than mineral fertilizer (Bolton et al. 1985; Kirchener et al.1993; Abdallahi and N'Dayegamiye 2000).

Cover crops or green manure N could represent an important N source for a subsequent crop. In a study where residual effects of five green manure species were studied over a period of five years, green manure application provided 15 to 36 kg N ha^{-1} to as subsequent wheat crop, and this contribution accounted for 25 to 31% of the total wheat N uptake (N'Dayegamiye and Tran 2001).

However, estimating the amount of N released from green manure or cover crops can be difficult due to many interacting factors, which are involved in the mineralization process including temperature, moisture, physical and chemical composition of residues (Pare and Papendick 1978; Bending and Turner 1999).

Manure nitrogen availability

Animal manures contain important quantities of plant nutrients and, therefore, can substitute for mineral fertilizers such as N, P and K. Nitrogen content and availability from manure depends on animal species and age, composition of feed, type and amount of bedding, climatic conditions, storage and handling systems, and method of field application (Dawson and Kelling 2002). A better understanding of manure N availability to crops and, its effects on soil N mineralization is important to allow estimation of correct credit for N supplied and to adjust fertilizer accordingly (Eneji et al. 2002). However, it is difficult to estimate manure nutrient supply because of many factors that influence manure N mineralization rate.

Internal factors such as manure characteristics as well as external factors such as climatic conditions greatly influence the N mineralization rate of manure. Nitrogen mineralization is a microbial process and is influenced by substrate characteristics, but also by temperature, soil water status and aeration (Griffin and Honeycutt 2000). Water content has been long known to exert a pronounced influence on the rate at which N is mineralized (Stanford and Epstein1974; Flowers and O'Callaghan 1983).

Nitrogen mineralization is also influenced by soil type. Gordillo and Cabrera (1997) carried out an incubation assay for 140 days to study N mineralization of broiler litter applied to nine soils. There was a positive correlation between sand content and mineralization rate, whereas a negative correlation was observed with slit and clay content.

Temperature is also important in N mineralization. Stark (1996) observed that a maximal nitrification rate occurs between 30-35 C, whereas the optimal range was between 20 and 25 C (Grundman et al. 1995). The effects of moisture and temperature on N mineralization were evaluated for three poultry manures (Sims 1986), and the results showed that temperature generally accelerated N mineralization.

Cropping systems also influence the rate at which manure is mineralized. Two different systems: a rotation (maize-maize-soybean- wheat) fertilized with manure and with cover crops were compared to a maize monoculture fertilized conventionally (Sanchez et al. 2001). At 70 and 150 days of laboratory incubation, net N mineralized was 90 and 40%, respectively, greater for the rotation system, compared to the monoculture. This indicates that, there are other factors beside temperature, moisture and soil characteristics that highly influence manure N mineralization rate, such as substrate from residue incorporation.

Several studies have evaluated N mineralization rates of various animal manures and, a broad range of values are reported. Bitzer and Sims (1988) found that N mineralization from 20 different types of poultry manure averaged 66% of organic N over a 140-d incubation but rates varied widely among manures. Chai and Tabatai (1986) and Castellanos and Pratt (1981) found rates varying from 57% of organic N for chicken manure, to only 17% for dairy manure. Chai and Tabatai (1986) obtained similar values in a 26-week laboratory incubation, with chicken manure mineralizing 53%, compared to 31% for horse manure. Approximately 45% of N in poultry manure is released, compared with 18% for beef manure (Schmitt et al.1999).

Fescue N uptake was also used to study N availability from manure, compost manure, and plant residue compost; the values were 11%, 6%, and 2% of total N, respectively (Hartz et al. 2000). Enghball and Power (1999) evaluated the effects of P and N from manure and compost application on corn yield in a four year study. They reported that biannual manure or compost applications resulted in similar grain yields as annual application, but increased available P in the soil. Estimated N availability was 40% for manure and 15% for compost in the first year and was 18% for manure and 8% for compost in the second year after application.

Because many factors are involved in N mineralization, the estimation of nutrient availability from organic sources needs to consider crop nutrient requirements, type of soil and environmental conditions. It is also important to consider methodology, as improved prediction tools can help to better understand N dynamics in soil for the best N management decision.

N use studies

The most frequent method of estimating N availability from an organic source is carried out under controlled conditions in laboratory by incubating a soil amendment mixture and determining the quantity of inorganic N produced. This method does not simulate field conditions where there is a great variation of temperature and moisture content. However, it does provide a consistent basis for relative comparison. Methods carried out under field conditions are more representative because they integrate realistic soil and climatic conditions. Field methods are frequently based on yield and/or plant N uptake and have the advantage in that they integrate soil and climatic conditions for a given crop. The most commonly used method is the apparent N recovery or difference method: N released from manure or fertilizer is estimated by difference method, measuring N crop uptake from the soil with manure/or fertilizer and the control without any N input as:

% Apparent N recovery= ((N uptake in manured or fertilized soils-N uptake from the control)/ amount of total N in manure or fertilizer))*100   (1)

This method assumes that mineralization, immobilization and, other N transformations are the same for both fertilized and unfertilized soils (Westerman and Kurtz 1974). This assumption does not always hold because soil microbial activity may be enhanced under organic amended soil, increasing the N mineralization rate.

A more precise method involves the introduction of a labeled ^{15}N input, such as fertilizer, manure or cover crop, and calculates the labeled N budget (Stevenson 1982). A labeled N source indicates how the labeled N interacts with the system by tracing its fate throughout the system. The tracer method is more accurate but more expensive (Stevenson 1982). Net recovery by using ^{15}N is calculated as follows (Hauck and Bremner 1976):

Percent recovery of ^{15}N= 100 *p*(c-b)/f *(a-b)   (2)

Where "p" is total N uptake (kg ha-1), "f" is enriched N fertilizer applied (kg ha^{-1}) and "a", "b", and "c" are atom percent ^{15}N in fertilizer, in plants grown with unlabelled fertilizer, and in plants grown with labeled fertilizer, respectively.

Comparisons between ^{15}N method and the difference method for estimating N recovery efficiency (RE) have been done (Westerman and Kurtz 1974; Olson and Swallow 1984; Rao et al., 1991). These authors reported that estimated RE is often higher using the difference method than the ^{15}N method. This may be caused by the priming effect of fertilizer application, which stimulates soil N mineralization (Westerman and Kurtz 1973). Apparent and net recovery methods are important tools to understand N dynamic by evaluating N recovered in plants. However, it is also useful to assess the fate of N in soil or lost to the system. Understanding the dynamic of nitrate during a growing season is needed to quantify N supply capacity from different N sources.

Methods for monitoring soil NO_3^--N pool

A method which allows measurement of plant available NO_3^--N will help to minimize environmental concerns of NO_3^--N. It also helps us to understand nitrate-N dynamics and synchronize nutrient release with plant uptake. It is possible to follow the dynamic of NO_3^--N availability by using anion exchange membranes (AEM), which act as ion exchangers. The membranes are charged by the addition of a counter ion, such as chloride (Cl^-). If the membrane is placed into a concentrated solution of NO_3^--N , the Cl^- will be exchanged.

Use of anion exchange allows an integrated approach to monitoring nitrate-N. Soil extraction techniques by contrast, provide a short-term measure of soil NO_3^--

N content, which can fluctuate widely within a few days. Nitrate held on the membranes should reflect NO_3^--N available by diffusion that is not removed by microbes or displaced by other anions. This provides an estimate of the quantity of NO_3^--N that is available to plants and/or susceptible to leaching.

Paré et al. (1995) compared soil nitrate extracted by 2M KCl to that adsorbed on an anion exchange membrane in situ from a soil amended with manure or inorganic N fertilizer. The Authors showed that NO_3^--N extracted by both methods was greater with the inorganic fertilizer treatment than with the manure or the control treatments throughout the growing season. The NO_3^--N concentrations measured by both methods were correlated with r of 0.78. In a study by Collins and Derek (1999), anion exchange membranes were found to provide a positive correlation between NO_3^--N and N application rate and between NO_3^--N and yields.

Ion exchange resins or membranes are increasingly used for measurement of potential N supply in soil. For example, Qian and Schoenau (1995) and Friedel et al. (2000) used AEM in an incubation system to assess N mineralization in Western Canadian soils. These Authors found that nitrate supply rate measured by AEM after two weeks of incubation was more closely correlated with plant N uptake than nitrate measured by a conventional incubation assay. Because of intimate contact and short diffusion paths, N mineralized from organic compounds are readily adsorbed by the AEM, thus processes like nitrification, accumulation, immobilization, or losses of mineralized N are prevented (Friedel et al. (2000).

By using AEM, it is possible to monitor nitrate-N dynamics after incorporation of cover crop and manure. This may help to manage N fertility for combinations of organic input and fertilizer

Organic matter fractions

Organic matter (OM) in soil can be divided into two categories: plant debris at different stages of decomposition and organic matter adsorbed on mineral surfaces. In many studies, these categories are often referred to as the light and heavy fractions respectively (Theodoru 1990). Light fractions of OM are in an intermediate state of decomposition between fresh plant tissues and stable soil organic matter. Organic matter in the light fraction decomposes quickly whereas that in the heavier fraction decomposes more slowly.

Light fraction content is frequently used as an indicator of soil quality and N availability. The light fraction and macro organic matter are mainly plant and microbial residues, in various stages of decomposition. These pools are significant for soil C and N dynamics, because they serve as a readily decomposable substrate for soil microorganisms and as a short-term pool for plant nutrients. The light fraction usually represents 0.1 to 4% of the total weight of cultivated topsoil, is highly enriched with C and N; up to15 times more C and 10 times more N percent concentration than whole soil (Janzen et al. 1992).

The soil light fraction content has been found to be a sensitive indicator of cropping systems and organic input effects on the soil organic matter quality. In a study of long-term crop rotations, Janzen et al. (1992) found that the light fraction content was generally greatest in treatments with continuous cropping or perennial forages and lowest in those with high frequency of summer fallow. Janzen (1987) observed that light fraction content was inversely proportional to the frequency of summer fallow in various spring wheat rotations. Wander and Traina (1993) compared three different systems; organic cover cropped rotation, conventional and, organic manure amended. The organic cover cropped rotation had a larger percentage and proportion of C and N in its light fraction than others soils studied.

The weight of light fraction of OM has been found to be strongly related to soil microbial respiration, carbon biomass and potential N mineralization (Janzen et al. 1992; N'Dayegamiye et al. 1997). Light fractions of OM are associated with a large portion of the microbial population and the soil enzyme and carbohydrate contents (Janzen et al. 1992). Cover crops or green manures may strongly stimulate soil microorganisms and thus increase the light fractions and labile N, which is related to N availability to crops (Liang et al. 1999).

N use efficiency on potatoes

Efficient use of N in agricultural production systems can be viewed from agronomic, economic and environmental perspectives (Westerman 1988). A potato is a high N demanding crop; although the exact amount of N required depends on yield goal, potato variety, climate, soil, and irrigation systems. Because higher potato yields are associated with relatively higher N fertilizer rates, growers tend to increase the N rate applied (Vitosh 1990). Over fertilization with nitrogen results in high residual N at the end of the season and can cause tuber quality problem. Inorganic N is susceptible to be lost either below root zone or into the atmosphere. The total amount of N applied as well as its partitioning during the season affects tuber quantity and tuber quality. Excessive N delays tuber growth (Westerman and Kleinkopf 1985), increases yield of non marketable tubers (Errebhi et al. 1998) and decreases specific gravity, an important tuber quality factor.

To minimize N losses and to ensure high N use efficiency in potatoes it is recommended to supply N in synchrony with plant demand (Snapp et al. 2002). N efficiency has been found to be increased by splitting N fertilization to multiple applications (Snapp et al. 2002, Vos 1999, Lauer 1985, Roberts et al. 1982, Stark et al. 1993, Ojala et al. 1990). High N demand corresponds to plant growth stages of tuber initiation and tuber bulking (Vitosh et al. 1997). These authors reported that 35-45% of total nitrogen uptake occurred between early tuber initiation and tuberization, whereas 30-40% of total N uptake corresponded to the moment of enlargement of tubers.

To avoid over fertilization, it is important to take into account N credits supplied by sources others than mineral fertilizer (Snap et al. 2002, Vitosh et al 1990). These N sources include N from irrigation water, legumes, cover crops, as well as N mineralized from the soil. For example, alfalfa may supply 89-112 kg ha^{-1} of N credits at 60-100% stand (Vitosh et al. 1990).

In the present study, N use on potatoes was assessed by monitoring total N budget of labeled N fertilizer; by partitioning into soil, plant and nitrate N pools in the profile. Cover crops and manure were integrated in the system to reduce mineral N fertilizer need, enhance yields and system sustainability.

The overall objective of this study was to increase the understanding of N dynamics in potatoes amended with cover crops and manure. In order to reduce leaching, N rate was maintained at recommended level and cover crop and manure were integrated into the system.

The specific objectives were; i) to calculate fertilizer, manure and cover crops N recovery and efficiency; ii) to evaluate the benefits of manure and cover crops on potato yields, quality and N dynamic; iii) to determine N budget; iv) to assess the influence of cover crops and manure on soil quality through changes in light fraction.

Hypotheses are:

1. Cover crops and manure will increase soil available N, potato yield and nutrient uptake.

2. The combination of manure and cover crops will result in lower nitrate leaching potential.

3. Organic fertilizer sources will enhance the soil labile (light fraction) organic matter more than mineral fertilizer will.

REFERENCES CITED

Abdallahi, M.M., and N'Dayegamiye, A. 2000. Effets de deux incorporations d'engrais verts sur le rendement et la nutrition en azote du blé (*Triticum estivum L.*), ainsi que sur les propriétés physiques et biologiques du sol. Can.J.Soil Sci. 80: 81-89.

Angle, T.S., C.M. Cross, R.L. Hill, and M.S. McInosh. 1993. Soil nitrate concentrations under corn as affected by tillage, manure, and fertilizer applications. J.Env.Qual. 22:141-147.

Baker, J.L., and H.P. Johson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Env.Qual. 10:519-522.

Bending, D.G., and M.K. Turner. 1999. Interactions of biochemical quality and particle size of crop residues and its effect on the microbial biomass and nitrogen dynamics following incorporation into soil. Biol. Fertil.Soils. 29:319-327.

Bickert, W.G. 2002. The paradigm shift: changing the viewpoints and approach to manure management. Michigan State University Extension. In service training: Manure management: new and emerging technologies. November 12&13, 2002.

Bitzer, C.C., and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field analysis. J.Environ.Qual. 17:47-54.

Blumenthal, J.M., D.D. Baltensperger, K.G. Cassman, S.C. Mason, and A.D. Paulista. 2001. Importance and effect of nitrogen on crop quality and health. p. 45-63. *In* Follett and Hatfield (eds). Nitrogen in the environment: sources, problems, and management. Elsevier. Amsterdam.

Bolton, H., L.F. Elliot, R.L. Papendick, and D.F. Bezdicek. 1985. Soil microbial biomass and selected soil enzyme activities: effect of fertilization and cropping practices. Soil Biochem. 17: 297-302.

Castellanos, J.Z., and P.F. Pratt. 1981. Mineralization of manure nitrogen-correlation with laboratory indexes. Soil Sci.Soc.Amer.J.45:354-357.

Chai, Y.M., and M.A. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. J. Environ.Qual.15:193-198.

Collins, S.A.., and W.A. Derek. 1999. Use of anion exchange membranes to assess nitrogen needs of perennial grasslands. Commun. Soil Sci. Plant Anal. 30 (15&16):2267-2282.

Dawson, M.A., and K.A. Kelling. 2002. Use of manure in potato production. Wisconsin's annual potato meeting 2002. Volume 15.

Eghball, B., and J.F. Power. 1999. Phosphorus and nitrogen based manure and compost application: corn production and soil phosphorus. Soil Sci. Soc.Am.J. 63:895-901.

Eneji, A.E., T. Honna, S. Yamamoto, T. Saito, and T. Masuda. 2002. Nitrogen transformation in four Japanese soils following manure and urea amendment. Commun. Soil Sci. Plant Anal. 33:53-56.

Errhebhi, M., C.J. Rosen, S.C. Gupta, and D.E. Birong. 1998. Potato yield response and nitrate leaching as influenced by nitrogen management. Agron. J. 90: 10-15.

Flowers, R.H., and J.R. O'Callaghan. 1983. Nitrification in soils incubated with pig slurry or ammonium sulphate. Soil Biol. Biochem. 15:37-342.

Friedel, J. K., A. Herrmann, and M. Kleber. 2000. Ion exchange resin-soil mixtures as a tool in net nitrogen mineralization studies. Soil Biol. Biochem. 32:1529-1536.

Gast, R.G., W.W. Nelson, and G.W. Randall. 1978. Nitrate accumulation in soils and loss in tile drainage following nitrogen applications to continuous corn. J.Env.Qual.7:258-261.

Gordillo, R.M., and, M.L. Cabrera. 1997. Mineralizable nitrogen in broiler litter. II. Effect of selected soil characteristics. J. Environ. Qual. 26:1679-1686.

Griffin, T.S., and, C.W. Honeycutt. 2000. Using growing degree-days to predict nitrogen availability from livestock manures. Soil Sci. Soc. Am. J. 64:1876-1882.

Grundman, G.L., P. Renault, L. Rosso, and, R. Bardin. 1995. Differential effects of soil water content and temperature on nitrification and aeration. Soil Sci. Soc. Am.J. 59:1342-1349.

Hartz, T.K., J.P. Mitchell, and C. Giannini. 2000. Nitrogen mineralization dynamics of manures and composts. HortScience, vol. 35(2):209-212.

Hauck, R.D., and J.M. Bremner. 1976. Use of tracers for soil and fertilizer nitrogen research. *In* Brady (Ed.). Adv. Agron. 28: 219-266.

Janzen, H.H. 1987. Soil organic matter characteristics after long term cropping to various spring wheat rotations. Can.J. soil Sci. 67:845-856.

Janzen, H.H., C.A.Campbell, S.A. Brandt, G. LaFond, and Townley-Smith L. 1992. Light-fraction organic matter in soils from long-term crop rotations. Soil Sci.Soc. Am.J. 56:1799-1806.

Jensen, B., P. Sorennsen, I.K. Thomsen, E.S. Jensen, and B.T. Christensen. 1999. Availability of nitrogen in ^{15}N-labeled ruminant manure components to successively grown crops. Soil Sci.Soc.Am.J. 63:416-423.

Kirchner, M.J., A.G. Wollum II, and L.D. King. 1993. Soil microbial populations and activities in reduced chemical input agro ecosystems soils. Soil Sci. Soc.Am.J. 57:1289-1295.

Kitchen, N.R., and K.W.T. Goulding. 2001. On farm technologies and practices to improve nitrogen use efficiency. p. 335- 369. *In* Follet and Hatfield. Nitrogen in the environment: sources, problems, and management. Elsevier. Amsterdam.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. Soil Sci. Soc. Am.J. 61:145-152.

Lauer, D.A. 1985. Nitrogen uptake patterns of potatoes with high frequency sprinkler applied N fertilizer. Agron. J. 77:193-197.

Liang , B. C., A.F. Mackenzie, and E.G. Gregorich. 1999. Changes in ^{15}N abundance and amounts of biologically active soil nitrogen. Biol. Fert. Soils 30: 69-74.

Malpassi, R.N., T.C Kaspar, T.B. Parkin, C.A. Cambardella, and N.A. Nubel. 2000. Oat and rye root decomposition effects of nitrogen dynamics in an on-farm study. Soil Sci. Am. J. 64:208-215.

McCraken, D.V., M.S. Smith, J.H. Grove, C.T. MacKown, and R.L. Blevins. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Sci. Soc. Am.J. 58:1476-1483.

Meisinger, J.J., W.L. Hargrove, R.L. Mikkelson, J.R. Williams, and V.W. Benson. 1991. Effects of cover crop on groundwater quality: 57-68. *In* W.L. Hargrove (ed.). Cover crops for clean water. Soil water conserv. Soc., Ankeny, IA.

Muller, M.M. and V. Sundman. 1998. The fate of nitrogen (^{15}N) released from different plant materials to spring wheat production. Agron. J. 85:305-309.

Mutch, D. R., and T. E. Martin. 2000. Cover crops. 44-53. *In* Michigan field crop ecology. Michigan State University. Extension bulletin. E- 2646.

N'Dayegamiye, A., and T. S. Tran. 2001. Effects of green manures on soil organic matter and wheat yields and N nutrition. Can. J. Soil Sci. 81:371-382.

N'Dayegamiye, A., R. Royer, and P. Audesse, 1997. Nitrogen mineralization and availability in manure composts from Quebec biological farm. Can.J.Soil Sci. 77 : 345-350.

Ojala, J.C., J.C. Stark, and G.E. Kleinkopf. 1990. Influence of irrigation and nitrogen management on potato yield and quality. Am.Pot.J. 67:29-43.

Olson, R.V., and C.W.Swallow.1984. Fate of labeled nitrogen applied to winter wheat for five years. Soil Sci.Soc.Am.J. 48:583-586.

Ordan, D., R.R. Bruce, and D.C. Coleman. 1996. Nitrogen availability to grain sorghum from organic and inorganic sources on sandy and clay soil surfaces in a greenhouse pot study. Biol. and fertil.Soils 21:271-276.

Paré, J.F., and R.I.Papendick. 1978. Factors affecting the decomposition of crop residues by microorganisms. p. 109-129. *In* W.R. Oschwald (ed). Crop residue management systems. ASA, Madison, WI.

Paré, T., E.G. Gregorich, and B.H. Ellert. 1995. Comparisons of soil nitrate extracted by potassium chloride and adsorbed on an ion exchange membrane in situ. Commun. Soil Sci.Plant Anal. 26 (5&6), 883-898.

Power, J.F., and J.W. Doran. 1988. Role of crop residue management in nitrogen cycling and use. p.103-113. *In* W.L. Hargrove et al.(ed). Cropping strategies for efficient use of water and nitrogen. ASA Spec.Publ. 51. ASA,CSSA, and SSSA. Madison, WI.

Qian, P., and J.J. Schoenau. 1995. Assessing nitrogen mineralization from organic matter using anion exchange membranes. Fert. Res. 40: 143-148.

Rajendra, P., and J.F. Power. 1997. Soil fertility management for sustainable agriculture. Lewis Publishers.

Rao, A.C.S., Smith, J.L. Papendick, R.I, and J.F Parr. 1991. Influence of added nitrogen interactions in estimating recovery efficiency of labeled nitrogen. Soil Sci. Soc.Am.J. 55:1616-1621.

Roberts, S., W.H. Weaver, and J.P. Phelps. 1982. Effect of rate and time of fertilization on nitrogen and yield of Russet Burbank potatoes under center pivot irrigation. Americ. Potat. J. 59: 77-86.

Saini, G.R., and W.J. Grant. 1980. Long-term effects of intensive cultivation on soil quality in the potato-growing areas of New Brunswick (Canada) and Maine (USA). Can. J. Soil Sci.60: 421-428.

Sainju, U.M., and B.P Singh. 1997. Winter cover crops for sustainable agricultural systems: influence on soils properties, water quality and crop yields. Hort Science 2:21-28.

Sanchez, J.E., T.C. Wilson, K. Kizilkaya, E. Parker, and R.R. Harwood. 2001. Enhancing the mineralizable nitrogen pool through substrate diversity in long term cropping systems. Soil Sci.Soc.Am.J.65:1442-1447.

Schmitt, M.A., M. Russelle, G.W Randall, and J.A. Lory. 1999. Manure nitrogen crediting and management in the USA: Survey of University and Faculty. J. Prod. Agric. 12:419-422.

Scow, K., K.M. Somasco, O. Gunapala, N. Lau, S. Venette, R. Ferris, H. Miller, and R. C. Shennan. 1994. Transition from conventional to low-input agriculture changes in soil fertility and biology. California agriculture 48:20-26.

Sikora, L.J., and N.K. Enkiri. 2000. Efficiency of compost fertilizer blends compared with fertilizer alone. Soil Science. Vol. 165:444-451.

Sims, J.T. 1986. Nitrogen transformation in a poultry manure amended soil: temperature and moisture effects. J. Environ.Qual. 15:59-63.

Snapp, S., D. Smucker, and M. Vitosh. 2002. Nitrogen management for Michigan potatoes. Michigan State University Extension. Extension Bulletin. E-2779.

Stanford G., and E. Epstein. 1974. Nitrogen mineralization and water relationships in soils. Soil Sci. Soc. Am.J. 38:103-106.

Stark, 1996. Modeling the temperature response of nitrification. Biogeochemistry 35: 433-445.

Stevenson, F.J. 1982. Nitrogen in agricultural systems. Madison, Wisconsin.

Stevenson, F.J. 1999. Cycles of soil, carbon, nitrogen, phosphorus, sulfur, micronutrients. New York, Wiley.

Theodoru, C. 1990. Nitrogen transformations in particle size fractions from a second pine forest soil. Commun. in Soil Sci.Plant. Anal. 21:407-413.

Tisdale, S.L., W.L. Nelson, J.D. Beaton. 1985. Soil Fertility and Fertilizers. McMillan publishing company. New York.

Upendra, M. Sainju, B. P. Singh, and W. F. Whitehead. 1998. Cover crop root distribution and its effects on soil nitrogen cycling. Agron.J. 90:511-518.

Vitosh, M.L. 1990. Potato Fertilizer Recommendations. Michigan State University. Extension bulletin E-2220.

Vitosh, M.L., E.A. Paul, R.R. Hardwood, and D.R. Smucker. 1997. Nitrogen stewardship practices to reduce nitrate leaching and sustain profitability in an irrigated potato production system. *In* R.Chase (Ed.). Michigan Potato Research Report Vol. 29, MSU and MPIC, Dewitt, Mich., pp. 66-80.

Vos, J. 1999. Split nitrogen application in potato: effects on accumulation of nitrogen and dry matter in the crop and on the soil nitrogen budget. J. Agric.Sci. 133:263-274.

Wagger, M. G., D.E. Kissel, and S.J. Smith. 1998. Time of dessication effects on plants composition and subsequent nitrogen release from several winter annual cover crops. Agron. J. 81:236-241.

Wander, M.M., and S.J. Traina. 1993. Organic matter fractions from organically and conventionally managed soils: I. Carbon and nitrogen distribution. Soil Sci. Soc.Am.J. 60: 1081-1087.

Westerman, D.T., and, G.E. Kleinkopf. 1985. Nitrogen requirements of potatoes. Agron. J. 77: 616-621.

Westerman, R.L. 1988. Efficient nitrogen fertilization in agricultural productions systems. p.137-151. *In* Fairchild M.D. Ground water quality and agricultural practices. Lewis Publishers, Inc. Michigan.

Westerman, R.L., and L.T. Kurtz. 1973. Priming effect of ^{15}N-labeled fertilizers on soil nitrogen in the field experiment. Soil nitrogen in the field experiment. Soils Sci.Soc. Am.Proc. 37:725-727.

Westerman, R.L., and. L.T Kurtz. 1974. Isotopic and non isotopic estimation of fertilizer and nitrogen uptake by sudan grass in field experiments. Soil Sci. Soc Am.Proc. 38:107-109.

Williams, A.E,, L.J. Lund, J.A. Johnson, and Z.J. Kabala. 1998. Natural and anthropogenic nitrate contamination of groundwater in a rural community, California. Environ.Sci.Technol. 1998. 32:32-39.

Chapter 2. Benefits of a mixture of winter legume and cereal cover crops on biomass harvested, N incorporated and on yield of the succeeding potato (*Solanum tuberosum L.*)

ABSTRACT

Integration of organic sources such as cover crops will allow decreased amounts of fertilizer to be used and will improve soil conditions in potato systems. Potato response to cover crops and N fertilizer was assessed by monitoring total yield and marketable yield. Winter cover crops constituted of rye (*Secale cereale*) cover (67.2 kg seed ha^{-1}), a mixture of rye-hairy vetch (*Vicia villosa*) at a rate of 67.2 and, 11.2 kg ha^{-1}, respectively were compared to a bare winter fallow. The study was carried out at three site-year combinations in Michigan: Montcalm Research Farm (MRF) in 2001 and 2002, and at Southwestern Michigan Research and Extension Center (SWMREC) in 2002. Fertilizer N was applied to potato at 224 kg ha^{-1}, and was split in three applications to minimize losses. Total N uptake by rye shoots was between 33 and 43 kg N ha^{-1} and between 53 and 101 kg N ha^{-1} for rye-hairy vetch mixture. The mixture of rye and hairy vetch significantly increased cover crop biomass and N uptake during 2002 at SWMREC and similar trend was observed at MRF. There was a trend toward total and potato marketable yields (US# 1) being increased in the following order: mix cover> rye> bare soil. On average, potato yield increases from rye and rye hairy-vetch mixture were 12% and 16%, respectively. Results indicate that repeated applications of cover crops could be

be

ch

IN

er

ar

ar

w

be

th

a

b

s

p

e

in

c

n

r

c

le

beneficial on potato farming systems and would help to reduce the amount of chemical fertilizer.

INTRODUCTION

Cover crops are defined as plants grown primarily to protect the soils from erosion and loss of residual nutrients though leaching and runoff. Cover crops are used for short-periods during rotations. Currently, winter season cover crops are used in temperate and subtropical zone cropping systems. In addition to winter cover crops, annual crops grown in summer such as cowpea and velvet bean are used as green manures. They are incorporated into soil at the end of the season to improve soils properties.

Effective winter cover crops should demonstrate rapid germination, aggressive, and extensive rooting systems (Sainju et al. 1998). Rye, hairy vetch, barley and crimson clover were found by Creamer and Bennett (1997) to be suitable, because of their competiveness, quick establishment and their possibility to produce adequate biomass when mixed. Although grasses are effective catch crops in regard to nitrogen (N), their wide C:N ratio may result in immobilization of nitrogen, increasing the fertilizer N requirement of following crops (Sustainable Agriculture Network 1998). Legumes cover crops can supply more N than grasses to a following crop (Amado et al. 1998), but typically recover only 20 to 30% of the mass of N recovered by grass or brassica cover crops (Shipley et al. 1992). It is therefore possible to combine benefits offered by legumes with those offered by grasses by combining them in a mixed culture.

Several studies have reported that a mixture of legume and cereal cover crops increased biomass and recovered N (Odhiambo and Bomke 2001,Clark et al. 1994, Holderbaum et al.1990). One reason may be that N fixation by legumes may benefit grasses through transfer of N to the plant by roots (Griller et al. 1991). Another explanation is that, grasses scavenge more N than legumes, and this would favor a rapid depletion of N in soil, increasing legume biological N fixation (Ofori and Stern 1987). The mutual advantage of mixing grass and legumes, is related to their quality.

Carbon and N play an important role in the regulation of soil biological activity and hence nutrient cycling. These parameters are related to cover crops quality when assessing their N availability. Cereals tend to have a wide C:N ratio with respect to legumes. The C:N ratios of 10 to 20 have been reported in legumes monoculture in the southeastern USA (Hargrove 1986, Wagger 1989, Clark et al.1994). In contrast, rye has been shown to have a high C:N ratio (>20) with the risk of N immobilization. For instance, Rosecrance et al. (2000) studied N mineralization from hairy vetch and rye cover crop monoculture and bicultures. Net N mineralization was observed in vetch and rye-vetch, while net N immobilization was observed in rye. Also, Wagger (1989) examined nitrogen release from crimson clover, hairy vetch and rye cover crops. In that study 75 to 80% of N in hairy vetch and crimson clover residue was released, compared with 50% from rye residues after eight weeks of dessication. A mixture of cereal and legume may increase decomposition rate of a grass while moderating the more rapid N mineralization of a legume (Rannels and Wagger 1997).

In order to recommend cover crops to growers as a standard practice, it needs to be evaluated from the economic standpoint (Reeves 1994). Increasing soil productivity by using cover crops needs to be well investigated. Rye has been shown to decrease corn yield (Johnson et al. 1998, Kessavalou and Walters 1997). The explanations behind are that rye may deplete or immobilize soil N causing early season N stress in corn, rye may use too much water in spring (Munawar 1990), or rye residues may cause allelopathic phytotoxicity (Kessavalou and Walters 1997, Shilling et al. 1986). The negative effects of rye may be reduced by application of fertilizer N. Reductions in corn yields were found when N fertilizer was not applied, and this was not observed when N fertilizer was applied, suggesting N deficiency caused by the immobilization of inorganic N during decomposition (Ebelhar and Blevins 1984, and Blevins et al. 1990). The age of the rye crop at the time of its incorporation in spring may play an important role in determining the degree of its phyotototoxicity to corn (Kessavalou and Walters 1997). Also, the lag time between incorporation of cover crop and planting play an important role. Corn yield increased when rye was incorporated two weeks before corn planting, as opposed to rye incorporated just before corn planting (Raimbault et al. 1990).

Conflicting response of potato yield on legume green manures have also been observed. Odland and Sheehan (1957) obtained 13% increase in total tuber yield following red clover, Emmond and Ledingham (1972) obtained a 25% yield increase following sweetclover and Griffin and Hesterman (1991) did not observe yield benefits because of asynchrony of crop demand and N supplied by legumes. Weinert et al. (2002) assessed N availability from different green manures to potato grown three weeks after incorporation of cover crops. They observed increases of soil NH_4^+ and NO_3^--N following cover crops and this increased N availability to the potato crop. Also Porter et al. (1999) compared different soil managements: green manure constituted by hairy vetch and pea versus oat, in potatoes systems. They did not observe any significant effect of green manure rotation on yields or tuber quality, compared with the oat rotation. They concluded that benefits on crop growth and yield from the rotation crop, in this case from a green manure, may be manifested only after more growing seasons or at lower rates of N fertilization.

Cover crop effects on crop yield could also be attributed to the non-nitrogen effects (Abdallahi and N'Dayegamiye 2000 ; N'Dayegamiye and Tran 2001). The non-nitrogen effects mainly refer to the improved soil physical properties primarily due to the production of biomass which serves as the source of soil organic matter and substrate for soil biological activity. It is well established that cover crops can maintain or increase soil C and N (Hargrove 1986; McVay et al. 1989). Cover crops frequently result in greater infiltration of water, due to direct effects of the residue coverage or to changes in aggregation and formation of macro pores by roots.

In this study, potato yield response to rye and to a mixture of rye-hairy vetch has been examined. A bare soil was maintained during winter in order to assess apparent increase in yield from each cover. The study was carried out in Montcalm Research Farm (MRF), Enrtican, Michigan, during two years (2001 and 2002) and in Southwest Michigan Research and Extension Center (SWMREC), near Benton Harbor during 2002.

MATERIALS AND METHODS

Site and soil description

Two sites were used to assess potato yield response to cover crops: Montcalm Research Farm (MRF) in Entrican , Michigan (43°20'; 85 01') and Southwest Michigan Research and Extension Center (SWMREC) near Benton Harbor (42.0841, -86.3570). The soil was well drained in both sites with a loamy sandy at SWMREC and sandy loam at MRF. The soil at MRF was Montcalm/MCBride loamy sand (coarse-loamy, mixed, frigid alfic fragiorthods) with 1% of organic carbon. Soil texture was constituted by 84%, 11%, 5% of sand,slit, and clay, respectively (Snapp and Fortuna 2003). At SWMREC the soil was an Oakville fine sand (mixed, mesic typic udipsaments) transition to loamy sand with 1.16% of organic carbon. Soil texture at SWMREC was 88.59%, 5.42%, 5.61% of sand, silt and clay respectively.

Variety and fertilization

Cover crops were grown in 2001 and 2002 in MRF and in SWMREC in 2002. On both sites, three winter managements were compared in four replicates: a bare soil, a rye cover crop and rye-hairy vetch mixture.

The potato cultivar used was the chip processing standard Snowde*n*. Seeds pieces (56 g) were planted in early May at 30.5 cm within row and 86 cm between rows. N fertilizer was applied at 224 N kg ha^{-1} in three splits as recommended by Michigan State University. One third was applied at planting, another at hilling, and the last at tuberization. Potassium (0-0-60) and phosphorus (19-17-0) were applied at 201.6 K_2O and 37.6 P_2O_5 kg ha^{-1}, respectively before planting. Supplemental overhead irrigation was used and pest and weed control measures were applied as standard practice. Two rows were harvested and tubers graded for US#1 category.

Analytical methods.

Soil analysis

Surface soil (0-15 cm) was sampled before potato seeding and fertilizer application. The soil pH was measured in water (1:1). Total N was extracted by Kjeldhal digestion (Bremner and Mulvaney 1982) and mineral N was extracted in a 1N KCl solution (Bremner 1965), and measured calorimetrically on ion chromatography (OI analytical flow solution IV). Organic C was determined by the modified Walkley-Black procedure (Nelson and Sommners 1982). Soil texture was determined by hydrometer (Bouyoucos 1962).

Plant sampling and analysis

Rye or hairy vetch were seeded in fall and the seeding rates were 67.2, or 11.2 kg ha^{-1}, respectively. Before incorporating cover crops, in early April, two sub samples were taken in 0.25 m^2 area to determine dry matter and total nitrogen. Thereafter, cover crops were ploughed down by chisel. Plant materials were dried at 70 C, weighed to determine dry matter, and finely ground to pass a 1mm mesh for N analysis by Kjeldhal. (Bremner and Mulvaney 1982).

Experimental design and statistical analysis

In both sites and years, the experimental design was a randomized complete block design with four replications with a total of 12 plots. The plot sizes were 5.5 x 15.25 m.

All data were subjected to analysis of variance (one way ANOVA) to test for main effects. The SAS GLM procedure was used for analysis.

RESULTS AND DISCUSSION

The mean low and high monthly air temperatures and total precipitation recorded for the growing season of 2001 and 2002 are presented for both sites (Figure 2.1). The two sites had similar temperatures regimes but rainfall tended to be lower at SWMREC than at MRF during 2002.

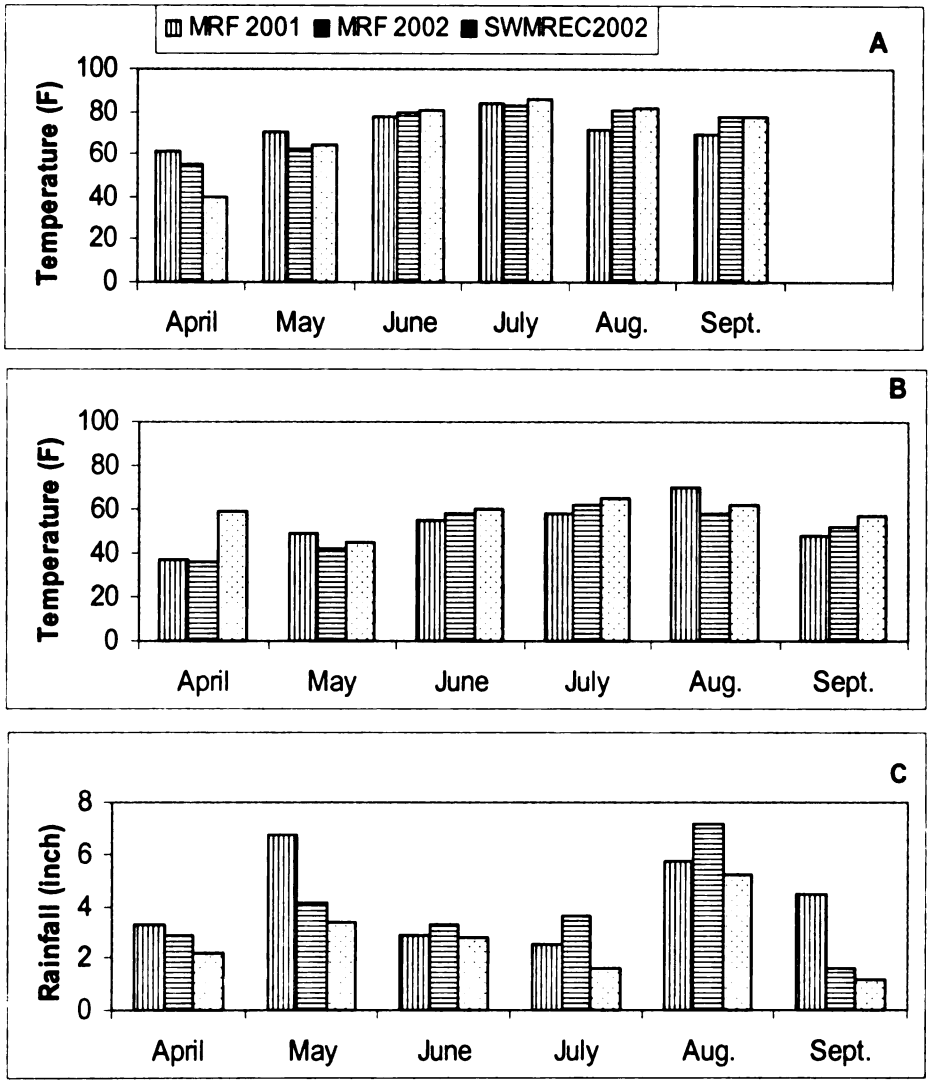


Figure 2.1.High (A), low (B) monthly temperatures and total monthly precipitation (C) at Montcalm Research Farm in 2001 and 2002 (MRF 2001 and MRF2002) and Southwestern Michigan Research and Extension Center in 2002 (SWMREC 2002).

Cover crops yields and N Content

Cover crop dry matter and N content for the two sites are presented in figure 2.2. Dry matter ranged between 1.5 to 2.1 ton ha^{-1} for rye and between 2.3 to 3.9 ton ha^{-1} for rye-hairy vetch mixture. Total N uptake for rye varied from 33.4 to 43.5 and from 53.7 to 101.7 kg N ha^{-1} for rye- hairy vetch mixture.

The dry matter and N recovered in cover crops produced in SWMREC during 2002 for rye and rye hairy vetch mixture was greater than that produced in MRF (Figure 2.2). This is probably due to differences in soil type and/or climate The SWMREC site is warmer in the early spring compared to the MRF site. This trend is similar to that obtained by Weinert et al. (2002) in central Washington. These Authors conducted a two-year study to identify winter cover crops for recovering N and to determine N uptake by a succeeding potato. The first year, the study was conducted in the Southern end of the state and during the second year in the Northern end. At spring incorporation, dry matter and shoot N in rye was 4600 kg ha^{-1} and 133 kg N ha^{-1} in the Southern end respectively, whereas it was greatly reduced at 2100 kg ha^{-1} and 60 kg N ha^{-1} in the Northern end. During the exponential growth period of early spring, cover crop biomass is greatly influenced by degree days which tend to be higher at Southern site in Michigan or Washington

In our study, the mixture produced greater biomass and greater N uptake, compared to rye alone (Table 2.1

The high productivity of mixing a legume with a cereal has been reported by others Authors (Odhiambo and Bomke 2001; Clark et al. 1997; Holderbaum et al.1990). Over the long term, the legume benefits a grass during spring by increasing the N concentration of the mixture by biological N fixation and by minimizing the potential for short term N immobilization (Rannels and Wagger, 1997). Hairy vetch has complementary root and shoot growth habit to an erect cereal which minimizes competition.

The shoot N amount recovered in our study, was close to that found by Shipley et al. (1992) in Maryland: in mid April, rye recovered 48 kg N ha^{-1}. Hairy vetch and rye mixture has been estimated to be equivalent to N fertilizer credit before corn of 56 to 112 kg ha^{-1}(Sustainable Agriculture Network 1998). Clark et al. (1994) reported N accumulation in rye of 51 kg N ha^{-1} in Maryland, even though, the N in vetch-rye mixture were very high compared to our finding (144-203 kg ha^{-1}). The high N content for the mixture in their study may be due to the high seeding rate of hairy vetch used (28 and 47 kg ha^{-1}) for vetch and rye, respectively. Also the difference in climate conditions may be a cause, as Maryland climate is warmer in the spring than Michigan.

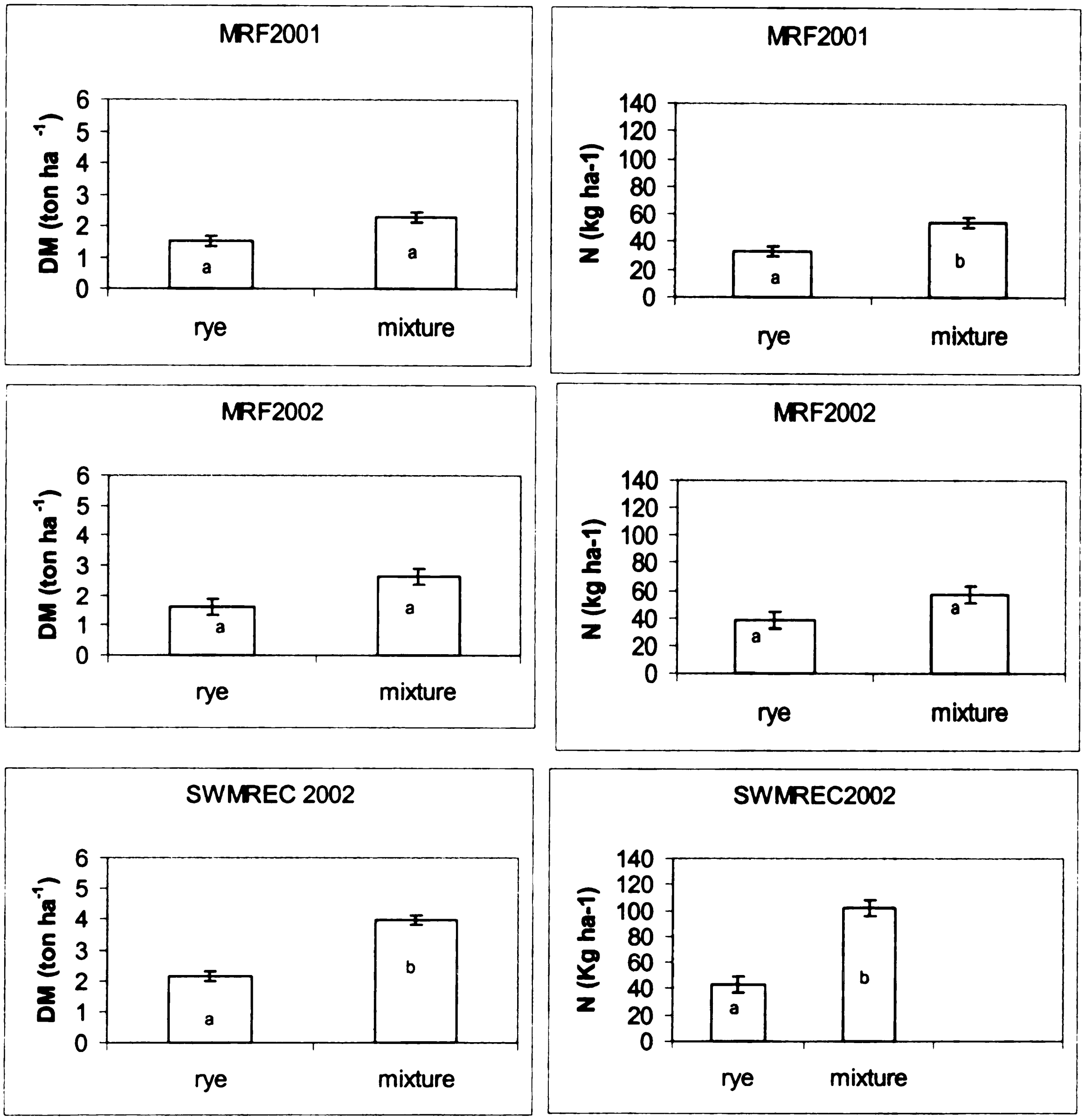


Figure 2.2. Dry matter and nitrogen recovered for rye and rye-hairy vetch mixture in Montcalm Research Farm in 2001 and 2002 (MRF 2001 and MRF 2002, respectively) and in South Western Michigan Research and Extension Center in 2002 (SWMREC 2002). Lsmeans are reported and bars represent standard errors. Lsmeans with different letters are different at P<0.05.

Table 2.1 Analysis of variance (p value) of dry matter biomass and nitrogen content at Montcalm Research farm in 2001 and 2002 (MRF 2001 and 2002, respectively) and at South Western Michigan Research and Extension Center (SWMREC 2002)

		Dry matter (t ha^{-1})			N uptake in cover crops (kg ha^{-1})		
		MRF 2001	MRF2002	SWMREC2002	MRF2001	MRF2002	SWMREC2002
Source of variation	df						
Block	3	0.631NS	0.9395NS	1225NS	0.6362NS	0.8897NS	0.1147 NS
Treatment (cover)	1	0.0738NS	0.0701NS	0.0034 **	0.0558*	0.1132NS	0.0070 **
Contrast							
Rye vs mixt		0.0738NS	0.0701NS	0.0034**	0.0558*	0.1132NS	0.0070**

NS, *,**, : not significant and significant at P<0.05, and, P<0.01 respectively.

Total and marketable potato yields.

Total and marketable potato yields are presented in table 2.2. Total yield ranged from 31 to 33, from 34 to 37, and from 36 to 39 t ha^{-1} for bare soil, rye and, rye plus hairy vetch, respectively (Table 2.2). Marketable tubers yield (US#1) represented 83, 85 and 88% of the total tuber yield for bare soil, rye and hairy vetch, respectively. Depending on the year and site, total potato yield increases for rye and rye-hairy vetch mixture represented on average 12 and 16%, respectively. The same trend was observed for the US#1 category. Overall a consistent, though non significant trend was observed, as tuber yield was in the following order at all site-year combinations: mixed cover> rye> bare soil.

As was observed in several other studies, the mixture of cover crops offered an advantage to the rye alone. However, the benefit depends on seeding rate. Clark et al. (1994) studied different mixture rates for rye and hairy vetch. Cover crops were incorporated in early April and early May, followed by no-till corn without fertilizer N. Within each kill-date, corn yield was greatest following vetch, least following rye, and intermediate following all mixtures. Corn yield following legume-wheat mixture was intermediate to that of pure stands, possibly due to N immobilization by the wheat component (Holderbaum et al. 1990).

Decreased yield of corn after a rye cover has been observed (Amado et al. 1998; Johnson et al. 1998; Tollenaar et al. 1993) and is possibly due to allelopathic effects or N immobilization. However, that was not observed in this study. Nitrogen immobilization and allelopathic effects are influenced by incorporation date of cover crops (Kessavalou and Walters 1997). In our study, the planting date was carried out after almost four weeks of incorporation of cover crop, which allowed net N mineralization.

Even though potato yield increases reported in this study are not statistically significant at $P<0.05$, results suggest the potential for improvements in potato yields, even though the amounts of cover crop biomass were relatively limited as these are established in late fall, after crop harvest. Repeated applications of higher amount of cover crops biomass should produce significant increases of crop yields. Shephered (1999) reported potato yield increases of 7% over seven years when cover crops were incorporated.

Several studies reported yield increases when organic sources were applied alone or in combination with fertilizer (Bhandari et al. 2002; Gami et al. 2001; Yacoob and Blair 1980; Abdallahi and N'Dayegamiye 2000; N'Dayegamiye and Tran 2001). Positive crop yields were attributed to large amount of biomass incorporated and increased nutrient availability (Bhandari et al. 2002; Gami et al. 2001 and Hattab et al. 1998), and/or improved soil physical and biological properties (Yaacob and Blair 1980; Abdallahi and N'Dayegamiye 2000). The trend towards increased potato yields with cover crops may also be due to the synchronization of nutrients released with plant uptake (Snapp and Fortuna 2003).

Table 2.2. Total and marketable potato yields (US#1) at Montcalm Research Farm in 2001 and 2002 (MRF 2001 and 2002, respectively) and at South Western Michigan Research and Extension Center in 2002 (SMWREC 2002)

Treatments	Total yield (t ha^{-1})			Marketable yield (t ha^{-1})		
	MRF2001	MRF2002	SWMREC2002	MRF2001	MRF2002	SWMREC2002
Bare	33.7	32.6	31.4	29.3	26.7	25
rye	37.5	37.5	34.8	32.6	32.7	28.5
mixt	39.2	38.2	36.5	34.1	34.7	32.1

Analysis of variance Pr>F

Source of variation	df	Total yield	Marketable yield
Block	3	0.3642NS	0.4008 NS
Site-year (S)	2	0.7348NS	0.5750NS
Treatment (T)	2	0.2723NS	0.1887NS
S*T	4	0.9999NS	0.9945NS

NS: not significant at P< 0.05. Least squares means are reported

CON

comp

0.10

mark

obse

and

Repe

the s

effec

leac

CONCLUSION

Mixed cover crops produced consistently higher biomass and N uptake, compared to a pure stand of rye at SWMREC. A similar significant trend ($p < 0.10$) was observed at MRF during 2001 and 2002. Total potato tuber yield and marketable yield increases were not significant, but a consistent trend was observed in the following order: bare< rye< mixture. Compared to a bare soil, rye and rye-hairy vetch mixture increased yield by 12 and 16%, respectively. Repeated cover crop applications in crop rotation may be necessary to increase the soil productivity. Future research is needed to better understand synergistic effects between cover crops and fertilizer in increasing yield, decreasing NO_3^--N leaching, and increasing N use efficiency.

REFERENCES CITED

Abdallahi, M.M., and A. N'Dayegamiye. 2000. Effets de deux incorporations d'engrais verts sur le rendement et la nutrition en azote du blé (*Triticum aestivum*) ainsi que sur les propriétés physiques et pédologiques du sol. Can.J. Soil Sci. 80:81-89.

Amado, T.J.C., S.B. Fernandez, and J. Mielniczuk. 1998. Nitrogen availability as affected by ten years of cover crop and tillage systems in southern Brazil. J. Soil Water Cons. 53: 268-271.

Bandari, A.L., J.K. Ladha, H. Pathak, A.T. Padre, D. Dawe, and R.K. Gupta. 2002. Yield and soil nutrient changes in a long-term rice-wheat rotation in India. Soil Sci.Soc.Am.J. 66: 162-170.

Blevins, R.L., J.H. Herbek, and W.W. Frye. 1990. Legume cover crop as nitrogen sources for no till corn and grain sorghum. Agron. J. 82:769-772.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analyses of soil. Agron. J. 54: 464-465.

Bremner, J.M. 1965. Inorganic form of nitrogen. p.1179-1237. *In* Black et al. (eds). Methods of soil analysis. Part 2. Agronomy n 9. ASA. Madison Wisconsin.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-total. *In* Methods of soil analysis. Part 2. Chemical and microbiological properties. ASA-SSSA. Madison Wisconsin.

Clark, A.J., A.N. Decker, and J.J. Meisinger. 1994. Seeding rate and kill date effects on hairy vetch cereal rye cover crop mixtures for corn production. Agron. J. 86: 1065-1070.

Creamer, N.G., M.A. Bennett, B.R. Stinner 1997. Evaluation of cover crop mixture for use in vegetable production systems. Hort. Sci. 32:866-870.

Ebhelar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no tillage corn. Agron. J 76: 51-55.

Emmonds, G.S., and R.J. Ledingham. 1972. Effects of crop rotation on some soil-borne pathogens of potato. Can. J. Plant Sci. 52: 605-611.

Gami, S.K., J.K. Ladha, H. Athak, M.P. Shah, E. Pasuquin, S.P. Pandey, P.R. Hobs, D. Joshy, and D.R. Mishra. 2001. Long-term changes in yield and soil fertility in a twenty-year rice-wheat experiment in Nepal. Biol. Fertil. Soils 34: 73-78.

Griffin, T.S., and O.B. Hesterman. 1991. Potato response to legume and fertilizer nitrogen sources. Agron. J. 83: 1004-1012.

Griller, K.E., J. Ormesher, and F.M. Awah. 1991. Nitrogen transfer from *phaseolus* bean to intercropped maize measured using ^{15}N enriched and ^{15}N isotope dilution methods. Soil Biol. Biochem.23:339-346.

Hargrove, W.L. 1986. Winter legumes as nitrogen source for no till grain sorghum. Agron. J. 78: 70-74.

Holderbaum, J.F., A.M. Decker, J.J. Meisinger, F.R. Multord, and L.R. Vough 1990. Fall-seeded legume cover crops for no-tillage corn in the humid East. Agron. J. 82: 117-124.

Johnson, T.J., T.C. Kasper, K.A. Kohler, S.J. Corak, and S.D.Logsdon. 1998. Oat and rye over seeded into soybean as fall cover crops in the upper Midwest. J. Soil Water Cons. 53: 276-279.

Kessavalou, A., and D. Walters. 1997. Winter rye as cover crop following soybean under conservation tillage. Agron. J. 89: 68-74.

McVay, K.A., D.E. Radcliffe, and W.L. Hargove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Sci. Soc. Am. J. 53: 1856-1862.

Munawar, A., R.L., Blevins, W.W. Frye, and M.R. Saul. 1990. Tillage and cover crop management for soil and water conservation. Agron. J. 82:773-777.

N'Dayegamiye, A., and T.S. Tran. 2001. Effects of green manures on soil organic matter and wheat yields and N nutrition. Can. J. Soil Sci.81: 371-382.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. Page et al.(Eds). Methods of soil analysis. Part 2, 2^{d} ed. Agronomy 9:539-579.

Odhiambo, J.J.O., and A. Bomke. 2001. Grass and legume cover crop effects on dry matter and nitrogen accumulation. Agron. J. 93:299-307.

Odland, T.E., and J.E. Sheehan. 1957. The effect of redtop and red clover on yields of following crops of potatoes. Am. Potato J. 34: 282-284.

Ofori, C.F., and W.R. Stern. 1987. Cereal- legume intercropping systems. Adv. Agron.26:177-204.

Porter, G.a., G.B. Opena, W.B. Bradburry, J.C. MacBurnie, and J.A. Sisson. 1999. Soil management and supplemental irrigation effects on potato: I. Soil properties, tuber yield and quality. Agron. J. 91: 416-425.

Raimbault, B.A., T.J. Vyn, and M.Tolenaar. 1990. Corn response to rye cover crop management and spring tillage systems. Agron. J. 82: 1088-1093.

Rannels, N.N., and M.G. Wagger. 1997. Nitrogen ^{15}N recovery and release by rye and crimson clover cover crops. Soil Sci.Soc.Am.J. 61: 943-948.

Reeves, D.W. 1994. cover crops and rotations. p.137-172. *In* Crop residues management, Hatfield and Stewart (eds). Advances in Soil Science. Lewis publishers.

Rosecrance, R.C., G.W. McCarty, D.R. Shelton, and J.R. Teasdale. 2000. Denitrification and N mineralization from hairy vetch and rye cover crop monocultures and bicultures. Plant and soil. 227:283-290.

Sainju, U.M., B.P. Singh, and W.F. Whitehead. 1998. Cover crop root distribution and its effects on soil nitrogen cycling. Agron. J. 90: 511-518.

Shephered. 1999. The effectiveness of cover crops during eight years of a UK sandland rotation. Soil use and management 15: 41-48.

Shilling, D.G., L.A. Jones, A.D. Worsham, C.E. Parker, and R.F. Wilson. 1986. Isolation and identification of some phytotoxic compounds from acqueous extracts of rye. J. Agric.Food chem. 34:633-638.

Shipley, P.R., J.J. Meisinger, and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops Agron. J. 84: 869-876.

Snapp, S., and A. Fortuna. 2003. Predicting nitrogen availability in irrigated potato systems. HortTechnology In press.

Sustainable Agriculture Network. 1998. Managing Cover Crops Profitability. Second Edition. Beltsville. pp. 212.

Tollenaar, M.M., M. Mihajlovic, and T.J. Vyn. 1993. Corn growth following cover crops: influence of cereal cultivar, cereal removal and nitrogen rate. Agron. J. 85:251-255.

Wagger, M.G. 1989a. Cover crop management and nitrogen rate in relation to growth and yield of no-till corn. Agron. J. 81:533-538.

Weinert, T.L., W.L. Pan, R.M. Moneymaker, G.S. Santo, and R.G. Stevens. 2002. Nitrogen recycling by nonleguminous winter cover crops to reduce leaching in potato rotations. Agron. J. 94: 365-372.

Yaacob, O., and G.J. Blair. 1980. Mineralization of ^{15}N-labelled legume residues in soils with different nitrogen contents and its uptake by Rhodes grasses. Plant and Soil 57: 237-24

Chapter 3. Potato (*Solanum tuberosum L.)* response to manure and cover crops: N use efficiency and N budget by using ^{15}N

Abstract

Cover crops and manure have several benefits when combined with fertilizer. They can help to improve soil properties over the long-term and they can also increase yield. We investigated potato response to manure and cover crop in two studies: a field experiment was conducted in parallel with a container study by using the same soil.

Field experiment: in the field experiment, three winter management strategies were compared: a bare soil, rye, and a mixture of rye and hairy vetch. In addition, manure was applied in a split plot design to study cover crop and manure interaction. Potato tuber yield and quality were assessed comparing different soil managements. Manure combined with rye-hairy vetch mixture increased yield by 18%. Total yield and marketable yield ranged in the following order: rye-hairy vetch mixture> rye> bare. Rye and manure tended to slightly increase scab disease, but not significantly.

Container experiment: the same soils from the field experiment were used in 75 containers. The objectives were to assess : i) nitrogen use efficiency and apparent nitrogen recovery of cover crop, manure, and fertilizer; ii) N partitioning in different pools following ^{15}N label; iii) nitrate released during the growing season by using anion exchange membranes; iv) changes in soil labile organic matter by determining light fraction. Four treatments were compared alone or in combination with fertilizer: soil without any amendment (bare), soil with

incorporated rye cover crops (rye), soil with incorporated manure (manure) and combined effect of rye and manure (rye+manure). The combination of rye and manure produced the highest yield and a very similar trend was observed for nutrient uptake. Apparent N recovery in tubers from rye, manure and fertilizer was 27%, 5%, and 30% respectively. Rye had the highest N use efficiency compared to fertilizer and manure. Total net N recovery by use of ^{15}N ranged from 71 to 76% with main allocations in tubers. Rye application increased significantly N content in the light fraction of the soil organic matter. NO_3^--N adsorbed by the anion exchange membranes (AEM) showed a similar pattern as yield and nutrient uptake, in this order: rye+manure>manure>rye>bare. Rye was associated with the increase of NO_3^--N released toward the end of the season.

Introduction

Nitrogen (N) from soil, fertilizer and manure sources is inefficiently used in most crop production systems (Burkart and Stoner 2001). Applying more N than is needed for optimum yield greatly increases the potential for losses from the crop-soil systems. N leached or lost in subsurface soil has been found to increase with increasing rate applied N (Angle et al. 1993).

Nitrogen use efficiency may be increased by minimizing losses and by maximizing use of available N (Kitchen and Goulding 2001). Research has shown that N efficiency can be enhanced in potatoes systems when N was applied in multiple splits (Vos 1999; Lauer 1985; Roberts et al. 1982; Stark et al. 1993; Ojala et al. 1990). However some authors did not find any effect of splitting (Joern and Vitosh 1995, Li et al 2003, Erhebhi et al. 1998). An important means to improve N efficiency and enhance potato systems sustainability is to use organic sources such as cover crops and manure to supply N and to enhance soil quality.

The influence of cover crops and manure amendment on yields and soils depends on their quantity and quality. Increases in yield were observed in potatoes following legume cover crop (Odland and Sheehan 1957; Emmond and Ledingham 1972). But Griffin and Hesterman (1991) did not observe any increase. Moreover, rye cover crop has been reported to decrease yield in some cases (Johnson et al. 1998; Kessavalou and Walters 1997). Negative effects of rye may be due to N immobilization (Ebhelhar et al. 1984; Blevins et al. 1990) or to phytotoxicity (Kessavalou and Walters 1997).

An additional difficulty with organic amendment is the potential for asynchrony between N released with plant uptake. To achieve maximum crop yield and to avoid environmental concerns, N needs to be available during high plant nutrient demand periods. Cover crops that have high C:N ratio frequently release N late in the season (Malpassi et al. 2000), or may not be available until subsequent year (Karlen and Doran 1991). Dynamics of N mineralization from two manures and N uptake for two crops (Maize and Wheat) were assessed by use of a simulation model (Pang and Letey 2000). These authors reported that N mineralization and corn N uptake curves did not match well. A synchrony study by Snapp and Fortuna (2003) showed that, potato N uptake demand and organic N supply could be highly synchronized if a mixed quality of organic input (manure and cover crop) was used, while seasonal temperature and soil temperature had minimal effects.

To optimize the use of organic sources in cropping systems, and to achieve maximum crop yields, combined mineral fertilizer with organic sources may be effective at reducing N immobilization from cover crops, with high C/N. Combining application of manure and fertilizer enhanced nutrient uptake in potato (Hattab et al. 1998). Even though there are not many studies, which assessed combined effects of organics sources and inorganic sources, N use efficiency by using fertilizer in potatoes has been studied by several authors.

Saffigna et al. (1977) reported N uptake on potatoes to be between 120 and 145 kg N ha^{-1} in Wisconsin. Some studies confirm that N efficiency depend on N fertilizer rate. Tyler et al. (1983) used ^{15}N depleted fertilizer and found N uptake efficiency to be 57% with 200 kg N ha^{-1} applied, but only 39% with 270 kg N ha^{-1}. However, Lauer et al. (1985) reported high recovery even at high rate; at maximum total uptake, N in tubers was 72% and 77% of 300 and 200 kg N ha^{-1} respectively. During a two year period, Tran and Giroux (1991) assessed N efficiency, using ^{15}N labeled fertilizer and found that foliage recovered 14-20 % and 12-14 % during the first and second year respectively, whereas tubers recovered 43-47% and 36-50% during first and second year respectively. Applying 336 kg N ha^{-1} to potato, Roberts et al. (1991) reported maximum N recoveries in the whole plant to be between 61-67% of ^{15}N-labelled fertilizer. Maidl et al. (2002) reported fertilizer N recovery in plant (tubers and foliage) to be between 35.9 and 68.5%, with the main fraction in tubers.

Cover crops and manure positively affect crop yields over the long-term by improving soil properties (structure, biological activities and organic matter). Porter et al. (1999) observed an increase in soil C and total aggregation in potato cropping systems after a single large application of compost or manure. Other research has indicated that soil organic matter and fertility can be enhanced by manure applications (Khaleel et al. 1981; Magdoff and Amadon 1980; N'Dayegamiye and Cote 1989; Gao and Chang 1996; Sommerfeldt and Chang 1985). Soil carbon is also increased by cover crop incorporation (Kuo et al. 1997a). Because organic sources provide a substrate, they have been frequently shown to stimulate soil microbial activity (Kirchner et al. 1993; Mullen et al. 1998). Moreover, cover crops have been found to increase the readily decomposable fraction of organic matter, the so-called "light fraction" (Kuo et al. 1997a; Miller et al. 1978; Abdallahi and N'Dayegamiye 2000). This active fraction of OM is an important N source for subsequent crops. Manure and cover crops frequently increase yield and improve soil properties, especially when combined with inorganic fertilizer.

A major limitation in using manure is the slow release of N from organic forms that need to be mineralized. Tyson and Cabrera (1993) reported values of N mineralization in broiler litter ranging between 0.4 to 5.8% of total N mineralized in composted materials compared with values ranging from 25.4 to 39.8% for uncomposted material. A slow N mineralization rate in composted manure was confirmed by other authors (Eghball 2000; Paul and Beauchamp 1994; Preusch et al. 2002). Low N availability from composted material reflects the loss of easily convertible N compounds during composting and the presence of stable N compounds (Eghball 2000). Nitrogen release from cover crops is also slow and depends on many interacting factors, such as temperature, moisture, type of residue; physical and chemical properties (Bending and Turner 1999; Ranells and Wagger 1997; Abdallahi and N'Dayegamiye 2000).

Disease such as common scab caused by *Streptomyces scabies* incidence is another potential problem associated with manure use. Contradictory findings exist about the increase of scab by manure application. Some authors reported that the disease increases only in sensitive varieties, or when manure is applied at high rate. In a trial evaluating crop rotation sequences of potato-snap bean-cucumber, Rotenberg and Cooperband (2002) assessed the effect of fresh and composted paper mill residues on the severity of common scab on potato. Scab disease was greatest for tubers grown in soil amended with the high rate of paper mill residues. Dawson and Kelling (2002) examined the effect of moderate (10,000 gal $acre^{-1}$) and high dairy manure application rate (20,000gal $acre^{-1}$), compared to mineral fertilizer (nitrogen or phosphate) applied at several rates. When manure was the primary source of N and P, higher tuber yields were found compared to fertilizer-derived nutrients. However, tuber solids were significantly lower when manure was applied and increased scab was observed at one of several sites. Effects of chicken, liquid swine and solid cattle manures on potato scab were studied by Conn and Lazarovits (1999) in Ontario. Generally, manure decreased scab disease over two years, although chicken manure was associated with scab incidence compared to an untreated plot.

There is no clear evidence that manure application increases common scab in potatoes, which appear to be influenced by multiple factors such as rate of manure applied, site characteristics and potato variety.

The main objective of this study was to increase our understanding on the effects of manure and/or cover crops on potato yield and quality. The specific objectives are to evaluate: i) nitrogen use efficiency and apparent nitrogen recovery of cover crop, manure and fertilizer; ii) N partitioning in different pools by using $^{15}NO_3{}^{15}NH_4$; iii) nitrate released from fertilizer, manure, and cover crop during the growing season by using anion exchange membranes; iv) changes in soil labile organic; v) potato yield and quality response to combined source of organic and nutrient sources.

MATERIALS AND METHODS.

MANURE PROPERTIES AND N MINERALIZATION

In order to account for manure credits, poultry manure was incubated as described by Hartz et al. (2000) with small modifications. In brief, poultry manure was mixed with sandy soil (1: 50 g/g) and the moisture content of the soil was adjusted at 12 %. The mix was incubated in plastic cup (specimen containers). The open containers were then put in a basin containing small amount of water. The basin was loosely closed by using transparent plastic sheet to allow gas exchange. The temperature of incubator was set at 25 C. After 0, 10, 30, 60, 90 and 120 days, NO_3-N was extracted using 1N KCl (Bremner 1965) and analyzed colorimetrically on ion chromatography (OI analytical flow solution IV). The poultry manure characteristics are presented in Table 3.2 and analysis were conducted on dry ashed sample by the Soil and Plant Nutrient Lab at Michigan State University. Organic C was carried out by using Leco carbon analyzer, K and Ca by fly flame photometer, and P and Mg were determined colorimetrically.

FIELD EXPERIMENT

The field experiment was conducted at Montcalm Research Farm (MRF) during 2002. Site and soil descriptions were presented in chapter 2. Three winter soil cover managements were compared; bare soil, rye cover crop and a mixture of rye and hairy vetch. In addition, manure was applied to half of each plot (5.4x15.2m) to study manure-cover crop interactions. All plots were fertilized as recommended and weed managements and irrigation were applied as needed, following Michigan State University recommendation. The experimental design was a split plot, randomized complete block design (RCBD) with four replications. The main factor was cover crop management and the sub factor was manure treatment. Before incorporating cover crops, sub samples were taken to determine cover crop dry matter and total nitrogen in a 0.25 m^2 area. Plant materials were dried at 70 C, weighed to determine dry matter, and finely ground to pass through 1mm mesh for N analysis by Kjeldhal.

Dry aged poultry manure at a rate of 5.6 t ha^{-1} and cover crops were incorporated by disking before planting. The potato cultivar planted was Snowden, tuber pieces of around 56 g sizes each were planted at a space of 30.5 cm. within row and 86 cm. between rows. Urea was the nitrogen fertilizer source applied in three splits for a total of 224 kg ha^{-1}, as recommended by Michigan State University (Snapp et al. 2002). One third was applied at planting, another at hilling and the last at tuberization. Source of potassium (0-0-60) and source of P (19-17-0) were applied at rates of 201.6 and 37.6 ha^{-1}, respectively before planting. Supplemental overhead irrigation was used and pest and weed control measures were applied as recommended. A two row harvester was used and tubers were graded for size classes, including US#1 category, internal and external defects as well as scab rating. Specific gravity was determined using a hydrometer with an 8 lb tuber sample.

CONTAINER EXPERIMENT

A similar study was conducted in a container experiment, to better monitor continuously the nitrate dynamics and to facilitate the application of ^{15}N in a limited area (see photo in appendix 7). The containers had a volume of 75 L, and were 58.4 cm tall, and 48.3 cm in diameter. The soils were collected from the topsoil of the field experiment described above at MRF. Four treatments were compared alone or in combination with fertilizer: a bare soil, a soil with incorporated rye, a manured soil and a soil with incorporated rye and manure. The experimental design was a randomized complete block design with four replications. The soil was sampled after manure and cover crops were incorporated, and then were mixed with perlite on a 50% volume based to redue soil compaction. Soils in the containers were left to mineralize over 10 days before planting.

The potato cultivar used was *"Atlantic"* and two seed pieces were planted and the more vigourous plant was left per container. The plants were watered as needed. To be able to measure soil moisture, four soil tensiometers were installed at two depths; two at 15 cm and two at 30 cm.

Fertilizer application

The objective of the study was to apply N at recommended rate by taking into account N credits supplied by manure and rye. Manure was applied at a rate of 5.6 t ha^{-1} (total N added = 250 kg). Manure was found to mineralize 15% of N after 60 days in incubation assay for 44.8 kg N ha^{-1}. From a previous study, rye was found to supply about 11.2 kg ha^{-1}. Taking into account all sources of nitrogen, the treatments were balanced in such a way to provide 224 kg ha^{-1} (table 3.1). N credits from manure and rye were substracted equally for all treatments.

Table 3.1. Balance of treatments in function of available N.

Treatments	Estimated N available ($kg\ ha^{-1}$) Organic source	N Added ($kg\ ha^{-1}$) Fertilizer	Total N ($kg\ ha^{-1}$)
bare	0	224	224
rye	11.2	212.8	224
Manure	44.8	179.2	224
Rye+manure	56	168	224

Estimated N available represented net N mineralization (treatment- bare soil)

Potassium and phosphorus fertilizers were applied as in the field. To avoid Ca deficiency in treatments without manure, a rate of 112 kg Ca ha^{-1} using $CASO_4.2H_2O$ was applied. Ammonium nitrate was used as the source of N at a rate of 224 kg ha^{-1}. As in field experiment, nitrogen fertilizer was split in three applications. Moreover, 15.2 N kg ha^{-1} was given as $^{15}NH_4{}^{15}NO_3$ at 99.9% enriched at tuber initiation. Labeled N was applied (30 days after planting) by diluting the required amount in 200 ml and sprayed uniformly to the soil surface by using a sprayer.

Nitrates dynamic

To follow dynamics of nitrate-N over time, anion exchange resin membranes (AEM) fixed into plastic probes (Plant Root Simulator (PRS ™), Western Ag. Innovations, Saskastoon) were used. For each container, two membranes were used; one membrane was inserted at the top of the container between 0-15 cm to monitor for nitrate released, and another one was inserted in the bottom of container (40-55 cm) to estimate N susceptible to leaching. The membrane in top was placed 2 cm from the container edge to avoid root competition. The one in bottom was inserted by creating a rectangular vertical slot in the container at 40 cm from the top of container. The membranes were attached to a wire to facilitate retrieval and to minimize soil disturbance. A tape was applied over the slot to facilitate good contact between the soil and the membranes. The membranes were changed every two weeks. The extraction and the membranes preparation were carried out by following the protocol from the supplier (http://www. Westernag.ca/innov). Membranes were charged by soaking them in 0.5 M sodium bicarbonate. This solution was changed four times at one hour intervals. The solution and membranes were slowly shaken at 100 rpm during that time. After that period, they were rinsed with ion free water before installation. After the burial period, membranes were cleaned under distilled water to ensure the complete removal of soil, then each membrane was placed in a zip bag and soaked in 0.5M HCl for one hour while shaking at 100 rpm. After the extraction, the extract was placed in vials for NO_3-N analysis. Analysis of NO_3^--N was carried out colorimatrically on ion chromatography (OI analytical flow solution IV). The ^{15}N content of the extract was analyzed by volatilizing the NO_3^--N and capturing the NH_3 on an acid trap using the methods developed by Brooks et al. (1989) and redescribed by Hart et al. (1994). Briefly 0.2 g of MgO was added in a specimen container containing NO_3^--N mixed with two acid washed glass beads. The solution was mixed to get MgO dispersed within the solution. The MgO makes the solution basic, causing NH_3 vapor to be released. To capture the gas, a filter disk was suspended on a wire inserted into the top of the container. The disc papers were previously acidified by using 10 μl of 2.5M K_2HSO_4. Nitrate in the extracts was reduced by 0.4 g of Devarda's alloy, and the resulting $NH4^+$ displaced to an acidified disc papers during incubation period of six days. After the incubation time, disk papers were dried over night in a desicator containing concentrated H_2SO_4. Finally, the disc papers were pushed into tin capsules by using a paper clip, and were sent to the University of California, Berkeley for ^{15}N analysis by mass spectrometry.

Harvest

Before harvesting, four random containers were selected for bulk density assessment; the cylinders used were 7.6x7.6 cm. An average was calculated. Fifteen small cores were taken in each container for chemical analysis including. (the soil OM, N, light fraction, N and C content in light fraction). In addition three cores were taken at three depths in each container (0-15, 15-30 and 30-45 cm), and composite by depth. They were immediately extracted with 1N KCl (Bremner 1965) to assess inorganic N (NO_3^--N and NH_4-N). Data were corrected for moisture content. Levels of NO_3^--N in membrane extracts and from soil KCl extracts were analyzed colorimetrically by using ion chromatography (OI analytical flow solution IV). For NH_4 analysis, samples were sent to Soil test laboratory of Michigan State University and were determined by using Lachat flow injection analyzer (FIA).

The harvest was carried out after 79 days (July 29, 2002) before the complete senescence of the shoot. Shoot were cut at the soil level, weighed and cut in small piece and dried at 70 C. To recover tubers and roots the soil in container was sieved. Tubers and roots were washed, and then weighed immediately. Tubers were cut and dried at 70 C. After drying, tubers, shoot, roots and soil were grinded to pass 100 mesh before analysis. The ^{15}N content of the biomass was analyzed by mass spectrometry at the University of California, Berkley.

Light fraction

To measure the light fraction of organic matter, 10 g of finely ground soil (<100 mesh) was suspended in 50 ml of NaI solution with a specific gravity of 1.59 g cm^{-3} (Janzen 1987; N'Dayegamiye et al. 1997). The suspension was centrifugated at 2500 rpm for 30 minutes. The supernatant was filtered through 0.45 μm filter under suction. The procedure was repeated another time to allow complete recovery of the light fraction. The material remaining on the filter is the light fraction, which was dried at 105 C, and weighed. Analysis of C and total N content were carried out by the Walkey-Black method (Nelson and Sommers 1982) and micro Kjeldhal digestion (Bremner and Mulvaney 1982) respectively.

The ^{15}N analysis in plant tissue, from membrane extract, and in the light fraction of OM was conducted at the University of California, Berkeley, on a mass spectrometer

Apparent and net N recovery calculation

Apparent N recovery, N use efficiency and nutrient uptake were calculated as follows:

Apparent N recovery for cover crop or manure = ((N uptake from treated plant- N uptake of control)/ total N applied))*100 (1)

N use efficiency= ((yield from treatment- yield from control)/ total N applied) (2)

Percent recovery of ^{15}N was calculated from the following equation (Hauck and Bremner 1976).

Percent recovery of ^{15}N= 100)*p*(c-b)/f *(a-b) (3)

Where"p" is total N uptake (kg ha^{-1}), "f" is enriched N fertilizer applied (kg ha^{-1}) and "a", "b", and "C" are atom percent ^{15}N in fertilizer, in plants grown with unlabelled fertilizer, and in plants grown with labeled fertilizer respectively.

Nitrogen derived from labeled fertilizer (Ndff) in different parts

A nitrogen budget was calculated by considering Ndff of the ^{15}N that is the percentage of nitrogen derived from labeled fertilizer.

%Ndff =100*(^{15}N excess in a sample (soil, plant tissues or NO_3 extract)/fertilizer ^{15}N excess (4)

This method allowed us to include ^{15}N recovered using anion exchange membranes. The nitrates adsorbed on anion exchanges membranes are expressed as μg cm-^{2} of membrane surface per unit burial time; there is no exact conversion per soil volume or per mass as the area absorbed from, cannot be calculated (Qian and Schoenau 2002). However, ^{15}N label of ion exchange membranes is a unique method of monitoring nitrate dynamics. A total of Ndff in nitrates adsorbed on anion exchange membranes was carried out by summing different values obtained at different sampling times over the growing season. Ndff partitioning was calculated for roots, tubers, soil, shoot and in nitrates extracted from the membranes during the growing season.

Experimental design and statistical analysis.

In the field experiment, a split plot, randomized complete block design (RCBD) was used with four replications. The main factor was cover crop managements and the sub factor was the presence or absence of a manure treatment. In the container experiment, a randomized complete block design was used, with two main factors and four replications. The first factor was fertilizer (yes or no) in combination with four different soil managements (bare, rye, manure and rye+manure). We performed analysis of variance for each data set using the SAS GLM procedure for the container experiment and the MIXED procedure for the field experiment. Nitrates released in the top soil and in the bottom soil of each container were monitored every 15 days, and were treated as repeated measurement of the corresponding experimental unit.

RESULTS AND DISCUSSIONS

ORGANIC INPUTS

Manure characteristics

Aged poultry manure had high total N levels and also contained other major nutrients such as P, K, Ca and Mg (Table 3.2). Mineral N contents (NH_4-N plus NO_3-N) represented 2.5% of total N, which indicates 97% of manure N was in organic form and has to be mineralized to be available to following crop. Aged poultry manure pH value in water was 8.9 and the organic C was 23.5%.

Table 3.2. Characteristics of aged poultry manure.

pH	8.95
Total N	50 g kg^{-1}
NO_3-N	148 mg kg^{-1}
NH_4-N	1144 mg kg^{-1}
Organic C	235 g kg^{-1}
Total P	1243 mg kg^{-1}
Total K	6275 mg kg^{-1}
Total Ca	6600 mg kg^{-1}
Total Mg	450 mg kg^{-1}

Available N was estimated by aerobic incubation over 120 days (Table 3.3). Mineralized N quantities increased linearly during the incubation period meaning that aged poultry manure contained labile N fractions as indicated by the low C:N ratio of 4.7. After 120 days of incubation, mineralized N was 23 % of total N (Table 3.3).

Table 3.3. Aged poultry manure aerobic assay and N mineralization at different periods.

Incubation period	N mineralized NO_3-N µg/g soil	Nmineralized (%)
0 day	4.89	------
10 days	30.72	3.07
40 days	63.75	6.37
60 days	53.63	5.36
120 days	83.16	8.36

Initial total N was 50 g kg^{-1} soil and the amount applied was 5.6 t $ha^{-1.}$ During the incubation 1mg N from manure was mixed with 1 gr soil.

FIELD EXPERIMENT

Potato yield, N uptake and tuber quality

Total potato yield without aged poultry manure varied from 33 to 38 t ha^{-1}, and ranged from 37 to 45 t ha^{-1} with aged poultry manure application (Table 3.4). On average marketable yield (US#1) represented 87% of total yield. Cover crops and manure application did not significantly affect total and marketable yield compared to the fertilized bare soil. However, manure application in combination with cover crops mixture increased total potato yields by 18%, compared to the control. The level of increase is large enough to benefit the farmer's profit margin (Labarta et al. 2002). There was a trend whereby rye and cover crops mixture slightly increased potato total yields compared to the fertilized bare, and yield tended to be higher for the mixture than for rye alone. Increased potato yield through application of manure alone or in combination with fertilizer has been reported previously (Antonious et al 2001, Sikora and Enkiri 2000, Dawson and Kelling (2002). These studies used relatively large amount of organic inputs: 10,000 to 20,000 gal acre^{-1} by Dawson and Kelling 2002, 50 t acre^{-1} by Antonious et al. (2001) and up to 25 Mg ha^{-1} by Sikora and Enkiri (2000). Hattab et al. (1998) observed large increases in rice yield and N uptake by using a small amount of N, 25% of organic N plus 75% of fertilizer.

Potato N uptake varied from 111 to 130 kg ha^{-1} (table 3.4). Although yield increase was on average 1.8 t with manure application, the increase in N uptake was only 3.4 kg. Nitrogen uptake efficiency has been observed to decrease with increased levels of N applied. Tyler et al. (1983) reported N uptake efficiency of white potato tubers in California to be about 57% at N rates up to about 200 kg N ha^{-1}, but only 39% at 270 kg N ha^{-1} rate. However, Lauer (1985) ; found high efficiency of 72% at a rate of 300 kg ha^{-1}.

If we consider the fertilized bare, soil which received 200 N lb acre^{-1}, the N uptake was near 50% (99 lb acre^{-1}) of applied N fertilizer. This value is intermediate compared to others. Errhebhi et al. (1998) found that, at a rate of 270 lb acre^{-1} " Russet Burbank" potato recovered 33% of applied N with heavy leaching and the recovery raised to 56% with few leaching. Our values (99 to 116 lb acre^{-1}) are also close to those found by Saffigna et al. (1977); in their study, tuber N uptake ranged from 120 to 145 kg N ha^{-1} in Wisconsin. Nitrogen uptake depends on many factors, such as variety, rate applied, application method and type of fertilizer used.

Table 3.4. Field experiment. Least square means (Lsmeans) and analysis of variance of potato total yield, marketable yield (US#1) and N uptake

	Total yield t ha^{-1}		US#1 t ha^{-1}		N uptake kg ha^{-1}	
	No manure	With manure	No manure	With manure	No manure	With manure
Bare	33.4	37.6	27.8	31.1	111.4	114.2
Rye	38.1	40.2	33.2	34.7	115.7	113.3
Mixture	38.2	45	34.7	34.5	116.4	130.4
ANOVA Pr>F						
Block	0.16 NS		0.27 NS		0.23 NS	
Cover crop	0.33 NS		0.28 NS		0.77 NS	
Manure	0.09 NS		0.18 NS		0.71 NS	
Cover*manure	0.68 NS		0.81 NS		0.86 NS	

NS: not significant at $P<0.05$.

Tubers health and quality

In the field experiment, tubers were graded for scab defects, in order to assess if manure application has increased scab rate. On average, the percentage of tubers with scab area greater than 50% (weight basis) was 18.7 % (table 3.5) indicating that scab is a problem at this site. However, manure and rye appeared to increase scab rate (Table 3.5). *Streptomyces scabies*, the causal agent of scab is generally enhanced by the decomposition of soil organic matter and increased pH. This may explain the slight increase of scab disease in the rye treatment and in the manure treatment.

The specific gravity was on average, 1.069, 1.071, 1.073 for bare, rye and rye-hairy vetch respectively (table 3.5). Also manure tended to increase specific gravity as well as mixed cover crops (Table 3.5). This is important as farmers are paid a premium by processors for high specific gravity potato tubers, which improves the chip product. Small increases were observed in this order: mixture > rye> bare. However, these values are slightly lower than the industry standard of 1.080 (personal communication D.S. Douches). In 2002, specific gravity levels were generally lower in Michigan, due to a higher than average temperature which increased tuber respiration and reduced starch accumulation.

Table 3.5.Least square mean (Lsmeans) and analysis of variance of specific gravity and scab rate.

	Scab rate		Specific gravity	
	With manure	No manure	With manure	No manure
Bare	25.1	11.2	1.069	1.069
Rye	21.4	27.1	1.074	1.069
Mixture	14.8	12.7	1.075	1.073
ANOVA Pr>F				
	df	Scab rate	Specific gravity	
Block	3	0.76 NS	0.36 NS	
Cover	2	0.23 NS	0.40 NS	
Manure	1	0.74 NS	0.62 NS	
Cover crop*manure	2	0.87 NS	0.54NS	
OVERALL LSMEANS				
	Scab rate		Specific gravity	
Bare	18.1		1.069	
Rye	24.5		1.072	
Mixture	13.7		1.074	
With manure	20.4		1.073	
No manure	17.0		1.070	

NS: not significant at $P<0.05$.

Scab rate was the percentage of tubers (weight basis) presenting > 50% of area with scab lesions.

CONTAINER EXPERIMENT

Potato yield and nutrient uptake

Potato tuber yield varied from 321 to 741g/plant in no N fertilized treatments (Figure 3.1). These values ranged from 766 to 1017g/plant when N fertilizer was applied (Figure 3.1). Potato yields were significantly increased by manure combined with rye cover crop without additional N fertilizer. This was was not apparent with additional fertilizer. Manure significantly increased yield with respect to a bare soil. Rye combined with manure alone produced as much as N fertilizer (224 kg ha^{-1}). This demonstrates the importance of organic sources in increasing yield. The combination of rye and manure produced the highest yield similar to the trend seen in the field experiment; there could be a number of reasons including effects on soil properties, or nutrient release in synchrony with crop demand.

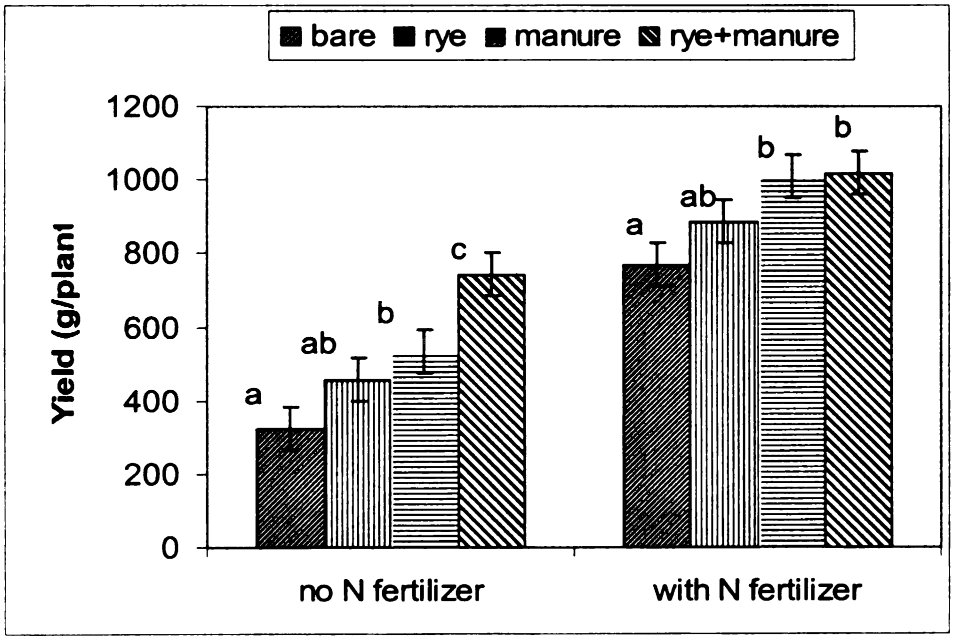


Figure 3.1. Container experiment. Potato yield. Least squares means ± standards errors. Treatments with different letters are statistically different at P< 0.05.

Potato N uptake response was similar to the pattern of response seen for potato tuber yield and fresh weight of different plant parts in term of the benefits of manure and rye, when these amendments were applied alone or in combination with fertilizer (Table 3.6 and Appendix 1). The biomass accumulated influenced uptake, as there were almost no difference observed in N concentration (Appendix 2). Rye plus manure significantly increased N uptake compared to manure, rye applied alone or a bare soil. The treatment effects were similar for other nutrients (K, P, Ca and Mg) uptake, where the highest nutrients uptake was associated with the highest potato tuber yield in the rye plus manure treatment (Table 3.6). Yield and nutrients uptake increases observed are due to several benefits offered by manure and cover crops. The non-N effects are showed by high P, K, Ca, and Mg uptake in the soil with rye cover crop compared to the bare soil. Rye tended to increase all nutrients uptake compared to a bare soil, which could be attributed to an improvement of soil physical and biological properties that have stimulated plant root growth and access to N and other nutrients.

Table 3.6. Least squares means (Lsmeans) and analysis of variance for potato nutrients uptake.

LSMEANS	Nutrients uptake (kg ha^{-1})				
Without fertilizer	N	P	K	Ca	Mg
Bare	21.8 a	9.9 a	89.9 a	15.2 a	8.5 a
Rye	32.4 ab	14.1 ab	135.6 ab	17.6 a	12.3 a
Manure	35.8 a	16.7 b	155.4 b	20.3 b	12.7 a
Rye+manure	57.8 b	22.5 c	241.9 c	34.9 b	18.7 b
With fertilizer					
Bare	89.6 a	23.1 a	1213.3 a	54.9 a	34.3 a
Rye	97.3 a	24.3 ab	233.5 a	59.9 ab	37.2 a
Manure	104.9 a	27.6 ab	267.5 ab	53.8 a	37.3 a
Rye+manure	101.8 a	29.5 b	308.1 b	64.4 b	40.7 b
Overall lsmeans					
Management effect					
Bare	55.7 a	16.5 a	151.6 a	35.0 a	21.4 a
Rye	64.8 ab	19.2 ab	184.5 ab	38.8 a	24.7 a
Manure	70.4 b	22.2 b	211.5 b	37.0 a	24.5 a
Rye+manure	79.7 b	26.0 c	274.9 c	49.3 b	29.7 b
Fertilizer effects					
With fertilizer	87.9 b	23.3 b	228.2 b	52.0 b	33.2 b
No fertilizer	32.9 a	14.1a	139.0 a	19.6 a	11.6 a
ANOVA (Pr>F)					
Block	0.56NS	0.6634 NS	0.4958 NS	0.3911NS	0.9122NS
Management (M)	0.0082**	0.0002 ***	0.0001***	0.0006***	0.0007***
Fertilizer (M)	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***
M x F	0.1915 NS	0.4002 NS	0.5954 NS	0.1924NS	0.6753 NS

Lsmeans with different letters within a group are statistically different at P< 0.05.

NS, *,**,***: non significant at P< 0.05, significant at P <0.05, P<0.01, and P<0.001 respectively.

Management is referred to the presence or absence of organic inputs (cover crop and/or manure).

Nitrogen partitioning by using ^{15}N

Nitrogen partitioning was evaluated for whole plants and in soil using ^{15}N (Table 3.7 and Figure 3.2). N recovery was high in shoot and tubers representing > 50%, and was low in roots (Table 3.7). N recovery in soil ranged from 16 to 21.5%. Total N recovery ranged from 71 to 76%. No significant effect of treatments was observed on total N recovered.

Table 3.7. N partitioning by using ^{15} N

LSMEANS	^{15}N recovery (%)			
	Soil	Roots	Shoot	Tubers
Bare	16.29	0.70	25.62	28.69a
Rye	16.32	0.58	26.59	31.30a
Manure	21.50	0.74	21.14	33.13a
Manure+rye	18.30	0.76	23.55	30.87a
ANOVA P>F				
Block	0.56 NS	0.35NS	0.07 NS	0.044*
Management	0.37NS	0.51NS	0.26NS	0.16 NS

NS, *: Not significant at P< 0.05, significant at P<0.05, respectively.

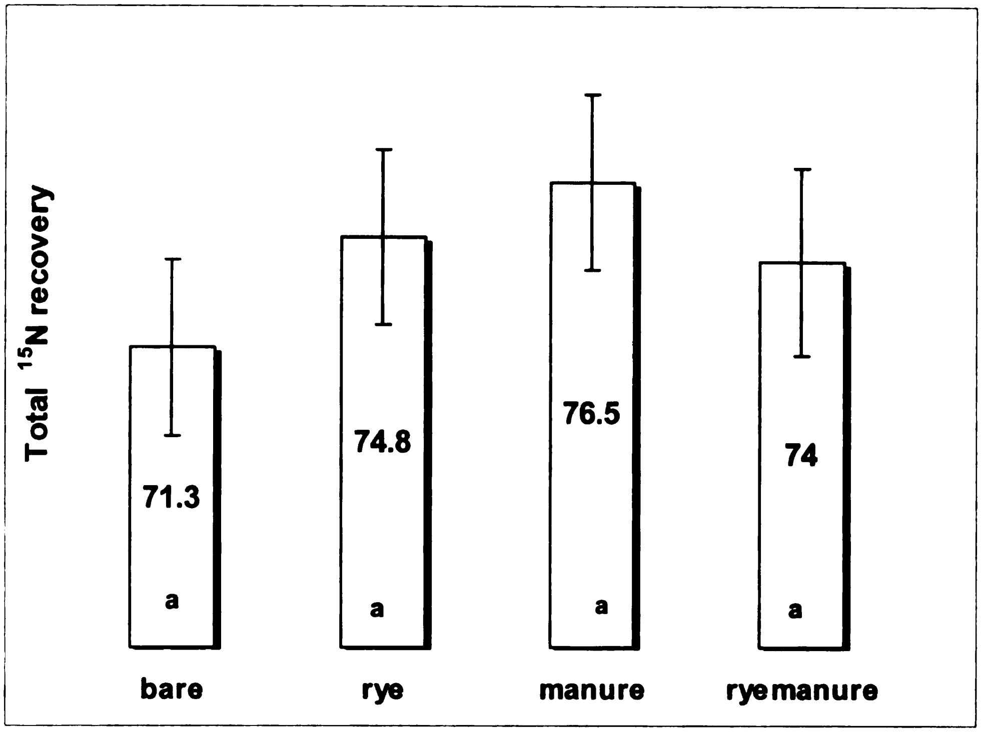


Figure 3.2. Total ^{15}N recovery (%) in plant and soil from ^{15}N labeled fertilizer applied 30 days after planting. Least squares means ± standard errors. Treatments with the same letters are not statistically different at P<0.05.

Nitrogen partitioning pattern observed for a ^{15}N labeled fertilizer, was high in shoot and tubers (50%) (Table 3.7), while N recovered in soil varied between 16 and 21%. On overall treatments, total N recovery ranged from 71 to 76% (Figure 3.2). These values are close to those found in a potato ^{15}N labeling experiment by Maidl et al. (2002), where total ^{15}N recovery ranged between 60 and 80%, N recovery in soil was between 19.5% and 24.6% and the main proportion of ^{15}N was found in tubers. Our data are also similar to those of Tran and Giroux (1991) where 12 to 20% of ^{15}N was recovered in the shoot and 36 to 50% in tubers. In our study, we harvested before the senescence and this may explain why N recovery in shoot was moderately high compared to Tran and

Giroux (1991). Roberts et al. (1991) found whole potato plant ^{15}N recovery ranging between 61 to 67%, with 42% to 54% in tubers. Slightly high values in the later study may be related to the high rate of N applied (336 kg N ha^{-1}).

Apparent N recovery in tubers and N use efficiency.

Apparent N recovery in tubers was in the following order: fertilizer (30%) > rye (27%) > manure (5%) (Appendix 3). N use efficiency by tubers was in this order: rye > fertilizer > manure (Appendix 3).

Apparent N recovery in tuber for N fertilizer (30%) is very close to the value obtained by using ^{15}N (28%). Several conditions such as the rate of N applied, climatic conditions, and the type of soil may influence N apparent recovery. For instance, Li et al. (2003), compared the effect of side dressed N versus split application on potatoes in Quebec. They found that apparent nitrogen recovery ranged between 29 and 70% depending on years and N rates.

Apparent N recovery of 27% for rye cover is similar to the findings by N'Dayegamiye and Tran (2001). In their study with five green manure species, N recoveries for the following wheat ranged between 19 and 36%. As for fertilizer, N recovery for cover crops is influenced by external factors such as crop grown, quality and quantity of residues, type of soil. For instance, Wagger et al. (1985) found that the proportion of ^{15}N from labeled sorghum residues (C/N ratio 25 to 38) recovered in the following crop was about 12% in a very sandy loam soil and 27% in a silt loam. Rye showed high N use efficiency compared to other treatments. This may be explained by the fact that rye cover provided low N; it is well known that N efficiency increases at lower levels of N inputs.

Apparent N recovery from manure was very low compared to the fertilizer and to the rye cover crop. However, nitrate membranes data showed that this treatment continuously released nitrate during the growing season, and was the treatment associated with the highest tuber yield and nutrient uptake. This apparent contradiction may be explained by the combined effects of high total N inputs in manure treatment and by the fact that most of N in manure was stabilized and mineralized slowly. It is well known that apparent N recovery calculations assume that immobilization-mineralization and other N transformations are the same for both treated and control plots, which was not the case in this experiment.

Light fraction dry matter, C and N contents

The light fraction ranged between 3.2 and 6.2 g kg^{-1} soil (Table 3.8). These values are similar to those reported by Janzen (1987) for a cropping system study, which were between 1.8 and 4.3 g kg^{-1} depending on rotations considered.

There was a trend towards increased C content of the light fraction of OM with rye and a significant increase in N content of the light fraction with rye application (Table 3.8). The high C and N contents in the light fraction associated with rye treatment are probably related to the amount and quality of organic residues applied (Janzen et al 1992). Light fraction is believed to consist primarily of incompletely decomposed organic matter of plant origin (Janzen 1987), but it also contains substantial amount of microbial biomass.

The amount of N present in the light fraction ranged from 11 to 24 mg kg^{-1} soil (Table 3.8). These values are lower in respect to those found by Janzen et al. (1987), which ranged from 29 to 72 depending on the treatments. Average N in light fraction was 1.69% in Janzen et al (1987) study, compared to values obtained in this study which ranged between 0.30 to 0.50% (data not shown).

Table 3.8. Least square means (lsmeans) and analysis of variance of light fraction drymatter, C, and N contents

lsmeans	LF g kg^{-1} soil	N content g kg^{-1}soil	C content g kg^{-1} soil
Without fertilizer			
Bare	4.53 a	0.014 a	0.208 a
Rye	4.27 a	0.016 a	0.319 a
Manure	4.15 a	0.0119 a	0.192 a
Rye+manure	4.24 a	0.0126 a	0.203 a
With fertilizer			
Bare	4.71 a	0.0112 a	0.181 a
Rye	6.24 a	0.024 b	0.415 a
Manure	3.54 a	0.0172 a	0.335 a
Rye+manure	3.22 a	0.013 a	0.213 a
Overall lsmeans			
Managements effects			
Bare	4.62 a	0.0130 a	0.194 a
Rye	5.25 a	0.020 b	0.367 b
Manure	3.84 a	0.014 a	0.264 ab
Rye+manure	3.73 a	0.012 a	0.208 ab
Fertilizer effects			
With fertilizer	4.42a	0.016 a	0.286a
Without fertilizer	4.30a	0.014 a	0.23a
ANOVA Pr>F			
Block	0.1986 NS	0.0475*	0.1065NS
Management (M)	0.6391 NS	0.0073**	0.0349*
Fertilizer (F)	0.8945 NS	0.1403NS	0.2040NS
MxF	0.6923 NS	0.0845NS	0.4796NS

Lsmeans with different letters within a group are statistically different at P<0.05.

NS, *,**. Not significant at P<0.05, significant at P<0.05, and 0.01 respectively.

Management is referred to presence or absence of organic inputs (cover crop and/ or manure).

Rye combined with fertilizer could have stimulated more soil microflora activity compared to other treatments due to the labile organic carbon addition. Cover crops, especially grasses (rye and annual rye grass) have been reported to increase total organic C and carbohydrate compared to legumes (Kuo et al. 1997a). An increase in readily decomposable C fraction may be associated with grass residues. Several authors reported increases in soil biological activity subsequent to cover crop incorporation (Hu et al. 1997, Bolton et al. 1985, Kirchner et al.1993, Abdallahi and N'Dayegamiye 2000).

Cover crops not only increase the soil organic carbon but also the soil organic nitrogen. Soil organic nitrogen is an important component of soil quality and positively affects soil N mineralization (Stanford and Smith 1972). Influence of cover crops on short-term and long-term N availability depends on the quantity, quality and degradation rate of biomass incorporated. Kuo et al. (1997b) evaluated effects of several cover crops (grasses and legumes) on soil inorganic N and organic N levels. Grasses were found to be ineffective in increasing soil inorganic N levels, whereas they were more effective than legumes in increasing soil organic nitrogen accumulation, presumably due to higher biomass.

The contribution of cover crops to soil organic nitrogen depends more on the input of organic C than total N (Kuo et al. 1997b), which may explain why rye plus fertilizer increased more N content in the light fraction compared to other treatments (manure plus fertilizer and manure plus rye and fertilizer). This suggests that labile carbon was probably the limiting factor in the other treatments. Also Hargrove (1986) reported increases in soil organic nitrogen from rye and crimson clover residues, even though rye contained only one fourth as much N, meaning that carbon source is very important in stimulating microflora activity. Comparing a livestock based rotation to a cover cropped rotation with a conventional system, Wander et al. (1994) reported that total C was greatest in the cover cropped, intermediate in the animal based and the lowest in conventional treatments soils. Increased soil organic matter levels with manure or cover crop incorporation compared to a conventional system were also confirmed by Drinkwater et al. (1998).

The light fraction of OM is known to be more sensitive than total organic matter content in assessing cropping practices effects (Dalal and Mayer 1987). In addition, light fraction is a transient property (Janzen et al. 1992), and, for these reasons, most probably our results reflect short-term effects. Further studies are needed, to better understand long-term effects of combination of cover crops or/and manure with fertilizer on building soil.

NO_3^--N dynamics during the growing season and residual NO_3^--N at harvest time.

Net soil nitrate dynamics were monitored using anion exchange membranes in the topsoil and at the bottom of the container. Soil mineral N was highest during the first period and decreased with time as plant N uptake occurred (Figure 3.3). The depletion over the season due to the plant uptake of NO_3^--N was observed also by Pare et al. (1995) and Jowkin and Schoenau (1998) by using anion exchange membranes. Contrasts between treatments showed that significant differences between treatments were observed at the beginning and disappeared with time (Appendices 4 and 5).

Rye plus manure showed a consistent high level of mineral N released over time compared to other treatments (Figure 3 and Appendix 6). In the top layer, for the rye treatment, inorganic N was significantly higher at the end of the season, indicating that late mineralization occurred with the rye cover crop (Figure 3.3 and Appendix 6).

If we consider cumulative nitrates over the season (Appendix 6), N released in the top soil was in the following order: rye+manure> manure>rye>bare soil, indicating that nitrates adsorbed on membranes were proportional to available N from different treatments. This is similar to data reported by Collins and Allinson (1999), and Ziadi et al. (1999), where NO_3^--N desorbed from membranes were found to be related to the rate of fertilizer N applied. The treatments that increased nitrate-membrane levels also increased yield and nitrogen uptake as has been reported by other authors (Collins and Allinson 1999; Qian and Schoeanau 2000; Ziadi et al.1999). Monitoring NO_3^--N by anion exchange membranes appeared to reflect the dynamic nutrient uptake by the crop during a growing season. This is in agreement with tuber yield and nitrogen uptake data, indicating that high level of NO_3^--N availability was sustained in the rye plus manure plus fertilizer treatment, which supported plant N uptake and optimized tuber yield.

Our nitrate results from membranes are much lower than those of Pare et al. (1995) in a study where 200 kg N ha-1 was applied (46 $\mu g\ cm^{-2}\ d^{-1}$). The soil in our study has very low organic matter compared to the previous cited study and a positive relationship has been observed between soil OM content and NO_{3-} -N sorbed on AEM (Ziadi et al. 1999). Thus, we might expect to find low nitrate levels in our study. Subler et al. (1995) observed a high correlation between NO_3^- -N released from membranes, soil NO_3^--N concentrations and net soil nitrification. It is well known that N mineralization potential is positively related to organic matter content (Simard and N'Dayegamiye 1993).

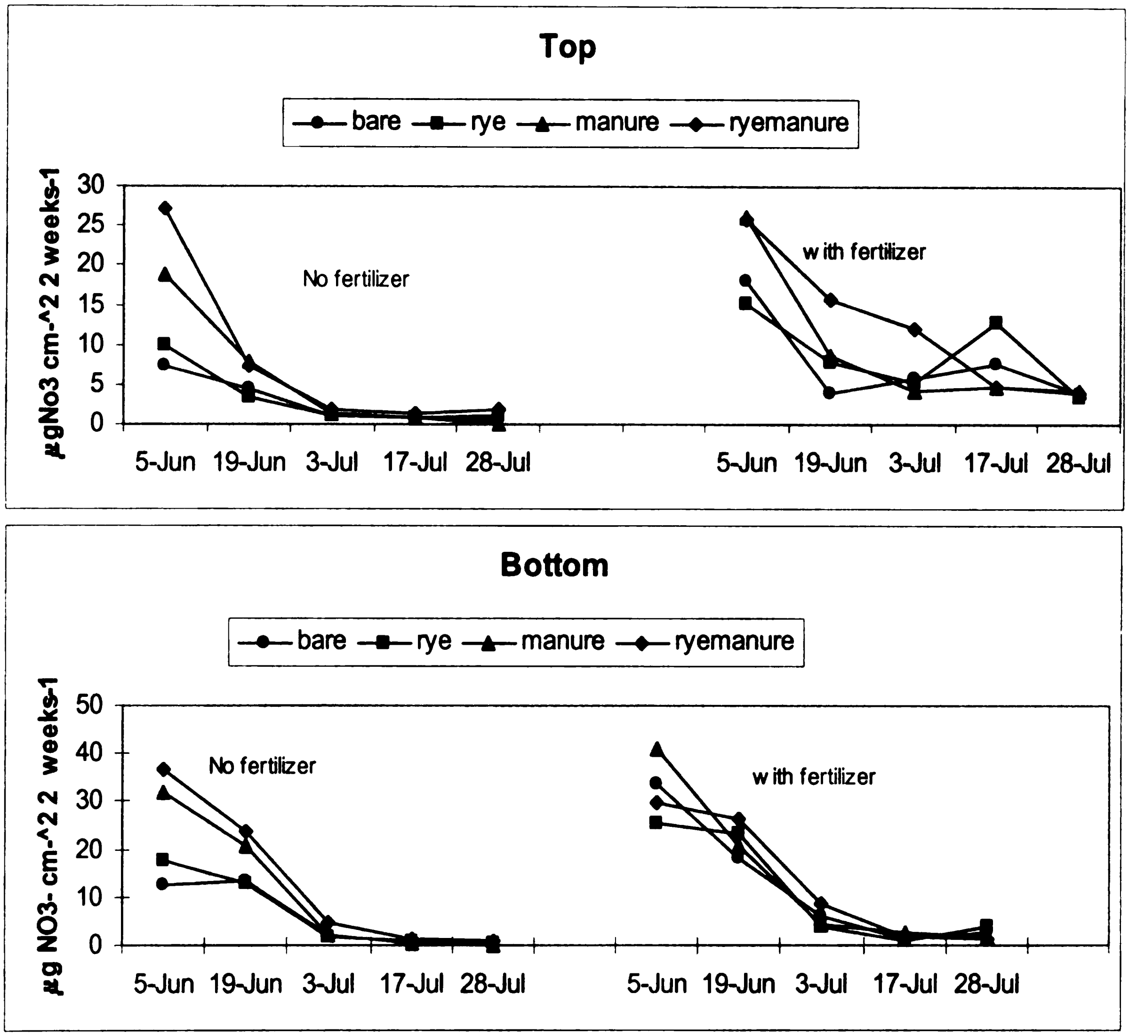


Figure 3.3. Container experiment: nitrate dynamics monitored by using anion exchanges membranes in top (0-15 cm) and in bottom layer (40-55 cm). Membranes were inserted 10 days after planting and were changed every 15 days.

Residual nitrates at harvest time

Residual NO_3-N at harvest was analyzed by KCl extracts of soil composite sampled at three depths: top (0-15 cm), middle (15-30 cm), and bottom layer (30-45 cm). No significant effects of treatments were observed, and low NO_3^--N was recovered (from 3 to 8 $\mu g\ g^{-1}$). Higher levels of mineral N were observed in the top and in the middle layers for rye treatment (Figure 3.4). This is in agreement with ion exchange probe data reported in Figure 3.3 where a peak was found late in the season for rye treatment. The high level of residual nitrate for rye was not observed when rye was combined with fertilizer.

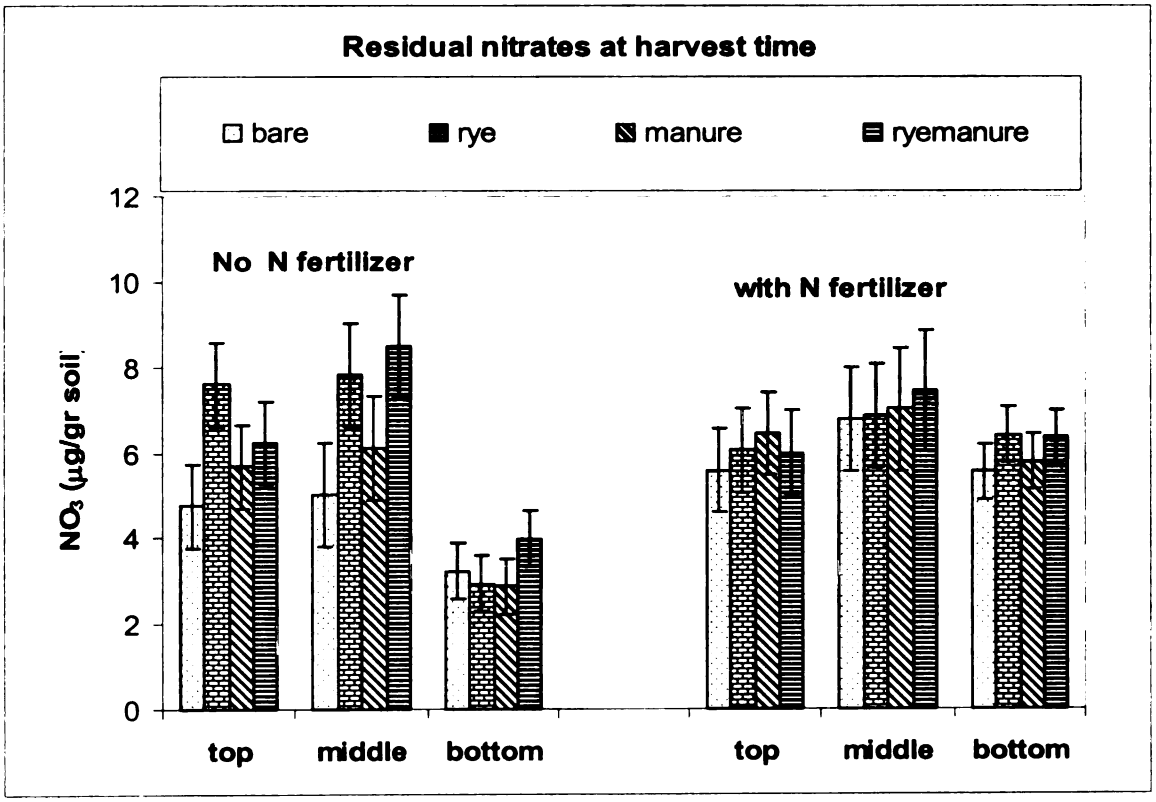


Figure 3.4. Container experiment. Nitrate at harvest time in top layer (0-15 cm), middle layer (15-30 cm) and in bottom layer (30-45 cm). Least squares means ± standard errors. Nitrates were extracted by using 1N KCl

In general, soil nitrate levels were low (<10 μg g^{-1}) by the end of the season. This may be related to the rate applied (recommended dose), to the split application of fertilizer and to the fact that N credits from different sources were taken into account. N-fertilizer combined with high level of organic input from manure and rye, were associated with slight increases of residual nitrates in the bottom layer (Figure 3.4).

Nitrogen derived from labeled fertilizer (Ndff)

This study using ^{15}N allowed us to distinguish N derived from labeled fertilizer from that derived from soil or other N sources. By using ^{15}N, it is possible to calculate percent N recovery or percent Ndff. While N recovery appears to be more realistic because it takes into account total N uptake and total labeled fertilizer applied, Ndff is the ratio between enrichment in samples and the enrichment in ^{15}N fertilizer. So the two parameters give different information (see equations on page 63). Percentage N derived from ^{15}N in roots, in soil, in tubers, in shoots, and in nitrates is presented in Figure 3.5. Results indicate that for all treatments, % Ndff was presumably recovered in tubers, roots, shoot and little in soil. If we consider % Ndff as nitrates adsorbed on anion exchanges membranes in bottom layer, bare soil tended to have higher % Ndff more than other treatments.

Even though not significant, there was an interesting trend in that a large amount of ^{15}N fertilizer was recovered in lower layer for the bare treatment compared to other treatments. This may be explained by the fact that, other treatments tended to slowly supply nutrients because of the combination between fertilizer and manure/or cover crops. Therefore, only a small amount of N-nitrates was found down in the profile. In contrast, a bare soil has only fertilizer, which is high soluble and in case it is not taken up by the plant, the residual N is susceptible to be leached.

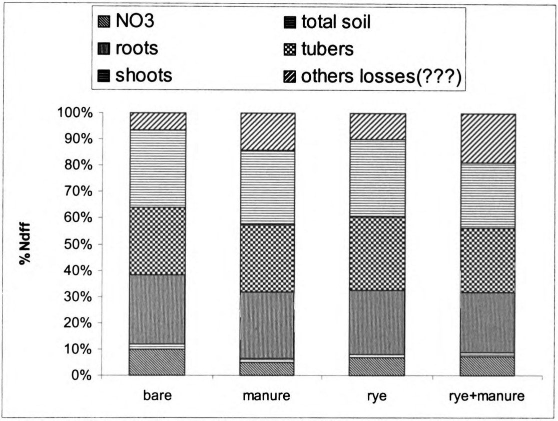


Figure 3.5. Percent Ndff in different parts

CONCLUSION

Results of this study in field and in containers indicated that manure and cover crops generally increased potato tuber yields. Cover crop application (rye) was associated with the highest N efficiency, and significantly increased the N content in the light fraction of the soil OM. This indicates that rye improves soil properties in short-term. The combination with rye, manure and fertilizer resulted in highest yield, and nutrient uptake overall. In addition, this combination showed a constant release of nitrates during the growing season, which could increase the synchrony between N released and potato uptake. Results of the experiment showed that the combination of organic sources with reduced N fertilizer was beneficial for potato yields and nutrient absorption. The Ndff values indicated that the bare treatment could be associated with higher NO_3^--N losses. Further research is needed to better understand the synergetic effects between different sources, especially over a long-term period.

Appendix 1. Container experiment: Least square means (lsmeans) and analysis of variance for fresh weight in tubers, shoot and in roots.

lsmeans	Fresh weight (g/container)		
Without fertilizer	Roots	Tubers	Shoot
Bare	16.0 a	321.8 a	135.5 a
Rye	19.7 a	456.5 ab	199.0 ab
Manure	28.0 b	533.2 b	260.5 b
Rye+manure	24.4 b	741.7 c	383.0 c
With fertilizer			
Bare	25.9 a	766.2 a	567.0 a
Rye	26.9 a	883.5 b	607.5 ab
Manure	40.2 b	1009.6 b	600.0 ab
Rye+manure	43.6 b	1017.3 b	710.0 b
Overall lsmeans			
Bare	20.9 a	544.0 a	351.2 a
Rye	23.3 a	670.0 b	403.2 a
Manure	34.1 b	771.4 bc	430.2 a
Rye+manure	34.00 b	879.5 c	546.5 b
Fertilizer effects			
With fertilizer	34.2 b	919.2 b	621.1 b
No fertilizer	22.0 a	513.3 a	244.5 a
Block	0.3439	0.3285NS	0.6824
Management(M)	0.0043**	<0.0001***	0.0014**
Fertilizer(F)	0.0004***	<0.0001***	<0.0001***
M x F	0.4937	0.3499 NS	0.5547

Lsmeans with different letters within a group are statistically different at P<0.05.

NS, *,**,***. Not significant at P<0.05, significant at P<0.05, 0.01 and 0.001 respectively.

Management is referred to the presence or absence of organic inputs (cover crop and/or manure).

Appendix 2. Container experiment. Least square means (lsmeans) and analysis of variance for nitrogen concentration in tubers, shoot and in roots.

	N concentration (%)		
Without fertilizer	Roots	Tubers	Shoot
Bare	1.29 a	1.13 a	1.83 a
Rye	1.18 a	1.09 a	1.56 a
Manure	1.02 a	0.98 a	1.53 a
Rye+manure	1.12 a	1.09 a	1.78 a
With fertilizer			
Bare	1.45 a	1.66 b	2.41 a
Rye	1.45 a	1.56 ab	2.41 a
Manure	1.37 a	1.44 ab	2.18 a
Rye+manure	1.32 a	1.42 a	2.14 a
Overall lsmeans			
Bare	1.37 a	1.39 a	2.11 b
Rye	1.32 a	1.32 ab	1.98 ab
Manure	1.20 a	1.21 c	1.85 a
Rye+manure	1.22 a	1.26 cb	1.96 ab
Fertilizer effects			
With fertilizer	1.39 b	1.52 b	2.28 b
No fertilizer	1.16 a	1.07 a	1.67 a
ANOVa Pr>F			
Block	0.6370NS	0.1401Ns	0.5060NS
Management(M)	0.4126NS	0.0092**	0.2281NS
Fertilizer(F)	0.0064**	<0.0001***	<0.0001***
M x F	0.8524NS	0.2225NS	0.2878NS

Lsmeans with different letters within a group are statistically different at P<0.05.

NS, *,**,***. Not significant at P<0.05, significant at P<0.05, 0.01 and 0.001 respectively.

Management is referred to the presence or absence of organic inputs (cover crop and/or manure).

Appendix 3. Container experiment. Apparent N recovery in tubers and N use efficiency

	Apparent recovery	N use efficiency
	%	Cwt[y]/lb total N
Rye	27	1.34
Manure	5	0.28
Fertilizer	30	0.75

Apparent recovery= ((N uptake in rye or manure-N uptake in bare soil)/total N applied) x100.

N use efficiency= ((Yield in rye or manure treatment-N bare soil)/total N applied.

Y: 1 metric ton=22.05 cwt

Appendix 4. Container experiment. Analysis of variance of nitrates adsorbed on anion exchange membranes in top layer (0-15 cm).

ANOVA (p-value)	df	Pr>F			
Treatment	7	<0.0001***			
Time	4	<0.0001***			
Treatment*time	28	<0.0001 ***			
Contrasts at different sampling time	t_1=June 5	t_2=June 19	t_3=July3	t_4=July 17	t_5=July 28
No fertilizer					
Bare vs rye	NS	NS	NS	NS	NS
Bare vs manure	**	NS	NS	NS	NS
Bare vs rye+manure	***	NS	NS	NS	NS
Rye vs manure	*	NS	NS	NS	NS
Rye vs rye+manure	***	NS	NS	NS	NS
Manure vs rye+manure	*	NS	NS	NS	*
With fertilizer					
Bare vs rye	NS	NS	NS	NS	NS
Bare vs manure	*	NS	NS	NS	NS
Bare vs rye+manure	*	***	**	NS	NS
Rye vs manure	**	NS	NS	**	NS
Rye vs ryemanure	**	*	***	*	NS
Manure vs rye+manure	NS	*	***	NS	NS

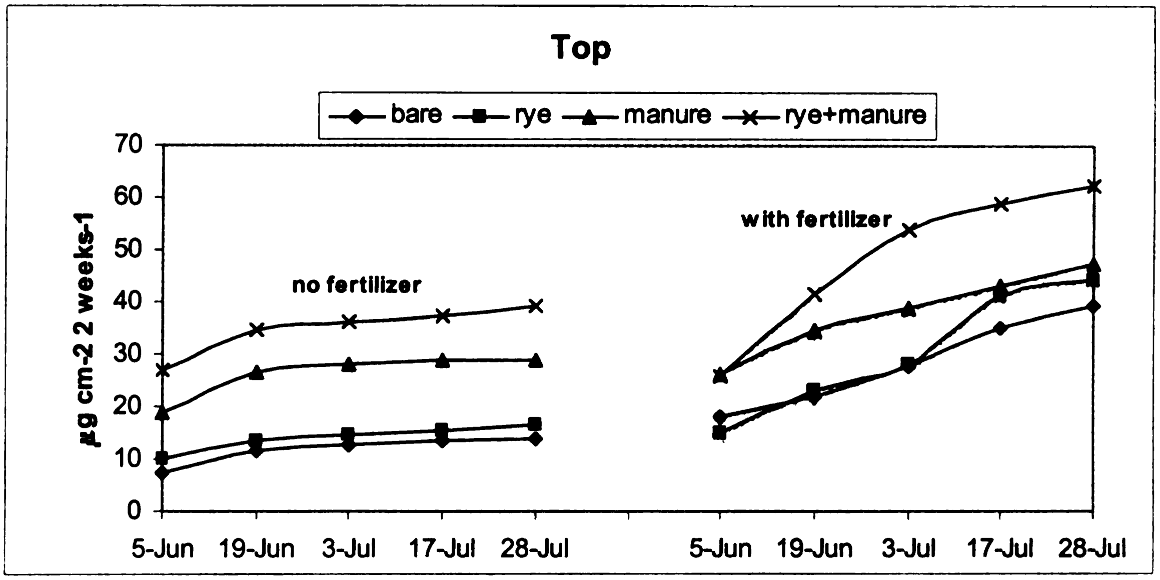
NS, *,**,***. Not significant at P<0.05, significant at P<0.05, 0.01 and 0.001 respectively.

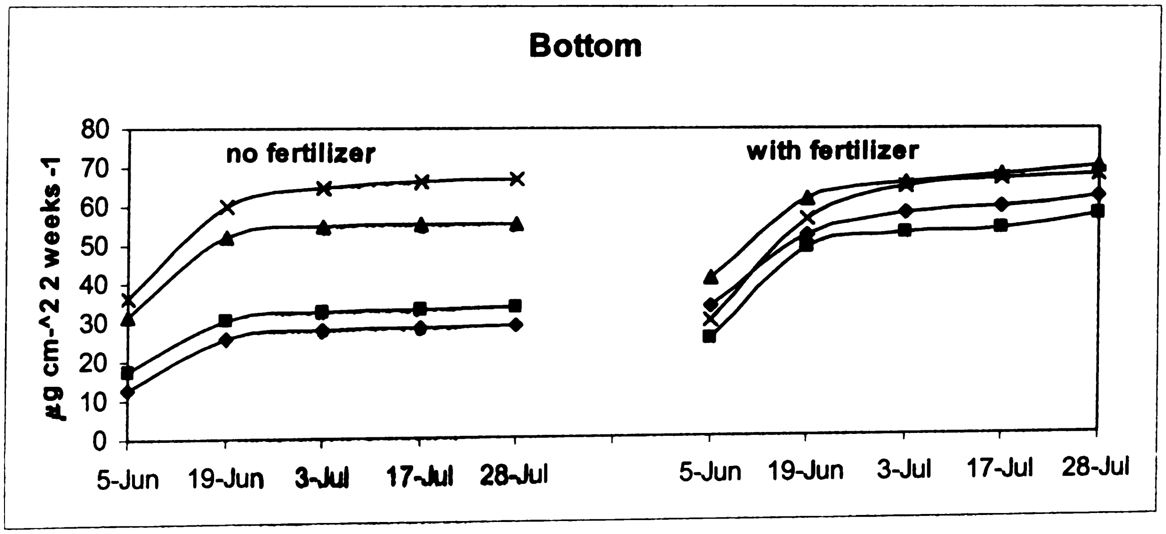
Appendix 5. Container experiment. Analysis of variance of nitrates adsorbed on anion exchange membranes in bottom layer (40-55 cm).

ANOVA (p -value)	df	Pr>F			
Treatment	7	<0.0001***			
Time	4	<0.0001***			
Treatment*time	28	<0.0001 ***			
Contrasts at different sampling date	t_1=June 5	t_2=June 19	t_3=July3	t_4=July 17	t_5=July 28
No fertilizer					
Bare vs rye	NS	NS	NS	NS	NS
Bare vs manure	***	NS	NS	NS	NS
Bare vs rye+manure	***	*	NS	NS	NS
Rye vs manure	**	NS	NS	NS	NS
Rye vs rye+manure	***	*	NS	NS	NS
Manure vs rye+manure	NS	NS	NS	NS	NS
With fertilizer					
Bare vs rye	NS	NS	NS	NS	NS
Bare vs manure	NS	NS	NS	NS	NS
Bare vs rye+manure	NS	NS	NS	NS	NS
Rye vs manure	**	NS	NS	*	NS
Rye vs rye+manure	NS	NS	*	NS	**
Manure vs rye+manure	*	NS	***	NS	NS

NS, *,**,***. Not significant at P<0.05, significant at P<0.05, 0.01 and 0.001 respectively

Appendix 6. Container experiment. Cumulative nitrate adsorbed on anion exchange membranes during the growing season in top layer (0-15 cm) and in bottom layer (40-55 cm) at different sampling dates.





Appendix 7. Large containers used to grow potatoes (75 L).

REFERENCES CITED

Abdallahi, M.M., and A.N'Dayegamiye. 2000. Effects de deux incorporations d'engrais verts sur le rendement et la nutrition en azote du blé (*Triticum aestivum*) ainsi que sur les propriétés physiques et pédologiques du sol. Can. J. soil Sci. 80: 81-90.

Angle, J.S., C.M. Cross, R.L. Hill, and M.S. MacIntosh. 1993. Soil nitrates concentrations under corn as affected by tillage, manure and fertilizers applications. J.Eviron.Qual. 22: 141-147.

Antonious, G.F., C.M. Lee, and J.C. Snyder. 2001. Sustainable soil management practices and quality of potato grown of erodible lands. Journal of environmental Sciences and health. Part. B. Pesticides, food contaminants and agricultural wastes. 36: 435-444.

Bending, D.G. and M.K. Turner. 1999. Interaction of biochemical quality and particle size of crop residues and its effects on the microbial biomass and nitrogen dynamics following incorporation into soil. Biol. Fertil. Soils. 29: 319-327.

Blevins, R.L., J.H. Herbeck, and W.W. Frye. 1990. Legume cover crop as nitrogen sources for no till corn and grain sorghum. Agron. J. 82: 769-772.

Bolton, H., L.F Elliot, R.L. Papendick, and D.F. Bezdicek. 1985. Soil microbial biomass and selected soil enzyme activities: effect of fertilization and cropping practices. Soil Biochem. 17: 297-302.

Bremner, J.M. 1965. Inorganic form of nitrogen. p. 1179-1237. *In* Black et al. (eds). Methods of soil analysis. Part 2. Agronomy n 9. ASA. Madison, Wisconsin.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-total. *In* Methods of soil analysis. Part. 2. Chemical and microbiological properties. ASA-SSSA. Madison. Wisconsin.

Brooks, P.D., J.M. Stark, B.B. McInteer, and T.Preston. 1989. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. Soil Sci. Soc Am. J. 53: 1707-1711.

Burkart, M.R., and J.D. Stoner 2001. Nitrogen in groundwater associated with agricultural systems. p. 123-145. *In* Follett and Hatfield (eds). Nitrogen in the environment: sources, problems and management. Elsevier. Amsterdam

Collins, S.A., and D.W. Allinson. 1999. Use of anion exchange membranes to assess nitrogen needs of perennial grasslands. Commun. Soil Sci. Plant Anal. 30:2267-2282.

Conn, K.L., and G. Lazarovits. 1999. Impact of animal manures on verticillium wilt, potato scab, and soil microbial populations. Can.J.Plant Pathol. 21:81-92.

Dalal, R.C., and R.J. Mayer. 1987. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. VI. Loss of total nitrogen from different particle size and density fractions. Aust. J. Soil Res. 25: 83-93.

Dawson, M.A., and K.A. Kelling. 2002. Wisconsin's annual potato meeting 2002. Volume 15.

Douches D.S. Potato breeder. Michigan State University.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396:262-264.

Ebhelar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no tillage corn. Agron.J. 76:51-55.

Eghball, B. 2000. Nitrogen mineralization from field applied beef cattle feedlot manure or compost. Soil Sci. Soc. Am. J. 64:2024-2030.

Emmonds G.S., and R.J. Ledingham. 1972. Effects of crop rotation on some soil-borne pathogens of potato. Can. J. Plant Sci. 52:605-611.

Errebhi, M., C.J. Rosen, S.C. Gupta and D.E. Birong. 1998. Potato yield response and nitrate leaching as influenced by nitrogen management. Agron.J. 90: 10-15.

Gao, G, and C. Chang. 1996. Changes in CEC and particle size distribution of soils associated with long-term annual applications of cattle feedlot manure. Soil Science 161:115-120.

Griffin, T.S., and O.B. Hsterman. 1991. Potato response to legume and fertilizer nitrogen sources. Agron.J. 83: 1004-1012.

Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. Agron. J. 78: 70-74.

Hart, S.C., J.M. stark, E.. Davidson, and M.K. Firestone. 1994. Nitrogen mineralization, immobilization and nitrification. p. 985-1016. In Weaver et al.(eds). Methods of soil analysis. Part. 2. Microbiological an biochemical properties. SSSA. Book series, n° 5.

Hartz, T.K., J.P. Mitchell, and C. Giannini. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. Hort Sci. 35:209-212.

Hattab, K.O., K. Natarajan, and A. Gopalaswamy. 1998. Influence of different organic manures on yield and N use efficiency of rice. J.Ind.Soc. Soil Sci. 46: 239-242.

Hauck, R.D. and J.M. Bremner. 1976. Use of tracers for soil and fertilizer nitrogen research. *In* Brady (Ed.). Adv. Agron. 28: 219-266.

Hodges, T. 1999. Water and nitrogen application for potato: commercial and experimental rates compared to a simulation model. J.Sustain.Agric.13: 79-90.

Hu, S., N.J. Grunwald, A.H.C. Van Bruggen, G.R. Gamble, L.E. Drinkwater, C. Shennan, and M.W. Demment. 1997. Short-term effects of cover crop incorporation on soil carbon pools and nitrogen availability. Soil Sci.Soc.Am.J. 61:901-911.

Janzen, H.H. 1987. Soil organic matter characteristics after long-term cropping to various spring wheat rotations. Can.J.Soil Sci. 67: 845-856.

Janzen, H.H., C.A. Campbell, S.A. Brandt, G.P. Lafond, and L.Townley-Smith. 1992. Light fraction organic matter in soils from long-term crop rotations. Soil Sci.Soc. Am.J. 56: 1799-1806.

Joern, B.C., and M.L. Vitosh. 1995. Influence of applied nitrogen on potato. Part II.: Recovery and partitioning of applied nitrogen. Am. Potato. J. 72: 73-84.

Johnson, T.J., T.C. Kasper, K.A., Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. J. soil Water conservation. 53: 276-279.

Jowkin, V., and J. J. Schoenau. 1998. Impact of tillage and landscape position on nitrogen availability and yield of spring wheat in the brown soil zone in southwestern Saskatchewan. Can. J. Soil Sci. 78: 563-572.

Karlen, D.L., and J.W. Doran. 1991. Cover crop management effect of soybeam and corn growth and nitrogen dynamics in an on-farm study. Am.J.Altern. Agric. 6:71-82.

Kessavalou, A., and D. Walters. 1997. Winter rye as cover crop following soybean under conservation tillage. Agron.J.89:68-74.

Khaleel, R., K.R. Reddy, and M.R. Overcash. 1981. Changes in soil physical properties due to organic waste application: a review. J.Environ.Qual. 110:133-141.

Kirchner, M.J., A.G. II Wollum, and L.D. King. 1993. Soil microbial populations and activities in reduced chemical input agroecosystems. Soil Sci.Soc.Am.J. 57: 1289-1295.

Kitchen, N.R., and K.W.T. Goulding. 2001. On farm technologies and practices to improve nitrogen use efficiency. p. 335-369. (In) Follet and Hatfield. Nitrogen in the environments: sources, problems, and management. Elsevier.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover crop effects on soil organic carbon and carbohydtrates in soil. Soil Sci. Soc. Am.J. 61:145-152.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover cropping influence on nitrogen in soil Soil Sci. Soc. Am. J. 61: 1382-1399.

Labarta, R.L., S.M. Swinton, J.R. Black, S. Snapp and R. Leep. 2002. "Economic Analysis Approaches to Potato-Based Integrated Crop Systems: Issues and Methods." Staff paper 02-32, Department of Agricultural Economics, Michigan State University, East Lansing.

Lauer, D.A. 1985. Nitrogen uptake patterns of potatoes with high frequency sprinkler applied N fertilizer. Agron J. 77: 193-197.

Li, H., L.E. Parent, A.Karam, and C. Tremblay. 2003. Efficiency of soil and fertilizer nitrogen of a sod-potato system in the humid, acid and cool environment. Plant and soil 251: 23-36.

Magdolf, F.R., and J.F. Amadons. 1980. Yield trends and soil chemical changes resulting from N and manure application to continuous corn. Agron. J. 72

Maidl, F.X., H. Brunner, and E. Sticksel. 2002. Potato uptake and recovery of nitrogen ^{15}N enriched ammonium nitrate. Geoderma 105: 167-177.

Malpassi, R.N., T.C. Kaspar, T.B. Parkin, C.A. Cambardella, and N.A. Nubel. 2000. Oat and rye root decomposition effects of nitrogen dynamics in an on-farm study. Soil Sci. Am.J. 64: 208-215.

Miller, P.L., and A.F. MacKenzie. 1978. Effects of manures, ammonium nitrate and S-coated urea on yield and uptake of N by corn and on subsequent inorganic N levels in soils in southern Quebec. Can. J. Soil Sci. 58:153-158.

Mullen, M.D., C.G. Melhorn, D.D. Tyler, and B.N. Duck. 1998. Biological and biochemical soil properties in no-till corn with different cover crops. Soil and water cons. 53: 219-224.

N'Dayegamiye, A., and D. Cote. 1989. Effect of long term pig slurry and solid cattle manure application on soil chemical and biological properties. Can. J. Soil Sci.69: 39-47.

N'Dayegamiye, A., and T.S. Tran. 2001: Effects of green manures on soil organic matter and wheat yields and N nutrition. Can. J. Soil Sci. 81: 371-382.

N'Dayegamiye, A., M. Goulet, and M.R. Laverdiere. 1997. Effect a long term d'apports d'engrais mineraux et du fumier sur les teneurs en C et en N des fractions densimetriques et des agregats du loam limoneux le Bras. Can. J. soil Sci. 77: 351-358.

Nelson, D.W., and L.E. Sommers. 1982. Total Carbon, organic carbon and organic matter. Page et al.(eds). Methods of soil analysis. Part. 2. Second ed. Agronomy 9: 539-579.

Odland, T.E., and J.E. Sheehan. 1957. The effect of redtop and red clover on yields of following crops of potatoes. Am. Potato J. 34: 282-284.

Ojala, J.C., J.C. Stark, and G.E. Kleinkopf. 1990. Influence of irrigation and nitrogen management on potato yield and quality. Americ. Potato J. 67:29-43.

Pang, X.P., and J. Letey. 2000. Organic farming: challenge of timing nitrogen availability to crop nitrogen requirements. Soil Sci. Soc. Am. J. 64:247-253.

Pare, T.E.G. Gregorich, and B.H. Ellert. 1995. Comparison of soil nitrate extracted by potassium chloride and adsorbed on an anion exchange membrane in situ. Commun. Soil Sci. Plant Anal. 26:883-898.

Paul, J.W., and E.G. Beauchamp. 1994. Short-term nitrogen dynamics in soil amended with fresh and composted cattle manures. Can. J.Soil Sci. 74:147-155.

Porter, G.A., G.B. Opena, W.B. Bradburry, J.C. McBurnie, and J.A. sisson. 1999. Soil management and supplemental irrigation effects on potato: I. Soil properties, tuber yield and quality. Agron.J. 91: 416-425.

Preusch, P.L., P.R. Adler, L.J. Sikora, and T.J. Tworkoski. 2002. Nitrogen and phosphorus availability in compost and uncomposted poultry litter. J.Environ. Qual. 31:2051-2057.

Qian, P., and J.J. Schoenau. 1995. Assessing nitrogen mineralization from organic matter using anion exchange membranes. Fert. Res. 40: 143-148.

Qian, P., and J.J. Schoenau. 2000. Use of ion exchange membrane to assess soil N supply to canola as affected by addition of liquid swine manure and urea. Can. J.Soil Sci 80: 213-218.

Qian, P., and J.J. Schoenau. 2002. Practical applications of ion exchange resins in agricultural and environmental soil research. Can. J. soil Sci. 82:9-21.

Rannels, N.N., and M.G. Wagger. 1997. Nitrogen ^{15}N recovery and release by rye and crimson clover cover crops. Soil Sci. soc. Am. J. 61:943-948.

Roberts, S., H.H. Cheng, and F.O. Farrow. 1991. Potato uptake and recovery of nitrogen 15 enriched ammonium nitrate from periodic applications. Agron. J. 83:378-381.

Roberts, S., W.H. Weaver, and J.P. Phelps. 1982. Effect of rate and time of fertilization on nitrogen and yield of Russet Burbank potatoes under center pivot irrigation. Americ. Potat. J.59:77-86.

Rotenberg D., and L. Cooperband. 2002. Wisconsin's annual potato meeting 2002. Vol. 15.

Saffigna, P.G., D.R. Keeney, and C.B. Taner. 1977. Nitrogen chloride and water balance with irrigated Russet Burbank potatoes in a sandy soil. Agron. J. 69: 251-257.

Sikora, L.J., and N.K. Enkiri. 2000. Efficiency of compost fertilizer blends compared with fertilizer alone. Soil Sci. 165: 444-451.

Simard, R.R., and a. N'Dayegamiye. 1993. Nitrogen mineralization potential of meadow soils. Can. J. Soil Sci. 73: 27-38.

Snapp, S., and A. Fortuna. 2003. Predicting nitrogen availability in irrigated potato systems. HortTechnology In press.

Snapp, S., D. Smucker, and M. Vitosh. 2002. Nitrogen management for Michigan potatoes. Michigan State University Extension. Extension bulletin. E-2779.

Sommerfeldt, T.G., and C. Chang. 1985. Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Sci. Am.J. 49: 983-987.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potential of soils. Soil Sci.Soc.Am. Proc. 36: 465-472.

Stark, J.C., I.R. McCann, D.T. Westermann, B. Izadi, and T.A. Tindall. 1993. Potato response to split nitrogen timing with varying amounts of excessive irrigation. Americ. Potat. J. 70 :765-777.

Subler, S., J.M. Blair, and A.C. Edwards. 1995. Using anion exchange membranes to measure soil nitrate availability and net nitrification. Soil Biol. Biochem. 27: 911-917.

Tran, T.S., and M. Giroux. 1991. Effects of N rates and harvest dates on the efficiency of ^{15}N-labelled fertilizer on early harvested potatoes (*solanum tuberosum L.*). Can. J. soil Sci.71: 519-532.

Tyler, K.B., F.E. Boradbent, and J.C. Bishop. 1983. Efficiency of nitrogen uptake by potatoes. Am.Potato J. 60: 261-269.

Tyson, S.C., and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. Commun. Soil Sci. Plant. Anal. 24: 2361-2364.

Vos, J. 1999. Split nitrogen application in potato: effects on accumulation of nitrogen and dry matter in the crop and on the soil nitrogen budget. J. Agric. Sci. 133: 263-274.

Wagger, M.G., D.E. Kessel, and S.J. Smith. 1985. Mineralisation of nitrogen 15 labelled crop residues under field conditions. Soil Sci. Soc. Am. J. 49:1.220-1226.

Wander, M.M., S.J. Traina, B.R. Stinner, and S.E. Peters. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Sci.Soc.Am.J. 58:1130-1139.

Ziadi, N., R.R. Simard, G. Allard, and J. Lafond. 1999. Field evaluation of anion exchange membranes as an N soil testing method for grasslands. Can J Soil Sci. 79: 281-294.