THE UNIVERSITY OF MANITOBA

EFFECT OF SOIL NO_3-NITROGEN CONTENT AND NITROGEN FERTILIZER ON YIELD OF BARLEY AND CANOLA GROWN ON ORGANIC SOILS

By

EDWARD JOHN TOEWS

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

Department of Soil Science

Winnipeg, Manitoba

ISBN 0-315-63284-4

EFFECT OF SOIL NO_3-NITROGEN CONTENT AND NITROGEN FERTILIZER ON YIELD OF BARLEY AND CANOLA GROWN ON ORGANIC SOILS

BY

EDWARD JOHN TOEWS

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
of the degree of

MASTER OF SCIENCE

ABSTRACT

Twenty field experiments were conducted in 1986 and 1987 to obtain information which would be useful for making N fertilizer recommendations for barley and canola crops grown on organic soils.

Nitrogen fertilizer applied as NH_4NO_3 at rates of 10 to 250 kg ha^{-1}, resulted in significant yield increases in eight of twelve barley experiments and five of eight canola experiments. Maximum grain yields for all sites averaged 2811 kg ha^{-1} for barley and 1122 kg ha^{-1} for canola. Fertilizer N required to reach 90% of maximum grain yield (90%MGY) and maximum economic grain yield (MEY) ranged between 30-130 kg ha^{-1} and varied inversely with spring soil NO_3-N levels for most sites where economic response to N fertilizer occurred.

Relationships between % yield [(yield of unfertilized treatment / maximum yield of fertilized treatment) * 100] and soil NO_3-N content were evaluated for the 0-15, 0-30, 0-60, 0-90, and 0-120 cm sampling depths. The relationship of % yield to soil NO_3-N to a depth of 30 or 60 cm was reasonably good and was best described by quadratic regression equations for both barley (r=0.86 for the 30 cm depth) and canola (r=0.86 for the 60 cm depth). The relationship between N uptake by the crop and soil NO_3-N content was described equally well by linear or quadratic equations for all depths down to 90 cm for barley, with r values ranging from r=0.80 to 0.91, whereas quadratic models fit the relationship better at all depths for canola. The relationship between seed yield and N uptake of the crop was poor and low r values were obtained for quadratic or linear regression equations for both barley (r=0.55 and 0.53, respectively) and canola (r=0.39 and 0.36, respectively).

Apparent amounts of N mineralized during the growing season ranged

from 7 to 73 kg N ha^{-1} and averaged 33.2 kg N ha^{-1} for soils low in NO_3-N at the time of seeding. Percent utilization of fertilizer N averaged 45% for barley and 28% for canola. Soil NO_3-N levels remained relatively constant from fall to spring at sites with low initial NO_3-N levels.

ACKNOWLEGEMENTS

I wish to express my appreciation to:

Dr. Geza Racz, Department of Soil Science, University of Manitoba, who acted as my advisor for this study. I thank you for your clear guidance, your sense of humour and your confidence in my ability to achieve our objectives.

Ken McGill, Provincial Soil Testing Lab, for helpful advice and for serving on my examining committee.

Dr. Merv Pritchard, Plant Science Department, University of Manitoba, for thorough and helpful criticism of this thesis.

Helen Nemeth and Hildred Thould for your kindness and competence.

Greg Morden, Val Huzel and Tim Stem for much needed help with computors, lab analysis and field equipment.

The Directors of the Manitoba Peatland Farming Association for making the project possible through their grant to the University of Manitoba.

The governments of Manitoba and Canada for providing the funding through the Agri-Food agreement.

Bev Toews, my partner, for your love and support.

Tyler, Bennie and Kelley, my little buddies, for
providing me with the motivation to complete this work.

The Creator of Life, for the marvel of science;
the game of hide and seek.

CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The study of organic soils as an agricultural resource has received very little attention in western Canada due to the limitations of these soils in terms of frost-free period, soil temperature, drainage and fertility. Despite these limitations, large areas of shallow organic soils have been developed for agricultural production in the past thirty years. Whereas organic soils were initially used for pasture and production of hay, recent improvements in drainage and widespread use of fertilizers has resulted in about 40,000 ha of organic soils being used for field crop production in Manitoba. However, farmers have experienced extreme variations in yield from field to field and among years, and it has long been evident that a separate system of management practices needed to be developed if farming of organic soils was to be economically viable.

One of the many barriers to crop production on organic soils has been the lack of information on nitrogen fertilizer recommendations for common field crops. Consequently there was no reliable soil test and no useful recommendation for year to year nitrogen fertilizer requirements. It was commonly perceived that organic soils were unlikely to require N fertilizer because of their large total N contents. However, many farmers observed substantial crop yield responses to fertilizer N on some fields. Although organic soils in Manitoba may contain 4500 kg ha^{-1} or more of organic nitrogen in a 15-cm depth of soil, only part of this nitrogen pool is available for plant growth during the growing season. The mineralization rate of this organic N pool and other factors affecting the plant available N content of organic soils in Manitoba has not been studied, however.

Therefore, studies of the plant available nitrogen status of shallow organic soils in Manitoba were conducted. The objectives of the project were to obtain sufficient field data to 1) develop nitrogen fertilizer recommendations for organic soils, and 2) determine whether or not the NO_3-N test used on mineral soils in Manitoba was reliable for organic soils. The information required to achieve this goal included:

1) Information on the yield and total N uptake of crops in response to added fertilizer N.
2) Information on the relationship between soil NO_3-N levels and crop response to fertilizer N.
3) Information on the amount of organic N that is mineralized during the growing season.
4) Information on the % efficiency of added fertilizer N.
5) Information on the stability of NO_3-N in the soil from fall to spring.

Barley and canola were used as test crops since they represent the most commonly grown annual crop species on organic soils in Manitoba.

II. REVIEW OF LITERATURE

The study of nitrogen transformations and consequently the availability of N for plant growth in organic soils has received far less attention than on mineral soils. This is due, essentially, to two factors. Firstly, organic soils represent only a small fraction of the cultivated agricultural soils and are therefore far less important to the agricultural industry than mineral soils. Secondly, nitrogen availability has not been a limitation for most agricultural crops in the areas of the world where extensive development of organic soils has occurred. Despite these factors, a considerable amount of literature describing transformations of nitrogen in organic soils was found, much of it motivated by concern for problems related to oversupply of mineralized nitrogen rather than deficiencies.

Studies describing crop responses to fertilizer N on organic soils were less abundant than those describing N transformations, and evaluations of soil testing methods for N availability on organic soils were not found. The section of this review describing soil testing methods for N therefore will involve only studies carried out on mineral soils in western Canada and the American Great Plains.

2.1 Nitrogen Transformations in Organic Soils

Organic soils are huge reservoirs of organic nitrogen, most of which is unavailable to plants. The nitrogen is present as a component of the semi-decomposed organic materials which must first be transformed into soluble mineral forms to benefit crop growth.

The phenomena which operates to make organic nitrogen available to plants is known as mineralization. It is a two step process involving 1) the conversion of organic nitrogen into water soluble NH_3 or NH_4, known as ammonification (Stevenson 1982), and 2) the further transformation of NH_3 or NH_4 to nitrite (NO_2) and nitrate (NO_3), called nitrification (Stevenson 1982). The inorganic products, NH_4, and NO_3, are plant available N forms. Ammonification is carried out by heterotrophic soil organisms using nitrogenous organic substances as energy sources (Stevenson 1982). Nitrification is carried out by chemosynthetic autotrophic nitrifying bacteria mostly from the family Nitrobacteriaceae (Watson 1974).

Denitrification is a transformation pathway involving the reduction of NO_3 to NO_2, and then to gaseous NO, N_2O, and N_2, which are readily lost to the atmosphere. Denitrification is performed by some 23 known genera, most of which are anaerobic heterotrophic bacteria (Stevenson 1982).
A third factor affecting nitrogen availability is the immobilization of N, that is, the conversion of inorganic N into organic forms of N for use as components of microbes and other living populations present in all soils.

Leaching of N, in the NO_3-N form, can also occur in organic soils. The amount of N leached depends upon the water holding capacity of the soil, precipitation, evaporation or evapotranspiration, amounts of N added, etc.(Puustjarvi 1970).

The quantity of nitrogen which is available for plant growth depends on the net balance of the processes described above.

2.2 Factors Affecting Nitrogen Transformations and Availability of Nitrogen to Plants

The most important factors influencing the above nitrogen transformations, are those which produce conditions favorable to the various microbial populations involved. These factors include temperature, pH, aeration, and the suitability of the organic matter as an energy source for microbes.

2.2.1 Temperature

Both nitrification and denitrification have been shown to be temperature dependant processes. Nitrification does not occur in soils below 4 or 5°C (Anderson and Boswell 1964). Rates of nitrification increase with temperature to a maximum depending on the given ecosystem. For example, 20-25°C was considered to be optimal for nitrification in mineral soils of the northwest U.S.A., while 30-40°C was found to be optimal for soil in the southwestern states (Mahendrappa et al. 1966). Keeney and Bremner (1967) found 40°C to be the maximum temperature for nitrification in soils in the midwest U.S.A., but Myers (1975) found that nitrification occurred up to temperatures of 60°C in an Australian tropical soil. The variation between optima was ascribed to differences between microbial species present in each ecosystem. Nitrifiers in temperate soils would for example, be expected, because of natural selection processes, to operate most efficiently at much lower temperatures than those present in tropical conditions.

Studies conducted on organic soils have found mineralization rate changes to vary with temperature, as they do on mineral soils. Avnimelech (1971) noted that a first order relationship between nitrogen mineralization rate and temperature occurred between 10 and 28°C. Terry (1980) and Reddy (1982) reported that the N mineralization rate of some Florida peat soils were highly correlated to soil temperatures between 9 and 28°C.

With regard to maximum temperatures of mineralization, Avnimelech (1971) found the rate of nitrate accumulation in an Israeli peat soil to be two to three times higher at 36°C than at 25°C. He was unsure, however, whether or not the reduced rates of NO_3 accumulation at temperatures above 36°C were attributable to adverse temperature conditions for microbes, or to a lack of sufficient oxygen supply necessary to maintain the very high nitrate production levels.

Mineralization rates in organic soils are unique in that they occur at a steady state over time at a constant temperature, unlike mineral soils where NO_3 production reaches a maximum shortly after incubation begins and then decreases. This steady state phenomena has been reported by Guthrie and Duxbury (1978), Avnimelech (1971) and Reddy (1982). These authors suggest that the above phenomena occurred because of the large pool of readily decomposable organic material available in organic soils. Avnimelech (1971) further postulated that organic soils may have an undefined buffering effect on fluctuations in microbial population levels.

Denitrification is also strongly affected by changes in soil temperature. Denitrification has been reported to occur over a range of temperatures from 2.7 (Cho 1979) to 75^{o}C, with optimums at about 65^{o}C (Bremner and Shaw 1958). Cho (1979) reported that the rate of denitrification increased linearly between 2.7 and 20^{o}C in a mineral soil. A linear relationship for the rate of denitrification between 9.4 and 28.5^{o}C was also found for an organic soil in Israel (Avnimelech 1971).

2.2.2 pH

Soil pH strongly affects microbial activity. Generally, mineralization and denitrification are inhibited by pH values above 8 and below 6 (Stanford, et. al. 1975). Most researchers consider the lower limit for denitrification and nitrification in mineral soils to be about a pH 4 (Stevenson 1982), whereas these processes have been reported to occur in a peat bog at pH 3.5 (Klemedtsson, et. al. 1977). It appears that organic soils may be anomalous in their ability to sustain microbial populations at extremely low pH values as compared to mineral soils. This is probably due to the high Ca, and low Fe, Al, and Mn which occur in many bog soils (Brady 1984).

Ammonification proceeds at a faster rate than nitrification in soils with low pH values. Mineral N was shown to accumulate as NH_4 when soil pH values were between 3.5 and 4.5 in incubation studies carried out with oligotrophic organic soils by Williams (1983). Soils that were classified as eutrophic bogs, with pH values above 4.5, accumulated mineral nitrogen as NO_3-N in the same study.

Ivarson (1977) studied the effect of liming on acid organic soils in Quebec. He observed a steady increase in decomposition rate as pH was increased from 3.8 to 7. Isolates of the soil indicated that no active nitrifiers occurred below pH 5. O'Toole (1975) found very similar results in liming an Irish bog. NO_3-N production increased and NH_4-N decreased as pH increased from 5 to 6, indicating that nitrification was accelerated in relation to ammonification in this range. Lucas and Davis (1961) observed a fourfold increase in N mineralization when the pH of two organic soils was increased from 3.4 and 4.3, respectively, to above 6. They also noted a strong correlation between total N content of the soil and pH. The soils with pH values of <4.0 had N contents of <1% whereas soils with pH values of >5 had total N levels >2.0%. Studies involving organic soils with pH values above 8 were not found in the literature.

2.2.3 Aeration

Mineralization and denitrification occur simultaneously in a soil system at rates depending on substrate availability and the presence of oxygen. Mineralization dominates under aerobic conditions whereas denitrification dominates under anaerobic conditions. Due to the complex nature of soils, however, both may be occurring simultaneously at microsites within the soil system.

Avnimelech (1971) studied the effect of moisture level on NO_3 mineralization and noted twice the accumulation of NO_3 at field capacity (125% gravimetric water) than at 60% water content. NO_3 accumulation decreased above 125% water content, especially at temperatures above $30^{o}C$, due to increasing denitrification rates as a result of available O_2 being consumed more quickly than it could be replenished. Terry (1980) observed no effect on mineralization rates when organic soil samples were subjected to various suctions between 0.03 and 0.3 MPa. He did note, however, that wetting and drying cycles of a few days in duration greatly increased NO_3 accumulation as compared to constant soil moisture levels.

Nitrification did not occur in flooded soils, except at the water/air interface (Terry 1980), but ammonification continued to take place. Isirimah and Keeney (1973) observed the equivalent of 30 kg N ha^{-1} $month^{-1}$ (mostly NH_4-N) was mineralized from nine Wisconsin peat soils incubated at $30^{o}C$ under anaerobic conditions. Guthrie and Duxbury (1978) found that 120-190 kg ha^{-1} of nitrogen mineralized per year in a flooded organic soil in New York state, mostly in the form of NH_4-N, as compared to 830 kg ha^{-1} mineralized when the soil was drained. Williams (1983) found N mineralization rates under anaerobic conditions actually exceeded the amount mineralized under aerobic conditions for 7 of 9 Scottish peat soils incubated for 28 days at $30^{o}C$. The dominant forms were NH_4 and NO_3 under anaerobic and aerobic conditions, respectively.

The effect of a raised water table on nitrogen availability to plants was first reported by Harris et. al. (1961). He observed that yield response of four field crops to nitrogen fertilizer increased dramatically when the water table rose from 60cm to 40cm. Soil subsidence was diminished at the same time, indicating decomposition processes had been retarded. Terry and Tate (1980a) observed changes in bacterial populations when organic soils were flooded. Denitrifying bacteria increased to 15 times normal populations within two days of flooding, and then declined thirteen days later apparently due to a lack of substrate. Nitrifiers dropped in number but did not disappear completely. This was attributed to low levels of nitrification taking place near the soil/water interface.

2.2.4 The Quality of the Organic Material as an Energy Source

At the most general level of description, organic soils are commonly known as bog, fen, or forest soil types. Bog peat is usually acidic, arising in oligotrophic conditions and is comprised of fibrous, low N material derived from mosses with total N contents of <1%. Fen peats are near neutral in pH, eutrophic, moderately fibrous, and are derived from grasses and sedges with total N concentrations as high as 3.5%. Forest peats have a high degree of woody components and are intermediate in N content. In practice, any given organic soil may be some blend of the above due to the constant changes in water levels and climatic conditions which occur during formation.

Total N content and C:N ratio of the soil have been demonstrated to be inversely related, because organic materials tend to have constant carbon contents of about 50% (Puustjarvi 1970). The mineralization rate of N is not positively related to the total N content or inversely to C:N ratio of the material, however. Instead, several investigators have reported relationships between the N mineralization potential of organic material and the presence of more easily decomposable components. Reddy (1982) discovered substantially higher mineralization rates in a virgin soil compared to an adjacent cultivated organic soil. He concluded this was at least in part due to the increased state of decomposition of the cultivated soil. Williams (1983) and Puustjarvi (1970) both measured higher rates of decomposition and consequently N mineralization in soils with high fiber contents, which they concluded were more accessible to microbial action. Ironically, these soils tended to have some of the highest C:N ratios and lowest total N contents.

Ivarson (1977) found that subsurface (older) organic soil samples contained lower levels of easily decomposed amino sugars and uronic acids than surface samples. Isirimah (1973) discovered that most of the mineral N which accumulated when incubating Wisconsin peat soils was derived from the acid soluble fraction. He divided the soil into six fractions and rated them in order of susceptibility to decomposition as follows: Hydrolyzable unknown N = hexose amine N > total hydrolyzable N > amino acid N > hydrolyzable NH_4 >> nonhydrolyzable N.

Puustjarvi (1970) found that total N content of organic materials was highest in soils which were under 'waterlogged' conditions as opposed to soils which were labeled as 'wet', 'moist', or 'dry'. He speculated that this was due to the absence of nitrification and leaching of nitrates from waterlogged soils, compared with the soils which were occasionally exposed to aerobic conditions.

Other workers found that the total N content of soil was inversely related to the particle size of the organic material and that particle size decreased over time as soils become more decomposed (Williams 1983; Sowden et al. 1978; Morita and Levesque 1980). In all the studies reviewed, decomposition rates were found to be a function of the type of material present and no relationship between decomposition rate and total N content or C:N ratio of the soil was observed (Puustjarvi 1970; Isirimah 1973 and Williams 1983).

Net N mineralization, unlike the rate of soil decomposition, does appear to be related positively with total N content. Both Puustjarvi (1970) and Maciak and Gotkiewicz (1983) have documented this. Puustjarvi explained this apparent contradiction by suggesting that the rates of immobilization of mineralized nitrogen were greater in more fibrous materials. He suggested that microbial populations grew more quickly in the fibrous soils because of these soils' higher susceptibility to decomposition. Consequently, mineralized nitrates were quickly utilized by the microbes and were unable to accumulate to appreciable levels.

2.3 Some Measurements of N Mineralization and Denitrification Rates in Organic Soils

Rates of apparent N mineralization in organic soils increase after drainage. Hortenstein and Forbes (1972) measured a tenfold increase in NO_3 levels due to drainage and cultivation of a Florida swamp. Nicholls and MacCrimmon (1974) measured an eightfold increase in NO_3-N content of soils in the Holland marsh of Ontario after drainage and cultivation. Some measurements of NO_3-N mineralization during a period of fallow have included values such as 100 kg ha^{-1} in Ontario (Miller 1974), 350 kg ha^{-1} in Poland (Gotkiewicz 1973), 830 kg ha^{-1} in New York state (Guthrie and Duxbury 1978), 1400 kg ha^{-1} in Florida (Terry 1980) and a range of 250 to 2000 kg ha^{-1} in various fields in Israel (Avnimelech 1971).

Even flooded organic soils can mineralize nitrogen. Gotkiewicz (1973) and Guthrie and Duxbury (1978) measured N mineralization rates of 150 and 190 kg $ha^{-1}yr^{-1}$, respectively, when previously cropped soils were flooded. Most of the N mineralized was present in the soil in the NH_4 form.

While some ammonification occurs in flooded soils, nitrates and nitrites are quickly denitrified under these conditions. Hortenstein and Forbes (1972) found negligible amounts of nitrate accumulated at soil depths below 30 cm. Duxbury and Peverly (1978) and Avnimelech (1971) both reported very low levels of NO_3-N present in water flowing out of fields which contained extremely high levels of soil NO_3-N. Terry and Tate (1980a) showed that only 20-40 kg N ha^{-1} of the 1400 kg ha^{-1} yr^{-1} NO_3-N which accumulated in a Florida soil left the field in drainage water. The remainder was apparently denitrified within three days of flooding the fields, a standard practice in Florida (Reddy et al. 1980). Raveh and Avnimelech (1973) also witnessed high levels of apparent denitrification in organic soils in Israel. They measured a decrease in NO_3-N levels of 70% after soils were flooded for a period of 1 wk.

Denitrification rates have been shown to be dependant on cropping history of a given soil. Terry and Tate (1980b) observed denitrification rates to be 3 times faster in soils previously cropped to sugar cane or grass than in soils previously fallowed. This increase was attributed to the availability of readily decomposable carbon in the cropped fields.

The rates of N mineralization obtained in organic soils in Manitoba are unlikely to be as rapid as for the soils noted above. Soil temperatures are much lower in Manitoba than in any of the soils used in the studies referenced above, exceeding 5^oC for less than a six month period in any year. Due to the much colder soil temperatures in Manitoba, mineralization rates would be expected to be much lower than the extremely high values noted for organic soils elsewhere.

2.4 Assessing Plant Available N Content of Soils using Soil Analysis

Researchers initiated studies on methods of determining plant available N contents of soils at the start of this century, and the search for a suitable method greatly increased after 1945 with the large increase in use of nitrogen fertilizers. However, while many studies of this type were conducted using mineral soils, no studies using organic soils were found in the literature.

The most important of the methods for determining available N can be categorized into three general areas: (1) chemical extractions, (2) incubations of soil followed by extraction and (3) measurement of inorganic forms of N such as NH_4-N and/or NO_3-N in the soil profile.

Chemical extractions were used in an attempt to remove from soil samples a fraction of the organic N which would reflect the amount of N available, via microbial processes, for plant growth. An alkaline permanganate extraction developed by Truog (1954) showed some promise. This method involved mixing soil with a $KMnO_4$:Na_2CO_3 oxidizing mixture in a flask and measuring the NH_3 which was distilled off. The quantity of NH_3 evolved was labelled "available N". The permanganate extraction method of Truog, and modifications of it, were tested in Western Canada by Synghal et al.(1958) in Alberta and Tolton (1957) in Manitoba. Synghal et.al. (1958) found significant negative correlations between "available N", obtained from permanganate extraction and the yield increases of oats fertilized with nitrogen, using six Chernozemic soils in greenhouse experiments. The amounts of organic N extracted did not correlate well with crop yields in the field, however, and Synghal concluded that the differences in recent cropping history between the field soils was responsible for failure of this method.

Incubation of soil followed by extraction showed more promise than chemical extraction as a useful predictor of the availability of soil N to plants, and received much attention until the late 1960's. Incubation of the soil under a controlled set of environmental conditions, and subsequently measuring the amount of N mineralized, was first reported by Bogdanov in 1900. He incubated soils for 48 hrs at 28^{o}C and then measured the amounts of NO_3 and NH_4 nitrogen present. Pritchett et. al. (1947) used a similar process of aerobic incubation at 30^{o}C but extended the period of incubation to three weeks. Various incubation procedures have been tested in western Canada (Cook et al. 1957; Synghal et al. 1958) but they were unsuccessful because of poor correlations with crop yield responses in the field. Bremner (1965a) summarized many of these methods and introduced strict standards for sampling and processing of soils before incubation. He eventually concluded however, that incubation methods simply would not work because none of them made allowances for the soil mineralization - immobilization cycles which are controlled by the presence of readily available energy sources for microbial activity (Bremner 1965b). Stanford et al. (1975) also suggested that short term aerobic incubations were flawed because the early rate of mineralization was so greatly influenced by recently introduced organic matter.

Measurement of the inorganic NO_3-N content of the soil profile has become the standard procedure for measuring plant available soil N in western Canada and the spring wheat producing areas of the U.S.(Stevenson 1982). Early appraisals of the usefulness of this method, made by Cook et al.(1957) in Saskatchewan and Synghal et al. (1958) in Alberta, were quite negative. Both of them found poor correlation between soil NO_3-N and response of crops to fertilizer N. Their lack of success, however, was very likely due to the exclusive use of a 0-15 cm sampling depth, which did not properly reflect levels of plant available N in the entire soil profile. Modifying sampling depth to 30, 60, 90 or 120 cm was largely responsible for improving this test's usefulness in predicting nitrogen fertilizer requirements (White and Pesek 1959; Soper and Huang 1963; Herron et. al. 1968; Soper et. al. 1971; Racz 1979). White and Pesek correlated soil NO_3-N levels measured to various soil depths versus uptake of nitrogen by oats. They found the r value of a linear regression improved from 0.609 to 0.827 when a 0-50 cm sample was used rather than a 0-15 cm sample. Soper and Huang found the relationship between %yield of barley and soil NO_3-N was best when sampling to a depth of 120 cm. A quadratic regression line with an r value of 0.95 was obtained for this relationship. In later publications which summarized several years of yield response data (Soper et.al. 1971 and Soper 1971), nitrogen uptake by barley and %yield of rapeseed was shown to be correlated best to soil nitrate nitrogen levels measured to a depth of 60 cm. An r^2 value of 0.84 was obtained for a quadratic regression of N uptake of barley versus soil NO_3-N measured to a 60 cm depth (Soper et.al.1971) whereas an r^2 value of 0.85 was obtained for a linear regression of % yield of rapeseed versus soil NO_3-N measured to 60 cm (Soper 1971).

Most researchers consider the amount of NO_3-N in the soil to be a useful means of assessing plant available N, particularly when soils are sampled to depths of 30 cm or greater (Smika and Greb 1973; Olson et al. 1976; Racz 1979). Some researchers, however, suggested that improvements in usefulness of the test could be obtained by including environmental variables in the regression equation. Racz (1979) noted that crop yield values fell below the regression line of yield vs. soil NO_3-N to 60 cm, when water deficits were greater than 10 cm. Smika and Greb (1973) found substantial improvement in predicting N fertilizer requirements when factors accounting for soil water, air temperature and seasonal precipitation were included in the regression equation. The r value of the regression increased from 0.82 to 0.98 when these factors were included. Regression equations of this type are not of practical value in making fertilizer recommendations, however, as the growing season precipitation and temperatures need to be known in advance. Herron et al. (1968) had early success using soil NO_3-N levels to predict the fertilizer N requirements of corn in Nebraska, but he was dissatisfied with the results over several years. Similarly, Brown et al. (1984) found soil NO_3-N levels to be unsuitable for predicting nitrogen requirements for corn in a Missouri soil.

Predicting N fertilizer requirements of the crop using soil NO_3-N levels, appears to be suitable to soils where percolation of water below the typical rooting depth is minimal (Dahnke and Vasey 1973). The relatively low levels of precipitation in the Canadian prairies, coupled with frozen soil conditions that essentially preserve the nitrate status from fall to spring, have led to the widespread adoption of this method for making nitrogen fertilizer recommendations in western Canada. Many parts of the North American continent and elsewhere have adopted variations of this method.

2.5 Crop Responses to Nitrogen Fertilizer

2.5.1 Nitrogen Uptake and Grain Yield

Yield response to nitrogen by annual crops is a well known phenomena worldwide, and has been thoroughly studied and reviewed elsewhere (Stevenson 1982). While nitrogen utilization of crops grown on organic soils has not been previously studied in western Canada, there have been many studies reported for mineral soils. Studies in Manitoba have consistently reported yield response of barley and rapeseed to nitrogen fertilizer on stubble fields and to a lesser extent on fallow (Soper and Huang 1963; Soper et. al. 1971; and Racz 1979).

A review of the literature indicated that crops grown on organic soils occasionally respond to nitrogen fertilizers despite the high rates of N mineralization reported in the section above (Terry 1980; Guthrie and Duxbury 1978; Hortenstein 1972; Miller 1974; Nicholls and MacCrimmon 1974). This is particularly true of perennial crops (Cole 1985; Maciak et al. 1980; Gotkiewicz 1973; Lightner et al. 1981), crops grown on organic soils with a high water table (Harris et. al. 1961) and crops grown on cold soils (Lucas 1982, Racz et. al.1978).

Cole (1985), in Ireland, observed hay yield increases of up to 6 tonne ha^{-1} when nitrogen fertilizer was added to organic soils. Lightner et al. (1981) in Indiana, observed that yields of Kentucky Bluegrass grown on organic soil increased from 6.2 to 8.3 tonnes ha^{-1} with the addition of 180 kg of N fertilizer ha^{-1}. Maciak et al. (1980) and Gotkiewicz (1973) both observed small but significant yield increases of hay on Polish muck soils. Other perennial crops, including peppermint (Matsusiewicz et. al. 1983) and spruce (Dickson and Savill 1974), have also responded to N fertilizer applications on organic soils.

Even fields with high rates of N mineralization may respond to N fertilizer when water tables are less than 60 cm from the soil surface (Harris 1961) or when spring soil temperatures are cold. Guthrie and Duxbury (1978) observed that vegetables responded to spring applications of N fertilizer in a field where annual N mineralization rates were measured at 500-600 kg N $ha^{-1} yr^{-1}$. He attributed this to a combination of two factors. Firstly, overwinter leaching of NO_3-N created a shortage of available NO_3-N near the soil surface in spring, and secondly, cold soil temperatures restricted early season root growth into lower soil depths. Because of factors noted above, Michigan State University recommends applications of 0-220 kg N ha^{-1} in spring for production of vegetables crops on organic soils, despite substantial mineralization rates during the summer season (Lucas 1982).

The only reference to N fertilizer studies on organic soils in western Canada was from Racz et. al.(1978), who observed a yield increase of barley in response to N fertilizer on one of three organic soils tested. Despite the lack of research information, the use of nitrogen fertilizer for producing hay, cereal, and grass seed crops on organic soils in Manitoba, is a common practice among farmers (personal observations).

2.5.2 Nitrogen Fertilizer Efficiency

Soper et al.(1971) reported recovery of N from ammonium nitrate fertilizer, by barley grown on a Chernozemic soil in Manitoba, to average 52% for a range of application rates from 22 to 134 kg N ha^{-1}. This was calculated as :

$$\frac{\text{N uptake with N applied - N uptake without N}}{\text{Rate of N fertilizer applied}} * 100$$

They indicated that these results were consistent with recoveries reported by Allison (1965).

Recent studies on mineral soils support values of fertilizer recoveries reported by Soper. Kucey (1986) studied the effectiveness of three Nitrogen sources on barley production in Alberta. His two year study demonstrated the importance of both rainfall and nitrogen fertilizer rate on the efficiency of N applications. Fertilizer efficiency was 54% when N fertilizer was applied at the rate of 30 kg ha^{-1} and 44% when N was applied at 120 kg ha^{-1} in 1982. In 1983 the efficiency dropped substantially to 22% and 18% for the two fertilizer rates, respectively. The reduced efficiency in 1983 was attributed to much lower precipitation and a consequent reduction in plant growth. Simonas (1987) found similar results to those of Kucey (1986) while studying the N fertilizer requirements of barley crops in Greece. N fertilizer efficiency dropped from 40% to 25% as the rate of N applied increased from 20 kg ha^{-1} up to 100 kg ha^{-1}. Nielsen et. al.(1988) observed recovery rates of fertilizer N by barley crops to be 45, 58, and 44% over three years of field study on a Danish sandy clay loam.

Although considerable variation between experimental treatments and years were evident in the studies cited above, the average efficiency of fertilizer N were about 50% of the amount applied.

Only one study was found in the literature which documented efficiency of N fertilizer applied to organic soils. Cole (1985) found the apparent utilization of fertilizer N (ammonium sulphate), applied at rates of 40, 80, and 120 kg ha^{-1} on established grass in a lysimeter study, to be 75%, 75% and 76% for the three rates, respectively.

III. GENERAL MATERIALS AND METHODS

Experimental procedures for individual experiments are outlined, along with the results obtained, in the appropriate section. Analytical procedures used in analysis of soil and plant materials are outlined below:

3.1. Soil Analysis

NO_3-N: Soil samples weighing 2.5 g were placed in a flask, 1.0 g of activated charcoal was added, and then the mixture was shaken with 50 ml of 0.5M $NaHCO_3$ at pH 8.5. The soil extract was filtered through a Whatman # 30 filter paper and the filtrate analyzed for NO_3-N using a Tecnicon Auto Analyzer system and the modified colorimetric procedure of Kamphake et al.(1967).

$NaHCO_3$-Extractable P: Soil samples were extracted with $NaHCO_3$ as noted above for NO_3-N. The P in solution was determined colorimetrically using molybdate-ascorbic acid as reagent (Olsen et.al. 1954) and a Tecnicon Auto Analyzer.

SO_4-S: A twenty-five gram sample of soil was placed into a 250 ml erlenmeyer flask, 50 ml of 0.001 M $CaCl_2$ extracting solution was added, and the suspension shaken for 30 min. The mixture was then filtered through Whatman # 42 filter paper and the S content of the filtrate was determined using the $BaCl_2$-methylthymol blue method of Hill and Lodge

(1966).

Rubbed and Unrubbed Fiber Content: Both characteristics were determined using the method developed by Lynn and McKenzie (1971). A 25cc sample of moist organic soil was washed in a dispersing solution overnight, transferred to a 100 mesh sieve, and rinsed with water. The volume of soil remaining on the sieve represented the unrubbed fiber content and was recorded as a % of the original soil volume. The unrubbed fiber sample was then further washed under a stream of water, while rubbing between thumb and forefinger, until the water passing through the sample was clear. The volume of the rubbed soil was then measured and recorded as a % of the original 25 cc sample.

pH: Fifteen grams of soil, 60 ml of water, and 30 ml of 0.01M $CaCl_2$ were stirred into suspension and allowed to sit for 30 min. The pH was read using a pH meter equipped with a glass and calomel electrode (Schofield and Taylor 1955).

Exchangeable H: A 2.0 g sample of soil was added to 100 ml of 0.5M $BaCl_2$-triethanolamine solution and allowed to stand overnight. The suspension was filtered and the soil rinsed several times with Ba_2Cl-triethanolamine solution to a total volume of 190 ml. The leachate was titrated with 0.1 M HCl to an endpoint at pH 8 (Peech et al. 1962).

Ash Content: A 2.0 g sample of soil was placed into a muffle furnace and ignited at 400^oC for 12 hours. After ignition, the samples were cooled and weighed and ash content calculated (Ball 1964; Davies 1974)

Extraction of Exchangeable Cations: A 1.0 g sample of soil was mixed with 30 ml of 1M ammonium acetate at pH 7.0, and left to stand overnight. The mixture was then placed into a buchner funnel, the filtrate was suctioned, and the sample leached with NH_4OAc to a total volume of 80 ml (Schollenberger and Simon 1945).

Analysis for Ca, Mg, Na, K in NH_4OAc Extract:

1) Ca and Mg

One ml of filtrate, 2 ml of $LaCl_3$ solution, and 5 ml of 0.15 M LiCl were added to a 50 ml volumetric flask and brought to volume with deionized water. Concentration of Ca and Mg in the solution were determined using a Perkin-Elmer 560 atomic absorption spectrophotometer.

2) Na and K

Ten ml of filtrate, 2 ml of $LiNO_3$ solution and 5 ml of 0.15 M LiCl were added to a 50 ml volumetric flask and brought to volume with deionized water. K and Na concentrations in the flask were read using the Perkin-Elmer 560 atomic absorption spectrophotometer.

DTPA-Extractable Cu, Fe, Zn and Mn: Twelve and one half grams of soil was mixed with 25 ml of DTPA solution and shaken for two hr. The suspension was filtered through Whatman # 42 filter paper and the leachate analyzed for Cu, Fe, Zn, and Mn using a Perkin-Elmer 560 Atomic Absorption spectrophotometer (Follet and Lindsay 1971).

C:N Ratio: The C and N content of finely ground soil samples was determined using a Carbon, Hydrogen, Nitrogen (CHN) Analyzer (Stanton et.al. 1974).

3.2 Plant Tissue Analysis

Total Nitrogen: Total nitrogen content of plant material was determined using a Techator Kjeltec Auto 1030 Analyzer and the modified Kjeldahl-Gunning method described by Jackson (1975). Finely ground plant material was digested in acid to release amide and amine groups. Ammonia in the acid digest was distilled into an acidic solution and the excess acid backtitrated with NaOH using methyl red as an indicator. Digestion of plant materials was accelerated using special Kjeltabs S3.5 which contained potassium, sulphate and selenium.

P, K, S, Ca, Mg, Cu, Zn, Mn, Fe:

Dried finely ground plant material was digested in a nitric-perchloric acid mixture as described by Chapman and Pratt (1961). A 0.6 g sample was treated with 4 ml of concentrated HNO_3 and allowed to stand for 3 hr . Then 1.5 ml of $HClO_4$ was added and it was heated at 220°C using a Techator 40 digestion block. After cooling and filtering, the solution was transferred to a 25 ml volumetric flask and brought to volume with deionized water. This stock solution was used for all the following analysis:

Phosphorous: A 0.2 ml sample of the stock solution was diluted to 10 ml using 0.5 M $NaHCO_3$ adjusted to pH 8.5. The concentration of P in the solution was determined using a Technicon Auto Analyzer and the ascorbic acid - ammonium molybdate method (Olsen et. al. 1954).

Potassium: A 0.5 ml aliquot of stock solution was brought to 10 ml using 1.0M NH_4OAc at pH 7. The samples were analyzed using a Technicon Auto Analyzer coupled to a flame photometer.

Sulphur: A 0.5 ml stock sample was diluted to 10 ml using 0.001 M $CaCl_2$. Concentration of SO_4-S was determined using the procedure of Hill and Lodge (1966) and a Technicon Auto Analyzer.

Calcium and Magnesium: 0.5 ml. of stock solution was diluted to 10 ml using 1% $LaCl_3$ acidified with HCl. A Perkin-Elmer 560 atomic absorbtion spectrophotometer was used to obtain the Ca and Mg concentrations in the solution.

Copper, Zinc, Manganese, Iron: The stock solution was analyzed for Cu, Zn, Fe, and Mn content using a Perkin-Elmer 560 atomic absorbtion spectrophotometer.

IV. EXPERIMENTAL PROCEDURES AND RESULTS

4.1 The Response of Barley and Canola to Fertilizer Nitrogen on Organic Soils

Field experiments were carried out to obtain information which would be useful in improving nitrogen fertilizer recommendations for organic soils. Barley and canola, which are the most common annual crops grown on organic soils in Manitoba, were chosen as test crops. Several types of information were gathered to provide a basis from which sound N fertilizer recommendations for organic soils could be made:

1) Information on the yield and total N uptake of crops in response to added fertilizer N. This was needed to develop a general profile of the crop's nitrogen requirements as well as the degree to which fertilizer nitrogen taken up by the plant was converted into seed yield.

2) Information on the relationship between soil NO_3-N levels and crop response to amount of fertilizer N added. This information was obtained by performing identical experiments in which crop yields at various rates of fertilizer nitrogen were measured on several soils varying in soil NO_3-N levels. This information could then be used to estimate optimum N fertilizer requirements for farm fields based on their soil NO_3-N levels.

3) Information on the amount of organic N that was mineralized during the growing season. This information was needed to estimate amounts of N available to plants during the growing season in addition to inorganic N present at time of seeding.

4) Information on the % efficiency of added fertilizer N, that is, determining what portion of N fertilizer was actually utilized by the crop during the growing season.

5) Information on the stability of NO_3-N in the soil from fall to spring. If NO_3-N did not vary in soils from fall to spring, then farmers could choose to soil sample fields in fall rather than spring, providing them with more time to plan their fertilizer program. Sampling of soils in fall would also provide farmers with the advantage of sampling soils free of frost.

4.1.1 Experimental Procedures

a) Soil Types. Twenty field experiments (12 with barley and 8 with canola) were conducted at twelve locations in the southeastern and Interlake areas of Manitoba between October 1985 and September of 1987. The soils varied with respect to type and depth of organic material, type of subsoil material, drainage, C:N ratio, degree of decomposition and initial levels of soil NO_3-N (Tables 1 and 2).

b) Soil Sampling. The soil on each site was sampled in fall (mid-October) and in spring (early May) for soil NO_3-N content. Six 1.2 M test holes were made using a 3.5 cm diameter auger in a grid pattern at each site, for each sampling time. Samples were taken from the 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm depths. Samples were placed into plastic bags, kept cool during transit, and stored in a frozen state prior to analysis. Samples were thawed at room temperature, and oven dried at $100^{o}C$. Soil samples were also taken at harvest from the above noted depths on plots which had not received nitrogen fertilizer to provide information to assess apparent N mineralization rates.

A composite sample from the 0 to 15 cm depth, representing 10 random spots on the experimental area was also taken prior to fertilization of the soils. This sample was used for determination of some physical and chemical characteristics.

Table 1. Locations and soil types of field experimental sites.

Year and Site	Legal Location	Soil Type
1986:		
1 Clandeboye(1)	SW-10-15-3E	Gleysol,peaty phase
2 Elma	SW-4-10 12E	Terric Mesisol
3 Marchand	SE-25-5-8E	Terric Mesisol
4 Piney	SE-25-1-11E	Terric Mesisol
5 Seven Sisters	NW-12-13-10E	Terric Mesisol
6 Sundown	SE-12-2-9E	Terric Mesisol
1987:		
7 Clandeboye(2)	NE-10-15-3E	Gleysol,peaty phase
8 LaBroquerie	SW-1-7-8E	Terric Mesisol
9 Medika	NW-28-9-12E	Terric Mesisol
10 Riverton	NW-33-23-4E	Terric Mesisol
11 Washow Bay	SW-19-25-4E	Regosol,peaty phase
12 Whitemouth	NW-14-12-11E	Terric Mesisol

Table 2. Physical and chemical characteristics of soils used.

	Site #					
Soil Characteristic	#1	#2	#3	#4	#5	#6
% organic matter...	58	92	84	85	89	74
pH	7.5	6.6	7.3	6.9	6.1	7.6
Depth of organic layer (cm)	20	50	90	100	60	40
Drainage	fair	good	good	good	good	poor
Unrubbed fiber(%)..	46	50	68	52	58	56
Rubbed fiber(%)....	18	32	42	24	38	26
Exch Ca (cmol/kg)	54	91	129	100	76	86
Exch Mg (cmol/kg)	11	28	33	37	27	21
Exch Na (cmol/kg)	1	2	0	1	2	2
Exch K (cmol/kg)	5	8	1	4	5	8
Exch H (cmol/kg)	5	23	18	23	38	14
Total cations (cmol/kg)	76	152	181	165	147	132
NO_3-N (kg ha^{-1}*) to:						
15 cm	20	52	25	65	1	5
30 cm	71	124	75	94	2	10
60 cm	280	193	260	130	5	12
90 cm	521	235	400	158	9	17
120 cm	639	260	518	209	13	21

* Factors used to convert NO_3-N measurements from ppm to Kg ha^{-1} are given in Table 4a, APPENDIX)

Table 2 continued.

Soil Characteristic	Soil Site # #7	#8	#9	#10	#11	#12
% organic matter...	50	72	84	88	88	87
pH	7.4	7.5	7.6	5.2	6.2	7.2
Depth of organic layer (cm)	20	50	60	40	40	110
Drainage	fair	poor	good	good	good	good
Unrubbed fiber(%)..	46	38	48	44	70	58
Rubbed fiber(%)....	20	22	26	26	38	38
Exch Ca (cmol/kg)	46	91	155	47	55	91
Exch Mg (cmol/kg)	12	28	30	48	46	28
Exch Na (cmol/kg)	7	2	2	2	2	2
Exch K (cmol/kg)	3	6	8	6	8	8
Exch H (cmol/kg)	6	14	12	53	34	23
Total cations (cmol/kg)	74	140	205	156	145	152
NO_3-N (kg ha^{-1}*) to:						
15 cm	20	6	11	22	14	26
30 cm	41	9	27	54	29	45
60 cm	151	13	38	130	36	77
90 cm	259	16	53	170	43	90
120 cm	357	--	66	191	48	120

* Factors used to convert NO_3-N measurements from ppm to Kg ha^{-1} are given in Table 4a, APPENDIX)

c) Cropping Procedures. Barley [*Hordeum vulgare* var. Bedford] was seeded at 90 kg ha^{-1} in 1986. The variety Argyle, rather than Bedford, was seeded (at 90 kg ha^{-1}) in 1987 because it was considered to be more tolerant to copper deficiency than Bedford. Canola (*Brassica campestris* var. Tobin) was seeded at 14 kg ha^{-1} in 1986 and 7 kg ha^{-1} in 1987. The seeding rate in 1986 was higher than intended due to error. The canola seed was treated with Furadan, a systemic insecticide, prior to seeding. The seeding dates for each crop and experimental site are shown in Table 3.

Table 3. Seeding dates for barley and canola.

	Seeding Dates	
Field Site	Barley	Canola
1986		
Clandeboye(1)	June 17	June 3
Elma	May 24	June 4
Marchand	May 20	June 5
Piney	May 29	June 5
Seven Sisters	May 28	June 4
Sundown	June 9	June 9
1987		
Clandeboye(2)	May 19	*
LaBroquerie	May 26	May 26
Medika	May 18	May 28
Riverton	May 22	May 22
Washow Bay	May 21	May 21
Whitemouth	May 15	May 28

* not seeded

The crops were seeded in rows 15 cm apart using a press drill. Individual treatment plots were 1.5 X 7 M, and were arranged in a randomized complete block design. Blocks consisted of eight treatments which were replicated five times and separated from each other by a 2-M pathway. The canola and barley experiments were separated by a 6-M area and a 1.5-M guard plot was located at the outer end of each replicate to prevent border effects.

Barley plots were sprayed with dicamba and MCPA-NH_4 to control broadleaf weeds. Canola plots were sprayed with glyphosate seven or more days prior to seeding to control perennials and with sethoxydim after emergence to control grassy weeds. All herbicides were applied at recommended rates.

d) Fertilizers. All plots were initially fertilized with 10 kg Cu ha^{-1} as granular $CuSO_4$ * $5H_2O$ which was broadcast and incorporated to a depth of 15 cm prior to seeding. An additional 0.2 kg Cu ha^{-1}, as Cu EDTA, was added to barley grown at Elma and Marchand as a foliar application. The EDTA fertilizer was added at the preheading stage using a field sprayer and was added because slight copper deficiency symptoms were observed at these two sites in 1986.

Nine kg P ha^{-1} (as monoammonium phosphate) plus 26 kg K ha^{-1} (as potassium chloride) were banded into the soil at a depth of 10 cm before seeding for all barley plots. Thirteen kg P ha^{-1} and 16 kg K ha^{-1} was also applied with the seed of barley at time of seeding. Nine kg P ha^{-1} (as monoammonium phosphate) and 42 kg K ha^{-1} (as potassium chloride) were banded into the soil at a depth of 10 cm before seeding for all canola plots. An additional 9 kg P ha^{-1} was applied with the canola seed at time of seeding.

All barley plots in 1987, as well as the Clandeboye(1) site in 1986 were also treated with 5 kg Mn ha^{-1} ($MnSO_4$ * 11 H_2O) drilled with the seed.

The nitrogen fertilizer treatments applied to both crops are given in Table 4. Nitrogen fertilizer treatments consisted of ammonium nitrate (NH_4NO_3), hand broadcast onto the soil surface after seeding. Rates of N included 0, 20, 40, 60, 90, 120, 180, and 240 kg N ha^{-1}. Since the barley and canola was treated with monoammonium phosphate to provide P, all barley and canola plots received 10 and 8 kg N ha^{-1}, respectively, above that applied as NH_4NO_3. Thus, the range of total N fertilizer applied to the plots was 10 to 250 kg N ha^{-1} for barley and 8 to 248 kg ha^{-1} for canola. Since the difference in rates for the two crops was very small, all tables and discussion to follow will refer to rates of N as being 10, 30, 50, 70, 100, 130, 190, and 250 kg N ha^{-1} for both crops.

e) <u>Midseason Harvest</u>: Thirty randomly selected whole-plant samples of barley and canola were harvested from the moderately fertilized plot (60 kg N ha^{-1}) at each site. [Barley and canola were cut at the early heading stage and early flowering stage, respectively (Tables 1a and 2a, APPENDIX)]. The samples were air dried, and analyzed to assess plant nutrient status.

f) <u>Final Harvest</u>. A representative whole-plant sample was harvested from the center three rows of each plot at maturity (Table 5). Samples were cut by hand, approximately 8 cm from the soil surface, from three 1.6-M row lengths. The samples were placed in labelled porous cotton or nylon bags and transported to a covered shed for air drying. When suitably dry, whole samples were threshed using a stationary threshing machine. Grain and straw from each sample were weighed and yield determined. Composite samples of straw and grain from the five replicates for each treatment were prepared and finely ground for total N analysis.

Table 4. Rates of fertilizer applied for canola and barley.

	Total amount of fertilizer applied in Kg ha^{-1}				
Crop	Nitrogen	P	K	Cu	Mn
Barley	10	22	42	10	5
	30	22	42	10	5
	50	22	42	10	5
	70	22	42	10	5
	100	22	42	10	5
	130	22	42	10	5
	190	22	42	10	5
	250	22	42	10	5

	Nitrogen	P	K	Cu
Canola	10	18	42	10
	30	18	42	10
	50	18	42	10
	70	18	42	10
	100	18	42	10
	130	18	42	10
	190	18	42	10
	250	18	42	10

g) Statistical Analysis: The MSTAT microcomputor program (version 4.0) was used to analyze experimental data. The field experiments were analyzed as randomized complete block designs using ANOVA and various range separation tests. Difference in NO_3-N values from soils sampled in fall and spring were compared using the Student's t-test. Relationships between % yield, N uptake and soil NO_3-N levels were explored using linear and quadratic regression equations.

Table 5. Harvest dates for barley and canola.

	Harvest Dates	
	Barley	Canola
Site and year		
1986		
Clandeboye	Sept 23	Aug 13
Elma	Aug 27	Aug 20
Marchand	Aug 25	Aug 22
Piney	Aug 21	Aug 21
Seven Sisters	Aug 27	Aug 19
Sundown	Aug 29	Aug 21
1987		
Clandeboye 2	Sept 9	*
LaBroquerie	Aug 17	Aug 10
Medika	Aug 17	Aug 17
Riverton	Aug 26	not harvested
Washow Bay	Aug 26	not harvested
Whitemouth	Aug 18	not harvested

* not planted

4.2 Results and Discussion

Barley at all twelve sites over the two years of the study matured and was harvested. Only eight of the eleven canola experiments were harvested; canola at the Riverton and Washow Bay sites did not emerge properly due to a very dry spring in 1987 and the canola crop at Whitemouth was destroyed by hail prior to harvest in 1987.

4.2.1 Crop Response to Fertilizer Nitrogen

a) YIELD: Barley plots with N fertilizer in excess of 70 kg ha^{-1} usually yielded between about 2,000 and 3,000 kg ha^{-1} at all sites for both years (Tables 6 and 7). Canola usually yielded between about 700 and 1500 kg ha^{-1} at all sites when N fertilizer in excess of 70 kg ha^{-1} was applied (Tables 8 and 9). Two exceptions to the above trends were noted; barley yielded exceptionally well (4120 kg ha^{-1}) at Seven Sisters, whereas canola yields were very poor (with a maximum of 250 kg ha^{-1}) at Elma. The canola plants at Elma were spindly and displayed a purpling in the leaves, but no phosphorous or other nutrient deficiency was detected in plants harvested at the flowering stage (Table 2a, APPENDIX). The reason for the low yield at Elma is unknown.

Table 6. The effect of N fertilizer on the yield of barley grain (kg ha^{-1}) in 1986.

Fertilizer N Added ($Kg\ ha^{-1}$)	Yield of Barley Grain ($kg\ ha^{-1}$) Cland(1)	Elma	Marchand	Piney	S.Sister	Sundown
10	1950 a*	2080 a	2360 bc	2572 a	2284 e	940 d
30	2200 a	2208 a	2606 abc	2498 ab	2580 de	1568 c
50	2100 a	2272 a	2406 abc	2478 ab	3552 abc	1856 c
70	2420 a	1920 a	2193 c	2498 ab	3786 ab	2306 b
100	2010 a	1938 a	3140 a	2660 a	4120 a	2342 b
130	2020 a	2484 a	2678 abc	2160 ab	3104 cd	2684 ab
190	2170 a	2356 a	2960 ab	1928 b	3314 bc	2452 ab
250	2410 a	-----	2788 abc	2240 ab	3360 bc	2904 a

* Duncan's multiple range test. Values followed by the same letter within columns are not significantly different at alpha=.10

Table 7. The effect of N fertilizer on the yield of barley grain (kg ha^{-1}) in 1987.

Fertilizer N Added ($Kg\ ha^{-1}$)	Yield of Barley Grain ($kg\ ha^{-1}$) Cland(2)	LaBroq.	Medika	Riverton	Washow B	W'mouth
10	2052 b*	1094 e	2054 c	2158 b	2348 b	2572 ab
30	2306 ab	1170 e	2424 bc	2894 a	2986 a	2498 abc
50	2180 ab	1222 de	2634 ab	2518 ab	3080 a	2478 abc
70	2220 ab	1468 bcd	2616 ab	2416 ab	3092 a	2498 abc
100	2259 ab	1622 b	2882 a	2352 b	2876 a	2660 a
130	2228 ab	1350 cde	2604 ab	2336 b	2892 a	2160 cd
190	2424 ab	1570 bc	2192 c	2174 b	2578 ab	1928 d
250	2530 a	2050 a	2588 ab	2266 b	2884 a	2240 bcd

* Duncan's multiple range test. Values followed by the same letter within columns are not significantly different at alpha=.10.

Table 8. The effect of N fertilizer on the yield of canola seed in 1986.

Fertilizer N Added (Kg ha^{-1})	Yield of Canola Seed (kg ha^{-1}) Cland(1)	Elma	Marchand	Piney	S.Sister	Sundown
10	938 b*	244 a	1164 b	1184 a	824 d	430 d
30	814 b	212 a	1004 b	806 b	1068 cd	626 abc
50	1038 ab	200 a	1106 b	884 ab	1158 bc	596 bc
70	942 b	192 a	1026 b	1072 ab	1426 ab	692 ab
100	948 b	202 a	924 b	1102 ab	1380 abc	562 bcd
130	918 b	190 a	948 b	916 ab	1130 bcd	756 a
190	966 b	238 a	1202 ab	872 ab	1514 a	520 cd
250	1236 a	250 a	1472 a	826 ab	1364 abc	592 bc

* Duncan's multiple range test. Values followed by the same letter within columns are not significantly different at alpha=.10.

Table 9. The effect of N fertilizer on the yield of canola seed in 1987.

Fertilizer N Added (Kg ha^{-1})	Yield of canola seed (Kg ha^{-1})	
	LaBroquerie	Medika
10	1194 b*	998 ab
30	1172 b	1008 ab
50	1322 ab	1108 a
70	1398 ab	1092 a
100	1342 ab	974 ab
130	1324 ab	996 ab
190	1456 a	984 ab
250	1334 ab	928 b

* Duncan's multiple range test. Values followed by the same letter within columns are not significantly different at alpha=.10.

A significant yield increase in response to one or more of the rates of fertilizer nitrogen added was obtained in eight barley experiments (Marchand, Sundown, Seven Sisters, Clandeboye2, LaBroquerie, Medika, Riverton and Washow Bay) and five canola experiments (Clandeboye1, Marchand, Sundown, Seven Sisters, and LaBroquerie) during the two years of study. Increase in yield, due to applied N, generally varied inversely with soil NO_3-N levels (Table 2 and Tables 6,7,8,9). Crops did not show significant yield response to applications of N fertilizer at most sites where soil NO_3-N levels were high. Significant responses occured at sites with high soil NO_3-N only when N application rates were very high. Yields were increased significantly by most rates of added N when the soil NO_3-N contents were low.

The yield of barley at Whitemouth generally decreased with increases in rate of fertilizer N. This site had a relatively high level of soil NO_3-N in spring and was damaged to some extent by hail four days prior to harvest. It is possible that greater damage occurred to the fertilized plots due to reduced straw strength as a result of excess N fertilizer.

Barley and canola demonstrated similar significant increases in yield in response to N fertilizer additions at six of the eight sites where both crops were grown. Exceptions occurred at Clandeboye(1) and Medika. At Clandeboye(1), canola increased in yield when a high rate of N fertilizer was applied, whereas barley did not. At Medika, barley yield increased when N fertilizer was applied but canola did not.

b) NITROGEN UPTAKE: Unlike grain yield, uptake of N continued to increase with increases in rate of fertilizer N added. Uptake of N by barley reached a maximum when 190 or 250 kg N ha^{-1} was added at eleven of the twelve soils tested (Tables 10 and 11). Similarly, maximum uptake of N by canola was achieved on plots fertilized with either 190 or 250 kg N ha^{-1} at all eight sites (Tables 12 and 13). This is consistent with observations made by others (Soper et.al. 1971; Kucey 1986) who noted that luxury consumption of nitrogen occurred at very high rates of N fertilizer.

Table 10. The effect of N fertilizer on the uptake of N by barley in 1986.

Fertilizer N Added (Kg ha^{-1})	N uptake by barley (kg N ha^{-1})					
	Cland1	Elma	Marchand	Piney	S.Sister	Sundown
10	77	112	119	111	50	26
30	81	119	137	135	55	43
50	72	120	123	126	71	50
70	75	115	116	135	80	64
100	66	120	149	137	106	72
130	74	117	126	142	103	82
190	79	130	138	133	152	93
250	86	---	139	155	175	124

Table 11. The effect of N fertilizer on the uptake of N by barley (kg N ha^{-1}) in 1987.

Fertilizer N Added (Kg ha^{-1})	N Uptake by Barley (kg ha^{-1})					
	Cland2	LaBroq.	Medika	Rivertn	Washow B	W'mouth
10	79	49	61	76	53	82
30	91	57	68	95	71	75
50	77	59	85	92	73	98
70	80	66	85	94	74	92
100	82	70	100	97	82	92
130	94	67	104	106	92	83
190	90	73	107	114	108	109
250	93	92	120	109	105	138

Table 12. The effect of N fertilizer on the uptake of N by canola in 1986.

Fertilizer N Added (Kg ha^{-1})	N Uptake by Canola (kg N ha^{-1})					
	Cland(1)	Elma	Marchand	Piney	S.Sister	Sundown
10	96	52	131	83	37	26
30	89	53	118	68	48	35
50	118	49	126	82	54	41
70	99	58	118	92	65	41
100	102	48	107	90	62	46
130	93	56	93	88	71	62
190	103	52	128	101	102	64
250	124	59	144	99	98	87

Table 13. The effect of N fertilizer on the uptake of N by canola in 1987.

Fertilizer N Added Kg ha^{-1}	N Uptake by Canola (Kg N ha^{-1})	
	LaBroquerie	Medika
10	59	59
30	62	57
50	68	71
70	75	74
100	75	66
130	83	74
190	106	74
250	100	88

4.2.2 The Relationship between Crop Response to N Fertilizer and Soil NO_3-N Levels in Spring

The field experiments indicated that response to nitrogen fertilizer decreased with increasing initial soil NO_3-N levels. To further study this phenomenon, relationships between initial soil NO_3-N and i) % yield [(grain yield of unfertilized plot / maximum grain yield of N fertilized plot) *100] and ii) total N uptake by the crop, were investigated.

a) <u>% Yield</u>: Both linear and quadratic equations were used to test the relationship between % yield and amounts of NO_3-N in the soil to various depths (Tables 14, 15, 16 and 17). The relationship between % yield and amounts of NO_3-N in the soil to various soil depths was determined in order to provide information on depth of sampling required to obtain a good measure of N supply to the plants. Figure 1 shows the relationship between % yield of barley and the amount of NO_3-N in the soil to a depth of 60 cm at time of planting. Percent yield increased as levels of soil NO_3-N increased to a maximum of about 130 kg NO_3-N ha^{-1}. An r value of 0.78 for a quadratic equation describing this relationship was obtained. Thus, about 61% of the variation in % yield could be explained by variations in amount of NO_3-N in the surface 60 cm of soil.

The relationships were described better by quadratic regression equations than by linear models. Linear models had a much poorer fit to the data, especially at soil sampling depths below 30 cm, for both barley and canola. Other researchers found that linear regression models described relationships between % yield and amounts of NO_3-N in the soil better than quadratic equation models. Soper (1971) found that a linear relationship existed between % yield and amount of soil NO_3-N for rapeseed (r=0.92). Herron (1968), working with wheat, also obtained a

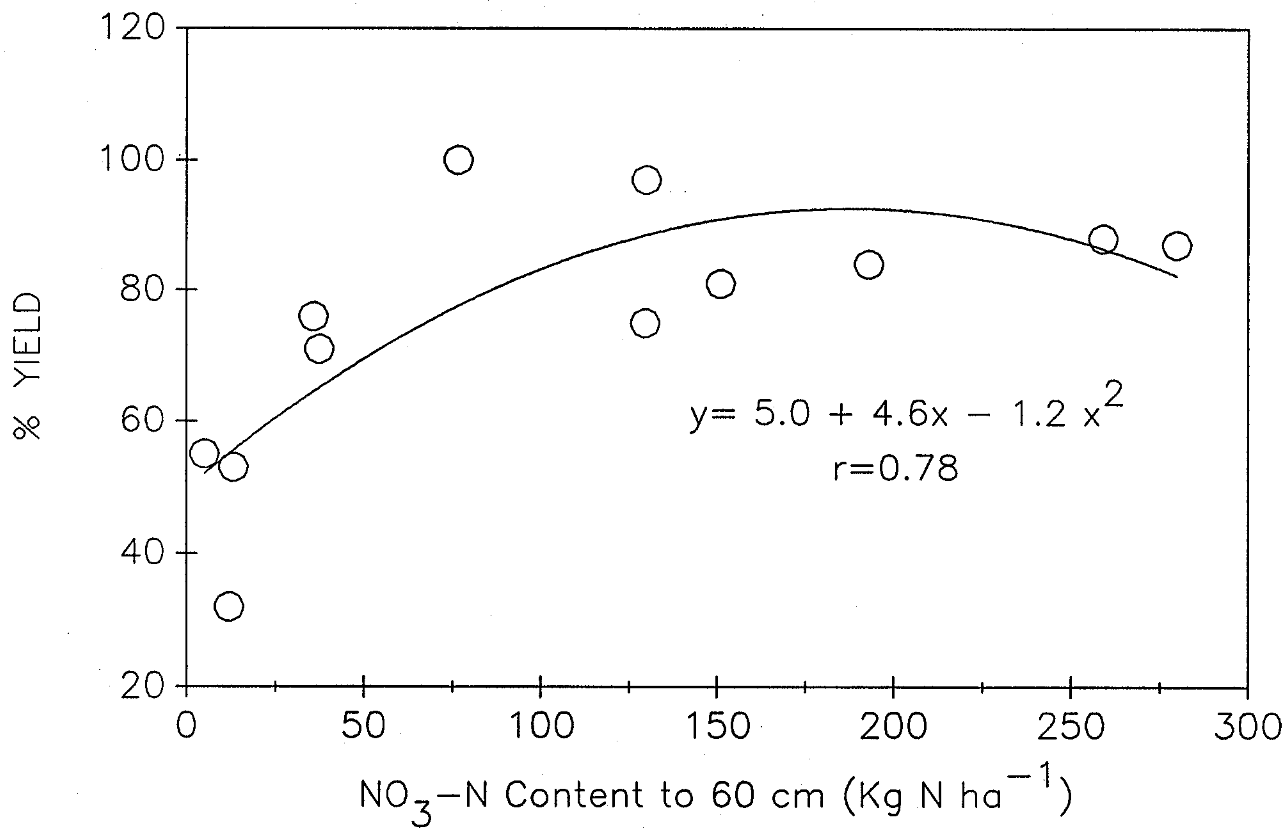

Fig. 1 Relationship between % yield of barley and NO_3-N content of soils to a depth of 60 cm.

linear relationship (r=0.73) between % yield and amount of NO_3-N in the soil. Soper and Huang 1963, however, found that the relationship was best described by a curvilinear function (r=0.95) in their work with barley.

The best relationships between %yield and soil NO_3-N content were obtained when NO_3-N was measured to a depth of 15 or 30 cm for barley (r=0.86), and 60 cm for canola (r=0.86). Correlation coefficients of 0.69 or better were achieved at all depths for the quadratic regressions. Soper (1971) found the best relationships were achieved when amounts of soil NO_3-N were measured to a depth of 60 cm (r=0.92), although the relationship between % yield and amount of NO_3-N to depths of 30 and 90 cm were also reasonably good. Other researchers (Cook et. al. 1956; Brown 1984; Herron et. al. 1968) reported various r values ranging from r=0.38 to r=0.73 for linear or quadratic equations relating yields to NO_3-N contents at depths of 15, 60, and 180 cm.

Table 14. Linear regression equations describing the relationship between % yield of barley and soil NO_3-N content to various soil depths.

Sampling Depth (cm)	Linear Regression Equation	r Value
0-15	y = 58.7 + 0.73x	0.70
0-30	y = 56.7 + 0.38x	0.71
0-60	y = 60.66 + 0.13x	0.63
0-90	y = 64.10 + 0.066x	0.55
0-120	y = 66.39 + 0.047x	0.51

Table 15. Quadratic regression equations describing the relationship between % yield of barley and soil NO_3-N content to various soil depths.

Sampling Depth (cm)	Quadratic Regression Equation	r value
0-15	$y = 41.1 + 2.53x - (.03)x^2$	0.86
0-30	$y = 42.0 + 1.20x - (.007)x^2$	0.86
0-60	$y = 49.8 + 0.46x - (.001)x^2$	0.78
0-90	$y = 54.25 + 0.24x - (.0004)x^2$	0.71
0-120	$y = 54.80 + 0.20x - (.0002)x^2$	0.69

Table 16. Linear regression equations describing the relationship between % yield of canola and soil NO_3-N content to various soil sampling depths.

Sampling Depth (cm)	Linear Regression Equation	r value
0-15	$y = 66.48 + 0.57x$	0.79
0-30	$y = 65.84 + 0.27x$	0.72
0-60	$y = 73.34 + 0.05x$	0.37
0-90	$y = 76.09 + 0.02x$	0.23
0-120	$y = 74.67 + 0.019x$	0.25

Table 17. Quadratic regression equations for the relationships between % yield of canola and soil NO_3-N content to various soil depths.

Sampling Depth (cm)	Quadratic Regression Equation	r value
0-15	$y = 62.19 + 1.13x - (.0086)x^2$	0.81
0-30	$y = 64.91 + 0.34x - (.0006)x^2$	0.73
0-60	$y = 61.58 + 0.55x - (.0019)x^2$	0.86
0-90	$y = 65.60 + 0.25x - (.0005)x^2$	0.75
0-120	$y = 59.17 + 0.25x - (.0004)x^2$	0.85

b) Total N Uptake: Figure 2 shows the relationship between N uptake of barley and the amount of NO_3-N in the surface 30 cm of soil. There was a very high degree of fit (r=0.80 to 0.91) between N uptake and soil NO_3-N content when a quadratic regression equation was used for all depths for barley and for all depths except the 0-15 cm depth for canola (Tables 18, 19, 20, and 21). Linear regression equations provided a high degree of fit between N uptake and soil NO_3-N content ($r > 0.80$) at all sampling depths except for the 0-120 cm depth for barley . Linear relationships between N uptake and amount of NO_3-N to depths of 60, 90, and 120 cm were reasonably good but the relationships between N uptake and soil NO_3-N content to depths of 15 or 30 cm were poor for canola. Soper (1971) found that quadratic and linear relationships described N uptake by rapeseed as a function of soil NO_3-N content almost equally well (r=0.92 and r=0.88, respectively). Soper and Huang (1963) suggested that a logarithmic function best described the relationship between N uptake of barley and

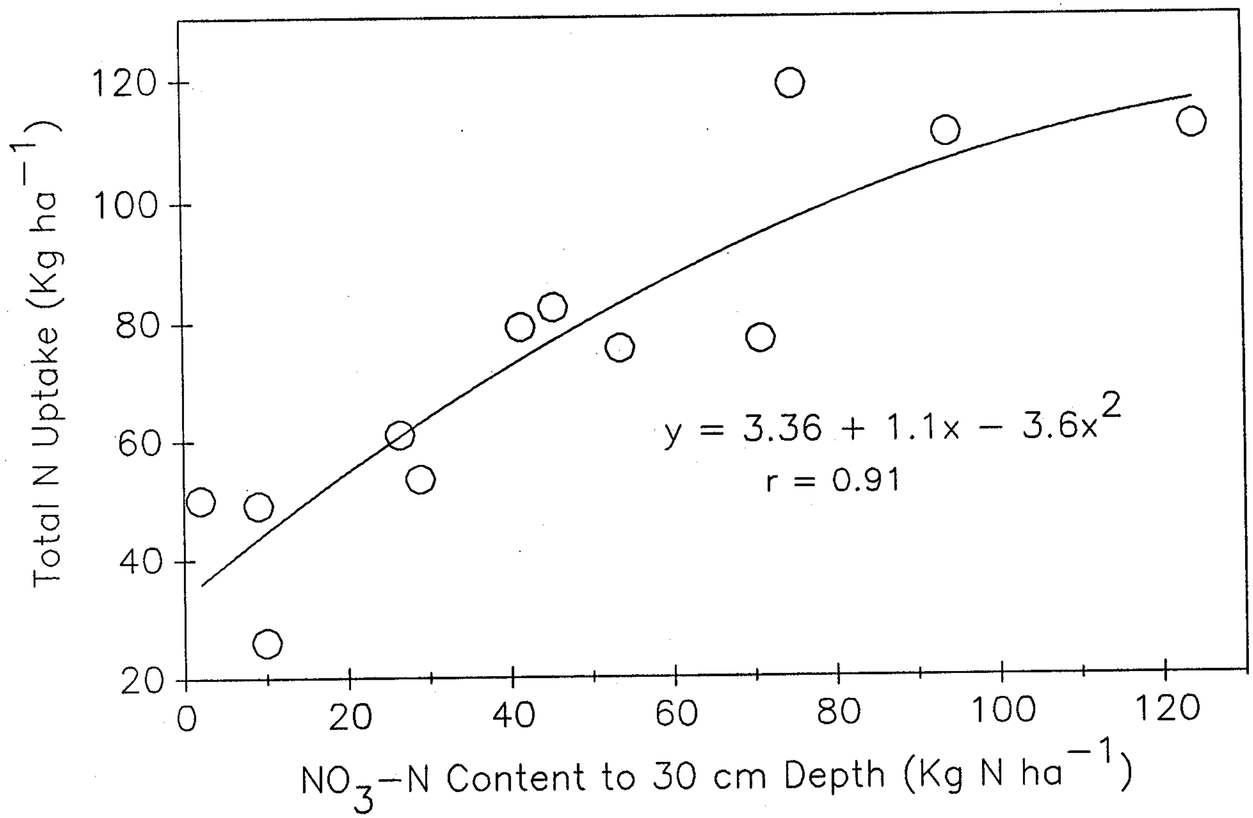

Fig. 2 Relationship between N uptake by barley and soil NO_3–N content to a depth of 30 cm.

soil NO_3-N content. The two studies showed that the best r values for the above relationships were obtained when amounts of NO_3-N in the soil to depths of at least 60 cm were considered (ie.) the values increased as depth of sampling for NO_3-N content increased.

Table 18. Linear regression equations for the relationship between total N uptake of barley and soil NO_3-N content to various soil depths.

Sampling Depth (cm)	Linear Regression Equation	r value
0-15	$y = 46.87 + 1.24x$	0.82
0-30	$y = 41.36 + 0.69x$	0.89
0-60	$y = 40.37 + 0.24x$	0.80
0-90	$y = 43.41 + 0.14x$	0.80
0-120	$y = 58.55 + 0.08x$	0.59

Table 19. Quadratic regression equations for the relationships between total N uptake by barley and soil NO_3-N content to various soil depths.

Sampling Depth (cm)	Quadratic Regression Equation	r value
0-15	$y = 29.60 + 3.02x - (.027)x^2$	0.89
0-30	$y = 33.69 + 1.12x - (.0036)x^2$	0.91
0-60	$y = 42.12 + 1.12x - (.0003)x^2$	0.80
0-90	$y = 38.34 + 0.25x - (.0002)x^2$	0.81
0-120	$y = 35.96 + 0.37x - (.0005)x^2$	0.85

Table 20. Linear regression equations for the relationships between total N uptake by canola and soil NO_3-N content to various soil depths.

Sampling Depth (cm)	Linear Regression Equation	r value
0-15	$y = 56.36 + 0.50x$	0.34
0-30	$y = 48.80 + 0.37x$	0.50
0-60	$y = 40.37 + 0.24x$	0.80
0-90	$y = 43.42 + 0.14x$	0.80
0-120	$y = 38.50 + 0.12x$	0.84

Table 21. Quadratic regression equations for the relationships between total N uptake by canola and soil NO_3-N contents to various soil depths.

Sampling Depth (cm)	Quadratic Regression Equation	r value
0-15	$y = 27.47 + 4.30x -(0.058)x^2$	0.72
0-30	$y = 22.92 + 2.36x -(0.017)x^2$	0.88
0-60	$y = 42.12 + 0.162x -(0.0003)x^2$	0.80
0-90	$y = 38.34 + 0.25x -(0.0002)x^2$	0.81
0-120	$y = 30.54 + 0.24x -(0.0002)x^2$	0.87

4.2.3. The Relationship between Grain Yield and Total N Uptake

Both linear and quadratic regression equations were used to test the relationship between grain yield and the total amount of N taken up by barley and canola at all sites (Table 22). The relationship was described slightly better by quadratic than by linear equations for both barley (r=0.39 vs. 0.36) and canola (r=0.55 vs. 0.53). None of the regression equations had a very high degree of fit to the data, however; only 13 to 30% of the variation in yield among all sites could be ascribed to plant uptake of nitrogen. This indicates that many factors other than total uptake of N by barley and canola are involved in determining grain yields. Figures 3 and 4 illustrate two of the relationships given in Table 22.

Table 22. The relationship between grain yield and N uptake of barley and canola at maturity.

Crop	Quadratic Regression Equation	r value
Barley	$y = 977 + 22.5x - (.08)x^2$	.39
Canola	$y = -73.7 + 18.9x - (.071)x^2$	.55
	Linear Regression Equation	
Barley	$y = 1706 + 6.6x$	.36
Canola	$y = 361 + 7.16x$	.53

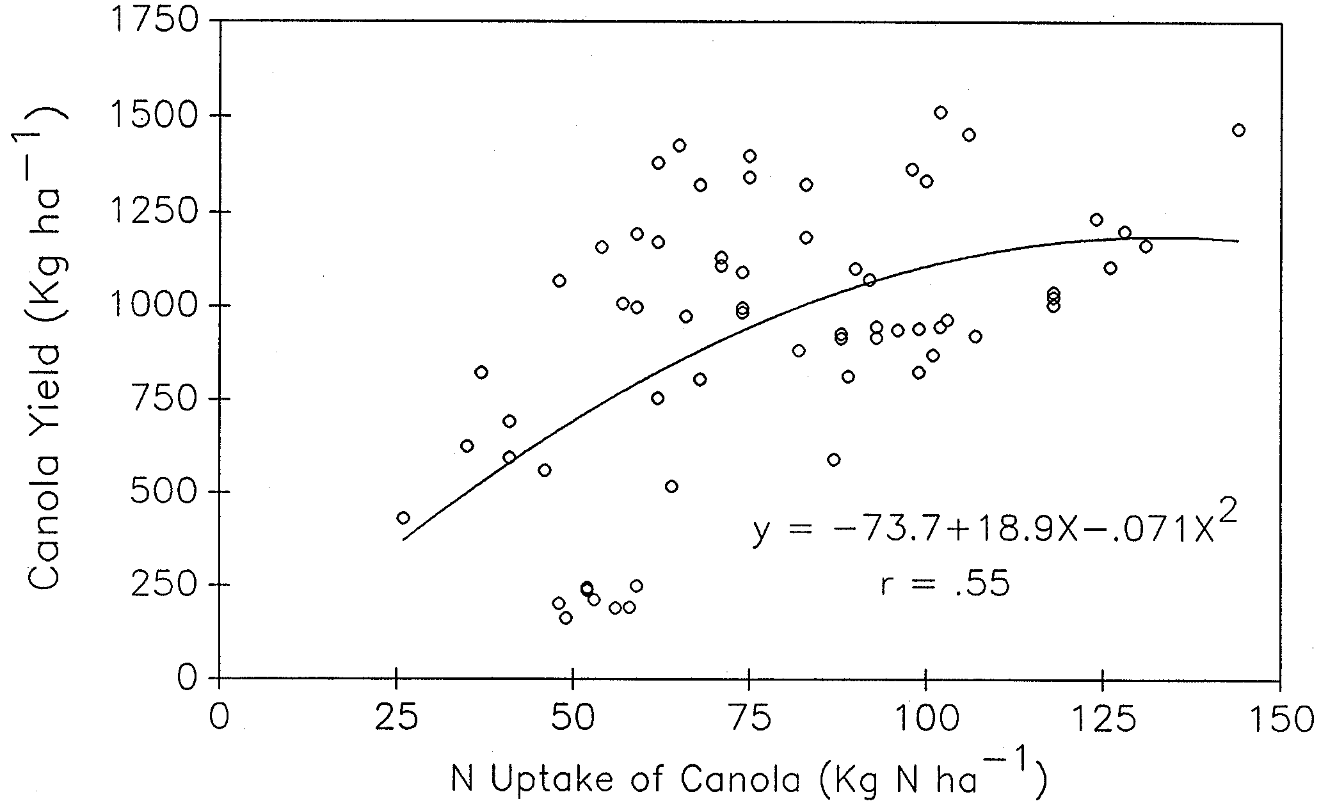

Fig. 3 Relationship between grain yield of canola and total N uptake.

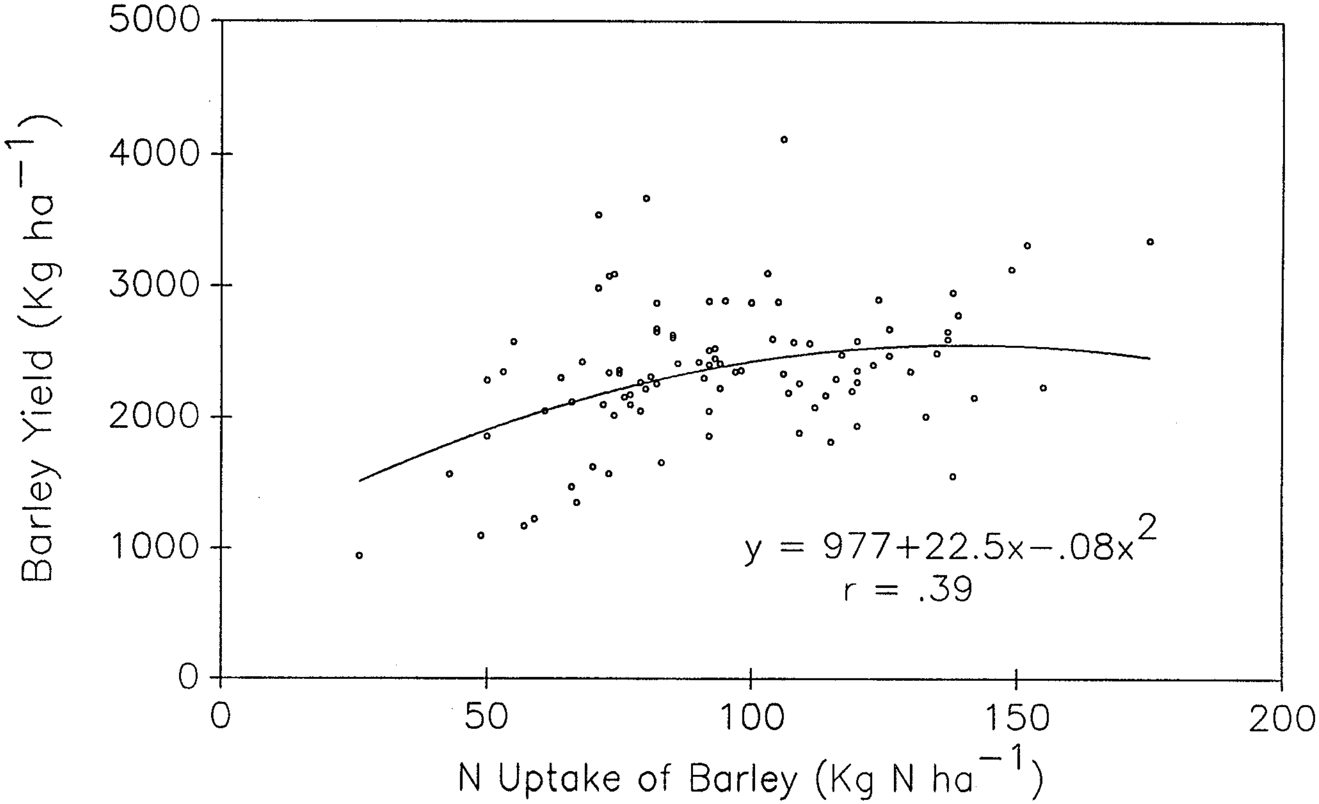

Fig. 4 Relationship between grain yield of barley and total N uptake.

4.2.4 Mineralization of Soil Nitrogen during the Growing Season

The apparent amount of soil N mineralized during the growing season at each site, and for each crop, was calculated using the following expression:

Amount of N mineralized =

[soil NO_3-N content at harvest, to a depth of 120 cm for plot without fertilizer N + total N taken up by the crop grown without fertilizer N] - [soil NO_3-N content in spring to a depth of 120 cm].

Apparent amounts of N mineralized varied considerably among sites, especially for sites which contained very high levels of NO_3-N in spring (Table 23). Measured amounts of N mineralized varied from -105 kg ha^{-1}, at Clandeboye(2), to +170 kg ha^{-1} at Marchand, for sites with very high concentrations of NO_3-N in spring. At these sites, apparent mineralization was also often quite different for barley and canola. The variation noted above was most likely a function of spatial variation of NO_3-N in the soil, resulting in a large sampling error, rather than the influence of the type of crop or of N transformation processes. The coefficient of variation (C.V.) for NO_3-N levels among groups of fall and spring soil samples varied between 17% and 64% at the twelve sites (Table 24). For sites with NO_3-N levels of about 200 kg ha^{-1}, even a variation of 17% would result in errors of 34 kg N ha^{-1}. Thirty-four kg N ha^{-1} represents a very large error when gains that might be expected from mineralization of organic N over the same period of time would be about 34 kg N ha^{-1}. Variability in the measured amount of N mineralized could also have been influenced by processes such as denitrification and leaching in plots with very high concentrations of NO_3-N.

Table 23. Amounts of N mineralized during the growing season for sites with low and high levels of soil NO_3-N.

Site	NO_3-N content in spring to 120 cm (Kg ha^{-1})	N Mineralized (kg ha^{-1}) Barley	Canola	C:N Ratio	Average Soil Temp °C (Jn 15-Au 15) at 20 cm depth
Low soil NO_3-N:					
Sundown	21	23	22	15.4	15.5
S. Sisters	25	25	59	23.1	16.7
LaBroquerie	16	73	56	12.6	16.1
Medika	66	11	7	16.5	14.6
Washow Bay	48	23	----	15.4	11.5
Average N mineralized in sites above:				33.2 kg/ha	
High soil NO_3-N:					
Clandeboye1	639	0	-60	15.0	15.8
Elma	260	15	-105	16.4	15.6
Marchand	518	170	32	21.6	15.2
Piney	209	-56	-62	15.6	15.7
Clandeboye2	357	-72		13.0	15.7
Riverton	191	-46		13.4	13.6
Whitemouth	120	-14		21.1	14.9
Average N mineralized (all 12 sites): 5.0 kg/ha					

Table 24. Temperature, drainage, soil C:N ratio and amounts of N mineralization in sites with low initial NO_3-N levels.

Site	N Mineralized (kg ha^{-1})*	Soil Temp. (°C)	Drainage	Soil C:N Ratio	Subsoil material
Sundown	23	15.5	poor	15.4	sand
S. Sisters	42	16.7	good	23.1	slt/clay
LaBroquerie	65	16.1	poor	12.6	gravel
Medika	9	14.6	good	16.5	clay
Washow Bay	23	11.5	good	15.4	clay

* mean for barley and canola plots

Amounts of N mineralized for sites which contained low levels of NO_3-N showed much less variability (Table 23). Mineralization rates at these sites averaged 33 kg N ha^{-1} and ranged from 7 to 73 kg N ha^{-1}. The amounts measured under barley and canola at each site were quite similar, with the exception of the Seven Sisters site. These measurements indicate that amounts of N mineralized in an organic soil may be similar or slightly higher than a typical mineral soil. Measurements of apparent amounts of N mineralized in typical Manitoba mineral soils during the growing season have averaged about 25 kg N ha^{-1} under crops such as barley (personal correspondence R.J. Soper, Dept. of Soil Sc., U of Manitoba).

There was no relationship observed between apparent amounts of N mineralized and the C:N ratio of the soil material (Table 23). C:N ratios of organic materials, at the five sites with low soil NO_3-N levels, varied from 12.6 to 23.1. The two highest rates of apparent N mineralization occurred at the sites with lowest (LaBroquerie) and highest (Seven Sisters) C:N ratios, however. There are conflicting reports concerning such a relationship found in the literature. Puustjarvi (1970) and Maciak and Gotkiewicz (1983) reported that net N mineralization rates increased in soils as the C:N decreased. Williams (1983) and Terry (1980) found no such relationship. Several authors felt that other soil factors such as moisture, pH, the type of organic matter, and the presence of a suitable energy source, were more important than the C:N ratio in determining the rate of soil decomposition (Williams 1983, Terry 1980, Isirimah 1973).

N mineralization, for sites with low NO_3-N levels, appeared to be unrelated to average soil temperature at the 20 cm soil depth (Table 23). A comparison of average soil temperatures during June, July, and August indicated only slight differences among sites. The average temperature for all sites was 15.1^{o}C with a standard deviation from the mean of only 1.0^{o}C. The site with the lowest soil temperature (Washow Bay 11.5 ^{o}C) mineralized an almost identical amount of N as the warmest soil (Seven Sisters 16.7 ^{o}C) under barley.

Drainage and subsoil type also seemed to be insignificant as major factors influencing mineralization rates (Table 24). Drainage was categorized as good, fair, or poor, according to the degree to which it impeded spring field operations. Of the five sites with low initial NO_3-N levels, three were well drained and two were poorly drained. The two poorly drained sites, Sundown and LaBroquerie, had water tables at 30 cm from the surface early in spring. However, the poorly drained conditions appeared to have no effect on the mineralization rate. The Sundown soil mineralized 23 kg NO_3-N ha^{-1}, only slightly less than the average for all sites. The LaBroquerie soil had the highest rate of mineralization (65 kg N ha^{-1}) of all sites studied.

C:N ratio, soil temperature, drainage, and type of mineral subsoil, did not appear to have a major effect on N mineralization rates of nitrogen in the study. This may have been due to the very small sample size (five sites) and the lack of more precise descriptions of soil properties, such as subsoil type and drainage. It is also possible that the above factors did produce substantial, but opposite, effects within sites which could not be measured in an experiment of this design.

4.2.5 Fertilizer N Required to achieve Maximum Grain Yields.

Maximum grain yield for all sites averaged 2811 kg ha^{-1} for barley and 1122 kg ha^{-1} for canola. The maximum yields for barley and canola were about 94% and 85%, respectively, of average farm yields in Manitoba in 1986. The rate of N fertilizer required to achieve at least 90% of maximum yield (90% MGY) usually varied inversely with spring soil levels of NO_3-N (Table 25) except at Clandeboyel, and Marchand, where crops responded slightly to very high rates of N fertilizer despite high soil NO_3-N levels in spring. The amount of N fertilizer required to achieve maximum economic yield (MEY) also varied inversely with spring soil NO_3-N content (Table 25), with the exception of the site at Marchand where 100 and 250 kg N ha^{-1} were required for barley and canola, respectively, to obtain maximum economic yield. Maximum economic yield was considered to occur at the highest rate of N fertilizer application beyond which increases in crop yield were of less value than the cost of the fertilizer applied.

Table 25. Rates of N fertilizer required to achieve 90% of maximum grain yield (90%MGY) and maximum economic yield (MEY).

Site	Soil NO_3-N ($Kg\ N\ ha^{-1}$) in 0-60 cm depth	Rate of Fertilizer N Needed for MGY and MEY ($kg\ N\ ha^{-1}$) Barley 90%MGY	Barley MEY**	Canola 90%MGY	Canola MEY
S. Sisters	4	100	100	70	70
Sundown	12	70	130	70	70
LaBroquerie	13	250	100	50	70
Washow Bay	36	30	50		
Medika	38	50	100	30	50
Whitemouth	77	0	0		
Piney	130	0	0	0	0
Riverton	130	30	30		
Clandeboye2	151	30	30		
Elma	193	50	30	0	0
Marchand	260	100*	100*	250*	0
Clandeboye1	280	30	30	250*	50

* High value for N most likely a result of experimental error and variability.

** Prices assumed to calculate maximum economic yield:

N fertilizer $ .48/kg — Canola $300/tonne; Barley $100/tonne

4.2.6 Utilization of Fertilizer Nitrogen

Percent utilization of fertilizer nitrogen by barley and canola was calculated as follows:

$$\% \text{ Utilization} = \frac{\text{N uptake in fertilized treatment} - \text{N uptake in unfertilized treatment}}{\text{amount of N fertilizer added}} * 100$$

The % utilization of fertilizer N was calculated only for sites which contained relatively low soil NO_3-N levels. Percent utilization of fertilizer nitrogen averaged 45% for barley and 28% for canola (Table 26). The utilization of N fertilizer by canola was, perhaps, less than expected. This may have been due to adverse conditions experienced at three sites. At Sundown and LaBroquerie the water table was quite high early in the season due to poor drainage, and this appeared to retard growth of canola more than the growth of barley. The canola at Medika emerged poorly and N uptake was probably limited due to the poor stand obtained. These results are within the range of N fertilizer efficiencies reported in the literature (Allison 1961; Soper 1971; Nielsen 1988). Percent utilization decreased as the N fertilizer rate was increased for 5 of 9 experiments (3 with barley and 2 with canola). This is similar to results reported by Kucey (1986) and Simonas (1987). In one experiment, barley at Seven Sisters, % utilization appeared to increase with increases in rate of application.

Table 26. Percent utilization of fertilizer N in soils with low NO_3-N levels in spring.

Barley

N application rate (kg ha^{-1})	% utilization 30	50	70	100	Average
Site					
LaBroquerie	40	24	28	23	29
Medika	37	59	41	44	34
Washow Bay	90	48	34	31	51
Sundown	84	61	63	52	65
S.Sisters	27	54	51	63	49
				Average:	45.5%

Canola

N application rate (Kg ha^{-1})......	30	50	70	100	Average
Site					
LaBroquerie	17	24	26	18	21
Medika	0	29	26	8	16
Sundown	44	36	24	22	32
S.Sisters	56	43	46	28	43
				Average:	28%

4.2.7 Stability of Soil NO_3-N from Fall to Spring

Soil NO_3-N levels remained relatively constant from fall to spring at sites with low initial NO_3-N levels (Table 27). The NO_3-N content of soils at LaBroquerie and Sundown decreased from fall to spring whereas increases of NO_3-N content of soils occurred at Medika and Washow Bay during the same period. No significant change in NO_3-N content was detected at Seven Sisters. At the LaBroquerie and Sundown sites, water table levels in spring were very high and this may have contributed to losses of soil NO_3-N (Avnimelech 1971).

The NO_3-N content of three of the sites which had high initial levels of soil NO_3-N in fall (Whitemouth, Piney, and Marchand) was similar in spring and fall. Increases in NO_3-N content, between fall and spring, occurred at Clandeboye(2), Riverton, Elma, and Clandeboye(1). The large increase in NO_3-N content between fall and spring at the Clandeboye(2) site was not statistically significant and was probably a result of sampling error due to the large spatial variation in NO_3-N content of this site (c.v.=65%). The increase in NO_3-N between fall and spring measured at Riverton was statistically significant, however, as were the large increases at Elma and Clandeboye(1). There was no obvious reason why the large increases occurred.

While the data was inconclusive with respect to changes which might occur over winter, it appears at least, that no large losses of NO_3-N occurred during the fall to spring period. Among sites with low soil NO_3-N level, it appears that little or no change in NO_3-N status can be expected over winter when soils are well drained.

Table 27. Changes in NO_3-N content from fall to spring at twelve organic soil sites.

	NO_3-N to 60 cm Depth (kg ha^{-1})				Level of t-test
Site	FALL	SPRING	DIFFERENCE	C.V.	Signif.
Low NO_3-N sites					
S. Sisters	5	5	0	39%	ns
Medika	18	38	+20*	53%	.04
Washow Bay	23	36	+13*	20%	.005
Sundown	23	12	-11	64%	ns
LaBroquerie	27	12	-15*	49%	.04
High NO_3-N sites					
Whitemouth	83	77	-6	33%	ns
Clandeboye(2)	99	151	+52	65%	ns
Riverton	105	130	+25*	21%	.10
Piney	130	130	0	29%	ns
Elma	137	193	+56*	27%	.06
Clandeboye(1)	152	280	+128*	52%	.08
Marchand	263	259	-4	33%	ns

* Student's T-test. Differences at these sites were significant at the 10% level, or better.

V. SUMMMARY AND CONCLUSIONS

5.1 Summary

Organic soils in Manitoba are often deficient in plant available soil nitrogen for profitable production of barley and canola. Although these soils have large reservoirs of organic N, the organic N is often not mineralized at a rate sufficient to supply adequate N for high yielding crops. Whereas many farmers have recognized the need for fertilizer N, no reliable soil test or general recommendation for year to year N fertilizer requirements was available.

Twenty field experiments were conducted in 1986 and 1987 to obtain information which would be useful in making N fertilizer recommendations based on soil analysis. Nitrogen fertilizer, applied as NH_4NO_3 at rates of 10 to 250 kg ha^{-1}, resulted in significant yield increases in eight of twelve barley experiments and five of eight canola experiments. Increases in yield for barley and canola generally varied inversely with soil NO_3-N levels. Maximum yields for barley and canola, at sites which responded to fertilizer N, were achieved with additions of 30-100 kg N ha^{-1}. N fertilizer application increased N uptake by the crop in all twelve barley experiments and six of eight canola experiments. In contrast to grain yield response, N uptake generally increased with increasing rates of N fertilizer and was highest with the two highest rates of N added.

Maximum grain yield for all sites averaged 2811 kg ha^{-1} for barley and 1122 kg ha^{-1} for canola. Fertilizer N required to reach 90 % of maximum grain yield (90%MGY) and maximum economic grain yield (MEY) usually ranged between 30 and 100 kg ha^{-1} at sites where significant yield responses occurred.

The relationship between % yield [(grain yield of unfertilized plot

/ maximum grain yield of N fertilized plot) * 100] and amount of NO_3-N in the soil to various soil depths was tested using both linear and quadratic regression models. The best relationships were obtained using quadratic regression equations when soil NO_3-N was measured to a depth of 15 or 30 cm for barley (r=0.86) and 60 cm for canola (r=0.86). Reasonably good relationships between % yield and amount of NO_3-N in the soil were described by linear regression equations at the 15 and 30 cm depths, respectively, for both barley (r=0.70 and 0.71) and canola (r=0.79 and 0.72). Linear regression equations had a poor fit to the data (r=0.25 to 0.63) at soil depths below 30 cm for both crops.

The relationship between N uptake by barley and soil NO_3-N content was almost equally well described by linear or quadratic equations up to a depth of 90 cm (r=0.80 to 0.91). The best relationship for barley was obtained at the 30 cm depth for both linear (r=0.89) and quadratic (r=0.91) equations. The relationship between N uptake by canola and soil NO_3-N content was better described by quadratic equations at the 15 and 30 cm depths (r=0.72 and r=0.88) than by linear equations (r=0.34 and r=0.50). Quadratic and linear equations described the relationship equally well at depths below 30 cm (r=0.80 to 0.87).

The above relationships between soil NO_3-N contents in the soil to various depths and the % yield or N uptake of crops have implications for commercial soil testing. Firstly, the relationships suggest that quadratic regression equations would be more useful than linear models for developing fertilizer recommendations on the basis of soil sample analysis. Secondly, that the analysis of samples taken from the 0-30 or 0-60 cm sampling depths is the most meaningful in terms of providing information on which to base N fertilizer recommendations for farmers.

The relationship between grain yield and N uptake of the barley and canola crops was also tested using linear and quadratic regression models. Quadratic equations fit the above relationship slightly better than the linear models for both barley (r=0.39 vs. r=0.36) and canola (r=0.55 vs. r=0.53). The amount of N taken up by the crops did not explain a large part of the yield variation in either case, however (approximately 26%).

Apparent amounts of N mineralized during the growing season ranged from 7 to 73 kg ha^{-1}, and averaged 33.2 kg ha^{-1} for soils low in NO_3-N contents at time of seeding. There was no apparent relationship between the amounts of N mineralized and soil parameters including C:N ratio, temperature, drainage and texture of the mineral subsoil. Spatial variation in levels of NO_3-N in soils with high NO_3-N content made estimation of net mineralization in these soils impossible.

Percent utilization (recovery of N in the crop) of fertilizer nitrogen averaged 45% for barley and 28% for canola. Percent utilization tended to decrease as fertilizer rates increased.

Soil NO_3-N levels remained relatively constant from fall to spring at sites with low initial NO_3-N levels.

5.2 Conclusions

Although these experiments were conducted only on twelve sites over a period of two years, sufficient information was obtained to improve N recommendations for organic soils. The data indicated that:

1) Soil test fertilizer recommendations for N can be based on soil NO_3-N levels measured to a depth of 30 or possibly 60 centimeters. Percent yield as well as N uptake were closely related to soil NO_3-N content to depths of either 30 or 60 cm. Soil temperatures increase very slowly

during the growing season in organic soils, and probably limit root penetration to less than 60 cm during the life of the plant (personal observations). Since yield potential is known to be most affected by availability of N in the first 28 days after emergence (Sharpe et. al. 1988), it may be reasonable to assume that nitrate availability to a depth of 30 cm is the critical factor in predicting crop yield potentials of annual crops on organic soils. Total N uptake was related best to sampling depths of 30 cm.

2) Amounts of N mineralized during the growing season averaged 33 kg ha^{-1} for five sites low in NO_3-N content at time of seeding. While the results varied considerably among sites, the amounts of N mineralized were similar to those obtained from studies on mineral soils in Manitoba. The amounts mineralized were not sufficient to provide adequate nitrogen for profitable crops of barley and canola on soils low in NO_3-N at seeding time. Although it would be preferable to have more field data describing amounts of N mineralized, it may be sufficient for practical purposes to use this average amount as a baseline for nitrogen fertilizer recommendations.

3) Maximum economic yield for barley and canola occurred with additions of 50 to 100 Kg N ha^{-1} in 8 of 9 soils which were low in NO_3-N at time of seeding. Therefore, N fertilizer recommendations for barley and canola crops to be grown on soils testing low in NO_3-N should range between 50 and 100 Kg N ha^{-1}.

4) N fertilizer efficiency (% utilization) averaged 45% for barley and 28% for canola. The much lower fertilizer efficiency in the canola crop may have been due to adverse conditions which reduced canola yields at several sites. In any case, insufficient information was obtained in

this study to suggest that efficiency of fertilizer N on organic soils would be substantially different than on mineral soils.

5) Soil NO_3-N was found to be reasonably stable during the fall to spring period. Although two of the five sites (Sundown and LaBroquerie) experienced a drop in NO_3-N levels from fall to spring, both sites experienced very high water tables in spring, which could have accounted for the losses. Thus, sampling can be conducted in fall provided that fields are well drained and are not extremely wet in fall or spring.

APPENDIX

Table 1a. Composition of barley tissue samples taken at the early heading stage from the 60 kg N ha^{-1} treatment at experimental sites in 1986 and 1987.

SITE	Macronutrients (% by weight) N	P	K	S	Ca	Mg
Clandeboye(1)	2.7	.28	2.3	.35	.46	.29
Elma	4.8	.40	2.5	.39	1.9	.52
Marchand	3.1	.36	1.9	.36	1.2	.37
Piney	3.9	.41	1.6	.38	1.0	.43
Seven Sisters	2.9	.41	3.7	.41	.68	.28
Sundown	3.9	.37	5.0	.27	.77	.26
Clandeboye(2)	2.8	.29	6.3	.38	.48	.38
LaBroquerie	3.3	.39	2.9	.34	.83	.38
Medika	2.4	.27	2.6	.30	.75	.32
Riverton	3.0	.60	2.6	.52	.63	.57
Washow Bay	2.9	.48	2.9	.35	.43	.34
Whitemouth	3.5	.32	3.4	.30	.83	.35

	Micronutrients (mg kg-1) Cu	Fe	Mn	Zn
Clandeboye(1)	7.2	78	10	36
Elma	2.3	195	73	17
Marchand	2.9	61	15	18
Piney	5.2	73	22	26
Seven Sisters	6.2	60	25	28
Sundown	6.1	155	18	14
Clandeboye(2)	10	95	22	52
LaBroquerie	8.5	87	13	54
Medika	5.2	110	39	21
Riverton	7.0	80	125	45
Washow Bay	5.9	69	36	22
Whitemouth	5.5	138	51	16

Table 2a. Composition of canola tissue samples taken at the early flowering stage from the 60 kg N ha^{-1} treatment at experimental sites in 1986 and 1987.

SITE	Macronutrients (% by weight) N	P	K	S	Ca	Mg
Clandeboye(1)	4.2	.31	4.3	1.0	.33	.80
Elma	4.3	.41	2.9	1.0	4.8	.74
Marchand	4.0	.36	1.8	.78	3.3	.49
Piney	3.9	.40	2.4	1.0	2.8	.62
Seven Sisters	3.1	.54	4.4	.84	2.0	.43
Sundown	2.9	.33	3.8	.59	2.4	.37
LaBroquerie	2.2	.34	2.1	.50	1.8	.49
Medika	3.2	.53	3.1	.97	2.8	.58
Whitemouth	2.3	.43	3.1	.76	2.9	.58

	Micronutrients (mg kg-1) Cu	Fe	Mn	Zn	B
Clandeboye(1)	7.2	166	25	45	42
Elma	4.7	145	125	32	60
Marchand	3.4	69	16	37	43
Piney	5.2	115	60	52	36
Seven Sisters	5.3	72	59	47	52
Sundown	3.9	69	24	25	32
LaBroquerie	4.3	69	22	40	
Medika	3.5	87	51	38	
Whitemouth	2.6	94	61	22	

TABLE 3a. Comparison of the NO_3-N content of soil samples prepared for analysis by either air drying or oven drying.

SAMPLING LOCATION	NO_3-N CONTENT of SOIL SAMPLES (ug g-1) AIR-DRY	OVEN-DRY	INCREASE of AIR Drying over OVEN Drying	% DIFFERENCE of AIR Drying over OVEN Drying
ELMA	112	78	34	44
	278	237	41	17
	186	146	41	28
	25	34	-9	-26
	9	10	-1	-11
MARCHAND	155	106	49	46
	197	192	5	3
	408	383	25	7
	393	363	30	8
	30	31	-1	-3
PINEY	212	225	-13	-6
	191	194	-3	-2
	110	80	30	38
	43	39	4	10
	8	7	1	12
SSISTERS	8	7	1	7
	6	6	0	3
	3	7	-4	-51
	1	2	-1	-56
	1	1	0	-33
SUNDOWN	42	23	19	84
	52	28	24	87
	65	51	15	29
	6	5	1	13
	2	1	1	160
TEULON	25	14	11	81
	18	14	3	22
	35	33	2	6
	58	51	7	14
	37	30	7	22
AVERAGE GAIN in NO_3-N content of Air-Dry over Oven Dry Samples:			11	18

Table 4a. Bulk density estimates and conversion factors used to convert soil NO_3-N content from parts per million (ppm) into Kg ha^{-1} for various soil types in the study.

Soil type	Von Post scale	Estimated bulk density (g cc^{-1})	Conversion factor per 15 cm of soil depth
Mesisol	4 to 6	.15	.225
Humisol	7 to 10	.30	.45
Clay/loam		1.33	2.0
Sand		1.8	2.5

LITERATURE CITED

Allison, F.E. 1965. Evaluation of incoming and outgoing processes that affect soil nitrogen. In: Soil Nitrogen p. 573-606. Monogram no. 10. Amer. Soc. Agron. Madison, Wisc.

Anderson, O.E. and F.C. Boswell. 1964. The influence of low temperature and various concentrations of ammonium nitrate on nitrification in acid soils. Soil Sci. Soc. Am. Proc. 28: 525-532. Cited In: Nitrogen in Agricultural Soils. F.J. Stevenson (ed.). p.256. Agronomy #22, Amer. Soc. Agron., Madison, Wisc.(1982)

Avnimelech, Y. 1971. Nitrate transformations in peat. Soil Sci. 111: 113-118.

Ball, D.F. 1964. Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. J. Soil Sci. 15: 84-92.

Bogdanov, S. 1900. Third report on the work in studying the fertility of soils. Selsk. Khoz. i. Lyesov., 198: 59-112, 241-288. Cited In: Huang, P.M. 1962. Evaluation of soil tests for predicting nitrogen requirements of cereals for some Manitoba soils. MSc Thesis, Soil Science Dept. U. of Manitoba.

Brady, N.C. 1984. In: The nature and property of soils, 9th edition. Macmillan Publishing Company, New York. p.490.

Bremner, J.M. and K. Shaw. 1958. Denitrification in soil. II. Factor affecting denitrification. J. Agric. Sci. 51: 39-52.

Bremner, J.M. 1965a. Nitrogen availability indexes. In: Methods of soil analysis, pt.2. C.A.Black (ed.) Agronomy 9: 1324-45. Am. Soc. of Agron. Madison, Wisc.

Bremner, J.M. 1965b. In: Organic Nitrogen in Soils. Agronomy 10: 93-149. Am. Soc. Agron. Inc. Madison, Wisc.

Brown, J.R., W.C. Rice and G.D. Hoette. 1984. Soil nitrate measurements for prediction of N response by corn in a Udollic Ochraqualf. Commun. In Soil Sci. Plant Anal. 15 (3), 239-251.

Chapman, H.D. and P.F.Pratt. 1961. Methods of analysis for soils and plants and waters. University of California.

Cho, C.M., L. Sakdinan, and C. Chang. 1979. Denitrification intensity and capacity of three irrigated Alberta soils. Soil Sci. Soc. Am. J. 43: 949-950.

Cole, A.J. 1985. Nitrogen, Phosphorous, Pottassium, Calcium and Copper as Plant Nutrients for Grass Grown on Wood Fen Peat. Irish J. Agric. Res. 24: 95-103.

Cook, F.D., F.G. Warder and J.L. Doughty. 1957. Relationship of nitrate accumulation to yield response of wheat in some Saskatchewan soils. Can. J. Soil Sci. 37: 84-88.

Dahnke, W.C. and E.H. Vasey. 1973. Testing soils for nitrogen. In: Soil Testing and Plant Analysis. L.M. Walsh and J.D. Beaton (ed.) p. 97-114. Soil Sci. Soc. Am., Inc. Madison, Wisconsin.

Davies, B.E. 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Sci. Amer. Proc. 38: 150.

Dickson, D.A. and P.S. Savill. 1974. Early growth of Picea sitchensis (Bong.) Carr. on deep oligotrophic peat in Northern Ireland. Forestry 47:57-88. Cited In: Williams, B.L. 1983. The nitrogen content of particle size fractions seperated from peat and its rate of mineralization during incubation. J. Soil Sci. 34: 113-125.

Duxbury, D.M. and J.H. Peverly. 1978. Nitrogen and Phosphorous losses from Organic soils. J. Environ. Qual. 7: 566-570.

Follet, R.H. and W.L. Lindsay. 1971. Changes in DTPA-extractable zinc, iron, manganese, and copper in soils following fertilization. Soil Sci. Am. Proc. 35: 600-602.

Gotkiewicz, J. 1973. Nitrogen mineralization in peat soils differently utilized, fertilized and irrigated. [Grasslands]. Zeszyty problemowe post epow nauk rolniczych. Vol. 146.

Guthrie, T.F. and J.M. Duxbury. 1978. Nitrogen mineralization and denitrification in organic soils. Soil Sci. Soc. Am. J. 42: 908-912.

Haby, V.A. C. Simons, M.S. Stauber, R.Lund, and P.O. Kresge. 1983. Relative efficiency of soil applied N and soil nitrate for winter wheat production. Agron. J. 75: 49-52.

Harris, C.I., H.T. Erickson, N.K. Ellis and J.E. Larson. 1961. Water level control in Organic soil, as related to subsidence rate, crop yield, and response to Nitrogen. Soil Sci. 94: 158-161.

Herron, G.M., G.L. Terman, A.F. Dreier and R.A. Olson. 1968. Residual nitrate nitrogen in fertilized deep loess-derived soils. Agron. J. 60:p.477-482.

Hill, K.C. and J.P. Lodge. 1966. A new colorimetric micro-determination of sulphate ion. In: Automation in Analytical Chemistry A.J.Lazrus et.al.(eds.) 1965. Technicon Synposium. Mediad: 291-293.

Hortenstein, C.C. and R.B. Forbes. 1972. Concentrations of Nitrogen, Phosphorous, Potassium, and total soluble salts in soil solution samples from fertilized and unfertilized Histosols. J. Environ. Qual. Vol.1, no.4.

Isirimah, N.O. and D.R. Keeney. 1973. Nitrogen transformations in aerobic and waterlogged histosols. Soil Sci. 115: 123-129.

Ivarson, K.C. 1977. Changes in decomposition rates, microbial population and carbohydrate content of a peat bog after liming and reclamation. Can. J. Soil Sci. 57: 129-137.

Jackson, W.A., C.A. Frost and D.M. Hildreth. 1975. Versatile multirange analytical manifold for automated analysis of nitrate-nitrogen. Soil Sci. Soc. Am. Proc. 39: 592-593.

Kamphake L.J., S.A. Hannah and J.M. Cohen. 1967. Automated analysis for nitrate by hydrazine reduction. Water Research Vol.1 p.205-216.

Keeney, D.R. and J.M. Bremner. 1967. Determination and isotope-ratio analysis of different forms of nitrogen in soils: 6. Mineralizable nitrogen. Soil Sci. Am. Proc. 31:34-39. Cited In: Nitrogen in Agricultural Soils. F.J. Stevenson (ed.). p.256. Agronomy #22, Amer. Soc. Agron., Madison, Wisc. 1982.

Klemedtsson, L., B.H. Svenson, T. Lindberg and T. Rosswall. 1977. The use of acetylene inhibition of nitrous oxide reductase in quantifying denitrification in soils. Swed. J. Agric. Res. 4: 179-185.

Kucey,R.M.N. 1986. Effect of fertilizer form, method and timing of application on barley yield and N uptake under dryland conditions in southern Alberta. Can. J. Soil Sci. 66: 615-621.

Lightner, J.W., C.L. Rhykerd, G.E. Van Scoyoc. 1981. Effect of N-P-K fertilization on mineral composition of Poa pratensis an a shallow muck soil. Proceedings of the 14th International Grassland Congress, J.A. Smith and V.W. Hays (ed.).p. 294-296.

Lucas, E.L. 1982. In: Organic soils (histosols) formation, distribution, physical and chemical properties and management for crop production. E.L. Lucas (ed.) p.43 Research Report no. 435, Michigan State University.

Lucas, R.E. and J.F. Davis. 1961. Relationship between pH values of organic soils and the availability of 12 plant nutrients. Soil Sci. 92: 177-182.

Lynn, W.C. and W.E. McKenzie. 1971. Field tests for organic soil materials. U.S.D.A. Soil Cons. Serv., Lincoln, Nebraska.

Maciak, F. and J. Gotkiewicz. 1983. Characteristics of nitrogen fractions and mineralization of nitrogen in peat soils of the Augustow canal region (Poland). Zeszyty problemowe postepow nauk rolniczych. 255.

Mahendrappa, J.K., R.L. Smith, and A.T. Christianson. 1966. Nitrifying organisms affected by climatic region in western United States. Soil Sci. Soc. Am. Proc. 30: 60-62.

Matusiewicz, E., Z. Madziar, J. Zbierska, A. Kraupe. 1983. Influence of nitrogen fertilization and soil moisture on the growth, oil content, and yield of peppermint (Mentha piperita L.) cultivated on mineral and peat soils. Rolniczych i. Lesnych. v. 53: 189-96.

Miller,1974. The contribution of nutrients and plant pesticides from agricultural lands to drainage water. Report of research conducted for Environ. Prot. Serv., Env. Canada, under DSS contract no.OSR3-0031. Cited In: Duxbury, D.M. and J.H. Peverly. 1974. Nitrogen and Phosphorous Losses from Organic soils. J. Envir. Qual. 7: 566-570.

Morita, H. and M.Levesque. 1980. Monosaccharide composition of peat fractions based on particle size. Can. J. Soil Sci. 60: 285-289.

Myers, R.J.K. 1975. Temperature effects on ammonification and nitrification in a tropical soil . Soil Biol. Biochem. 7: 83-86.

Nicholls K. H. and H. R. MacCrimmon. 1974. Nutrients in subsurface and runoff waters of the Holland Marsh, Ontario. J. Environ. Qual. 3: 31-35.

Nielsen, N.E., J.K. Schjorring, H.E. Jensen. Efficiency of fertilizer nitrogen uptake by spring barley. Cited In: "Nitrogen Efficiency in Agricultural Soils" D.S. Jenkinson and K.A. Smith eds. 1988. Elsevier Publishing Co. Inc. N.Y.,N.Y.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorous in soils by extraction with sodium bicarbonate. U.S. Dept. of Agric. Circ. 939.

Olson, R.A., K.D. Frank, E. Deibert, A.F. Dreier, D.H. Sander, and V.A. Johnson. 1976. Impact of residual mineral N in soil on grain protein yields of winter wheat and corn. Agronomy Journal 68: 769-772.

O'Toole, L. H. 1975. The influence of various treatments on nitrogen mobilization in peats. Ireland Department of Agriculture Journal. 72: 12-18.

Peech, M., R.L. Cowen, G.H. Baker. 1962. A critical study of the $BaCl_2$-triethanolamine and the ammonium acetate methods for determining the exchangeable hydrogen content of soils. Soil Sci.Soc. Proc. 26:37-40.

Pritchett, W.L., C.A. Blackand L.B. Nelson. 1947. Mineralizable nitrogen in soils in relation to the response of oats to nitrogen fertilization. Soil Sci. Soc. Am. Proc. 12: 327-331.

Puustjarvi, V. 1970. Mobilization of nitrogen in peat culture. Peat and Plant News 1970: 3.

Racz, G.J. 1979. The effect of depth of sampling on the relationship between nitrogen uptake and the amount of NO_3-N in the soil. 23rd Annual Manitoba Soil Science Meeting Proc. p.121-129.

Racz, G.J., D.W. McAndrew, J.M. Tokarchuk. 1978. Major and minor element requirements of crops grown on Organic soils. Proc. of the 22nd Annual Manitoba Soil Science Meetings, University of Manitoba pp.6-68.

Raveh,A. and Y. Avnimelech. 1973. Minimizing nitrate seepage from the Hula Valley into Lake Kinneret (Sea of Galilea): Enhancement of nitrate reduction by sprinkling and flooding. J. Environ. Qual. 2: 455-458.

Reddy, K.R., P.D. Sacco, and D.A. Graetz. 1980. Nitrate Reduction in an Organic Soil-Water System. J. Environ. Qual. Vol.9, no.2, p.283-288.

Reddy, K.R. 1982. Mineralization of nitrogen in organic soils. Soil Sci. Soc. Am. J. 46: 561-566.

Schofield, R.K. and A.W. Taylor. 1955. The measurement of soil pH. Soil Sci. Soc. Proc. 19: 164-167.

Schollenberger, C.J. and R.H. Simon. 1945. Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method. Soil Sci. 59: 13-24.

Simonas A.D. 1987. Studies on nitrogen use efficiency in cereals. In: "Nitrogen Efficiency in Agricultural Soils" D.S. Jenkinson and K.A. Smith eds. 1988. Elsevier Publishing Co. Inc. N.Y.,N.Y.

Smika, D.E. and B.W. Greb. 1973. Protein content of winter wheat grain as related to soil and climatic factors in the semiarid Great Plains. Agron. J. 65: 433-436.

Soper, R.J. and P.M. Huang. 1963. The effect of nitrate nitrogen in the soil profile on the response of barley to fertilizer nitrogen. Can. J. Soil Sci. 43: 350-358.

Soper, R.J., G.J. Racz and P.I. Fehr. 1971. Nitrate nitrogen in the soil as a means of predicting the fertilizer nitrogen requirements of barley. Can. J. Soil Sci. 51: 45-49.

Soper, R.J. 1971. Soil tests as a means of predicting response of rape to added N, P, and K. Agron. J. 63: 564-566.

Sowden, F.J., H. Morita and M. Levesque. 1978. Organic nitrogen distribution in selected peats and peat fractions. Can. J. Soil Sci. 58: 237-249.

Stanford, G., G.R.A. Vander Pol, and S. Dzienia. 1975. Denitrification rates in relation to total and extractable soil carbon. Soil Sci. Soc. Am. Proc. 39: 284-289.

Stanton, M.P., M.J. Capel, F.A.J. Armstrong. 1974. The chemical analysis of freshwater. Fish. Res. Board Cum. Misc. Spec. Publ. 25: 125.

Stevenson, F.J. 1982. In: Nitrogen in agricultural soils. F.J. Stevenson,ed. 1982. Agronomy # 22, Amer. Soc. Agron., Madison, Wisc.

Synghal, K.N., J.A. Toogood and C.F. Bentley. 1958. Assessing nitrogen requirements of some Alberta soils. Can. J. Soil Sci. 39: 120-128.

Terry, R.E. 1980. Nitrogen mineralization in Florida Histosols. Soil Sci. Soc. Am. J. 44: 747-750.

Terry, R.E. and R.L. Tate III. 1980a. Effect of flooding on microbial activities in organic soils: Nitrogen transformations. Soil Science 129: 88-91.

Terry, R.E. and R.L. Tate III. 1980b. Denitrification as a pathway for nitrate removal from organic soils. Soil Science 129: 162-166.

Truog, E. 1954. Comm Fertilizer 88, 72-73. Cited In: Huang, P.M. 1962. Evaluation of soil tests for predicting nitrogen requirements of cereals for some Manitoba soils. Master of Science thesis, Univ. of Manitoba.

Tolton, H.E. 1957. Response of cereals to anhydrous ammonia as correlated with tests for available soil nitrogen. MSc thesis. Dept. Soil Science, U of Manitoba.

Watson, C.J. and S.N. Adams 1986. Effect of simulated wet spring conditions on the relative efficiency of three forms of nitrogen fertilizer on grassland. J. Agric. Sci. Camb. 107: 219-222.

Watson, S.W. 1974. Gram negative chemolithotrophic bacteria. Family I p.450-456. Cited In: Nitrogen in Agricultural Soils, F.J. Stevenson, ed., 1982. p.263. Agronomy #22, American Soc. Agron., Madison, Wisc.

White, W.C. and J. Pesek. 1959. Nature of residual nitrogen in Iowa soils. Soil Sci. Soc. Proc. 23: 39-42.

Williams, B. L. 1983. The nitrogen content of particle size fractions separated from peat and its rate of mineralization during incubation. J. Soil Sci. 34: 113-125.