Final Technical Report to Manitoba Corn Growers Association

Optimum Nitrogen Management for Modern Corn Hybrids in Manitoba

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Table of Contents

Executive Summary

In summary, the scope of this project addressed all four “R’s” in the “4R Nutrient Stewardship” framework for nitrogen fertilization of modern corn hybrids in Manitoba: applying the right rate, at the right source, in the right place, and at the right time.

In more detail, this project had the following more specific objectives:

- Determine appropriate rates for N fertilization, based on pre-plant soil test reserves of nitrate-N and a realistic range of yield goals for modern corn hybrids (i.e., determining the total supply of soil test plus fertilizer N required on a per bushel basis)
- Determine the most effective and efficient combinations of N fertilization timing, placement and source, especially for supplemental applications during the growing season
- Evaluate some innovative pre-plant soil tests for measuring the amount of organic soil N that can be released by mineralization during the growing season
- Develop decision tools such as pre-sidedress and post-harvest soil nitrate testing, plus late season leaf colour ratings and stalk nitrate testing for evaluating nitrogen sufficiency at various stages throughout and after the growing season.

Most of this project was funded by the Manitoba Corn Growers Association, which has now joined forces with several other crop commodity organizations in Manitoba to form Manitoba Crop Alliance. Additional funding was provided by Nutrien, through one of its predecessors, Agrium.

These experiments, led by Lanny Gardiner (M.Sc. student), were conducted across a total of 17 locations in southern Manitoba during the 2018 and 2019 growing seasons. The studies were conducted at two levels of intensity, gold and silver. The 4 “gold” level sites were managed entirely by the University of Manitoba and included more treatments and measurements than for the 13 “silver” level sites, which were hosted within commercial corn growers’ fields. Overall, corn grain yields in 2018 and 2019 were limited by inadequate moisture at many of the field sites. Therefore, the results of this study need to be interpreted cautiously, recognizing that crop yield potential and N losses were probably smaller than usual during these two relatively dry growing seasons.

1. Optimum Rates of N

Economic optimum supplies of soil test N plus fertilizer N were determined using four methods. The optimum total supply of N varied substantially with the method of calculation, ranging between 1.1 and 1.4 lb N/bushel for 11 site-years where the yield potential exceeded 130 bushels/acre, assuming prices of $4.50/bu for corn and $0.45/lb for N fertilizer. The equivalent range of optimum N supplies for 7 lower yielding site-years where yields were less than 130 bu/acre was 1.5 to 2.1 lb N/bushel. Therefore, similar to the results of studies in the U.S., this study showed that situations with the potential for greater corn yields require less N per bushel at the optimum rate of N. However, the optimum supply of N on a per acre basis was remarkably similar for both yield groups, generally in the range of 150-190 lb N/acre, including soil test plus fertilizer N. Part of the reason for this similarity for the two yield groups was the more efficient N use at the higher yielding site-years, but part was due to more release (mineralization) of soil organic N during the growing season at the higher yielding site-years.

For both yield groups, the lowest estimate for optimum N supply per bushel was determined by the average of the numerically greatest return to N at each site-year or the average rate of fertilizer N for the most profitable statistical group of treatments. The highest estimate for the optimum rate of N supply was determined by fitting a quadratic response curve to the entire collection of N response data, as is often used in other studies. When quadratic response curves were fitted to each individual site-year, the average optimum rate of N determined for each yield group was intermediate, between these two extremes.

There are pros and cons to each method of determining the optimum rate of N, but for typical yields of corn in Manitoba, which are approximately 140 bushels/acre, a total N supply (soil test N plus applied N) of 1.1 to 1.3 lb N per bushel of target yield appears to be appropriate.

2. N Sources

N sources applied at planting - At the four gold level site-years, additional treatments applied at planting included urea-based products with a physical coating (ESN™) or chemical inhibitors (eNtrench™-treated urea and SUPERU™). The five treatments were 1) pre-plant broadcast and incorporated ESN™:Urea in a 1:1 blend, 2) pre-plant broadcast and incorporated SUPERU™, 3) pre-plant broadcast and incorporated eNtrench™-treated urea, 4) post-plant broadcast SUPERU™, and 5) the standard management practice treatment of pre-plant urea broadcast and incorporated. Each of these treatments was applied at 80 and 120 lb N/acre.

Within a similar rate of N fertilization application, there were no significant differences in corn grain yield among different sources and placements. This lack of difference between sources was not surprising, given that both growing seasons were relatively dry, resulting in low risk of N losses by leaching or denitrification. In addition, the relatively dry conditions resulted in the lowest rate of N used in these comparisons (80 lb N/acre) being close to the optimum N rate determined in the rate study, making any potential yield response differences between sources very small and difficult to detect.

N sources applied at mid-season - All 17 site-years included mid-season applications of UAN (28-0-0 liquid) applied with and without AGROTAIN™ urease inhibitor. The mid-season treatments were applied at V8 stage (mid-late July) and Y-drop simulated application of 53 or 106 lb N/acre in 2018 and 40 or 80 lb N/acre in 2019, in addition to 40 lb N/acre applied at planting.

Even though urease inhibitors often improve the efficiency of surface-applied urea or UAN fertilizer, the statistical analyses for this study showed no advantage to adding a urease inhibitor such as Agrotain™ when mid-season N was surface applied in 2018 and 2019. There was substantial variability within the sites, partly due to moisture stress at many sites, which made it difficult to detect statistical differences. However, the most important factor that probably contributed to the lack of yield difference was the insignificant difference in yield response to N for the low vs. high rates of mid-season N. Similarly, in the N rate portion of the study, the numerical difference in overall mean yield between the 80 and 120 lb N/ac fertilizer rate treatments applied at planting was only 3 bu/ac, which was not statistically significant. This shows that under the relatively dry conditions for this study, the response to N fertilizer application at rates above 80 lb/acre was minimal. Therefore, a response to the Agrotain™ treated UAN fertilizer compared to untreated urea would be unlikely because the untreated urea treatment applied at these rates probably provided sufficient N to achieve near maximum yield for these site-years.

3. N Timings and Placements

Across all 17 site-years, split application of N, applying 40 lb N/acre at planting and another 40 to 106 lb N/acre at side-dressed at V4 or tube dropped at V8, did not increase yield compared to applying similar or slightly smaller total rates of N at planting. However, split application decreased yield in 3 of the 17 site-years where soil test nitrate concentrations were very low. Once again, the dry weather during the 2018 and 2019 growing seasons probably contributed to this lack of benefit for split applications, because the risk of losing N applied at planting was very low and inadequate moisture was also a substantial limitation for yield.

However, the 3 site-years where split applications decreased yield illustrate that there is a downside risk of yield loss with split N applications if the corn crop is not supplied with sufficient N in the early part of the growing season. One of the reasons why large amounts of N fertilizer were required early in the growing season at these 3 site-years was that all three site-years had less than 40 lb of soil test nitrate-N/acre to 2 feet at planting. These were the 3 site-years with the least pre-plant soil N in the study and they indicate that there is a risk of yield loss for late application or even for split application overall when initial reserves of soil N are very low. Applying more than 40 lb N/acre at planting would be another way to mitigate the risks of early season N deficiency when planning for split application on soils with low levels of pre-plant N. Furthermore, in these trials 40 lb N/acre applied at planting was surface broadcast; it may also be beneficial to improve the positional availability of early season N by banding near the seed row.

4. N Management Tools for Corn Growers and Agronomists

N mineralization tests - The soil's ability to supply N to a crop is an important factor for developing agronomically and environmentally sound recommendations for N fertilizer rates. Most soil tests measure only the immediately available N in soil (e.g., residual nitrate-N). However, the amount of N released from decomposition of soil organic matter (mineralization) during the growing season can be large.

In this study, N mineralization varied from 12 to 95 lb N/acre across the 13 site-years where N mineralization was estimated in 2018 and 2019. This variability in mineralization was one of the reasons for differences in the optimum rate of N fertilization from one site-year to another. These values are substantial, but smaller than those measured in John Heard's corn fertilization preliminary trials in 2016 and 2017, when growing season moisture was greater and where estimated N mineralization exceeded 150 lb N/acre at several sites (e.g., at one site, his trial grew 200 bu/ac with zero N fertilizer).

None of the 10 pre-plant soil test measurements in our study, including soil organic matter concentrations and an incubation test, were useful for predicting the soil's capacity to mineralize additional N from soil organic matter under field conditions.

The poor relationships between laboratory tests for potential N mineralization and measured estimates for mineralization in the field was partly due to variability in the degree to which potential mineralization was realized under field conditions, which varied across the site-years. Inclusion of environmental data such as soil moisture and temperature might improve the ability to track mineralization and growing season crop N demand. However, the inability to forecast these weather conditions will probably limit the value of any pre-plant or early season soil test for estimating mineralization of soil organic N.

The purpose of the **pre-sidedress nitrate test (PSNT)** is to enable corn growers to determine the appropriate rate of N to apply via sidedressing at the V4 stage, after accounting for disappearance of N (e.g., leaching and denitrification losses in a wet spring) or appearance of N (e.g., due to mineralization of organic N) during the early part of the growing season. Preliminary analysis of the data for our study indicate for Manitoba corn production, soils that test below 30 mg N/kg (<120 lb N/ac in the top 12 inches) are likely to require an additional 80 lb of N/ac; soils that test 30-40 mg N/kg (120-160 lb N/ac) are likely to require an additional 40 lb of N/ac; and soils with more than 40 mg N/kg (>160 lb N/ac) are unlikely to require any additional N.

Late season leaf colour ratings have been used as a diagnostic tool in South Dakota, where researchers have found that if the third and fourth leaves below the primary ear leaf were green (without any visual symptoms of N deficiency), yield should not have been limited due to lack of N. Preliminary analyses indicate that overall as the N application rate increased, the first sign of leaf yellowing was detected lower on the plant and that N deficiency was highly unlikely if all of the third and fourth leaves below the ear were green. However, leaf yellowing was not a reliable predictor for N deficiency. Some of the inconsistent relationship between frequency of chlorosis may have been due to variation in late season drought stress during the dry growing seasons in 2018 and 2019 which may have caused leaf yellowing that was not necessarily related to N deficiency.

Pre-harvest stalk nitrate concentrations from this study tended to increase as N application rate increased, similar to observations elsewhere. According to research conducted in Iowa, stalk nitrate concentrations less than 700 ppm indicate low to marginally sufficient N nutrition; whereas concentrations greater than 2000 ppm indicate the plant has excessive N. The pre-harvest stalk nitrate and yield data for this study did not line up consistently with those thresholds. Therefore, perhaps due to late season drought stress, we were not able to determine the range of stalk nitrate concentrations for corn grown in Manitoba that would indicate N sufficiency.

Therefore, although the late season leaf colour ratings and pre-harvest stalk nitrate concentrations are well documented as being useful indicators of N sufficiency for corn grown under moist conditions, these indicators may require some modification to be useful for the semi-arid and sub-humid conditions in the Canadian Prairies.

On the Prairies, **post-harvest fall nitrate soil tests** are commonly used to determine N fertilizer requirements for the next crop. A post-harvest soil N test can also be used as an auditing tool for evaluating the nitrogen fertilization program for the crop that was recently harvested. In this study, post-harvest soil samples were collected from N fertilizer rate treatments at 8 of the site-years, with an additional 5 site-years having only the check plots post-harvest soil sampled. Preliminary analyses of the relationship between the residual soil test data and the yield response data indicates that a post-harvest nitrate-N test less than 20 lb N/acre to 24 inch soil depth indicates that the previous corn crop was probably deficient in N. A test value of 20-50 lb N/ac to 24" probably indicates that the previous corn crop was not excessively fertilized. And residual soil test values greater than 50 lb N/acre probably indicate that there was excess N available for the crop.

1. Introduction

This research project evaluated management options that Manitoba crop producers have for applying N fertilizer to corn. The motivation for this project was the recent expansion in corn production within the province of Manitoba coupled with advancements in fertilizer and application technology, hybrid genetics, and environmental concerns from excess nitrogen (N) fertilizer application.

A modern corn crop has a high yield potential and a large requirement for fertilizer N. Similar to many crops, corn requires more N than any other mineral nutrient for plant growth. Corn is, however, much different from other typical Manitoba crops such as wheat, oats, barley, canola, and flax. For example, corn has a much longer growing season; corn is grown as a row crop, not a solid seeded crop; and corn has twice the yield potential. All of these factors require N fertility to be managed differently from other crops that are typically grown in Manitoba. Furthermore, Manitoba has a unique climate compared to most other corn growing regions, with less rainfall and fewer heat units than the US Midwest, for example.

Therefore, the goal of this project was to develop best management practices for N fertilization by addressing the 4Rs of Nutrient Stewardship: Right Time, Right Rate, Right Place, and Right Source for corn production under Manitoba conditions. This project also addresses other questions surrounding N management such as how soil testing methods might help to predict the amount of N mineralized from soil organic matter.

Nitrogen Rate

Manitoba farmers are planting corn hybrids with much greater yield potential than when the last corn N fertilization trials were conducted by the University of Manitoba more than 35 years ago (Walley and Soper 1985). Studies in the U.S. have shown that today's high yielding hybrids are much more efficient than old hybrids with respect to nitrogen use efficiency, i.e., modern corn hybrids produce more grain per lb of N than old hybrids (e.g., Woli et al. 2016). We hypothesized that similar improvements in nitrogen use efficiency have reduced the N requirements per bushel of grain yield for modern corn hybrids grown in Manitoba.

A simple method for determining the fertilizer N a crop needs is to calculate the difference between crop requirement and soil supply. Throughout the Northern Great Plains, the pre-plant nitrate-nitrogen soil test is used to quantify mineral N in the soil, while crop requirement depends on crop species and yield potential, keeping in mind that yield will vary with annual fluctuations of precipitation and temperature. Examples of current N rate recommendations for Manitoba's corn growers, based on soil test nitrate-N include:

- The Manitoba Soil Fertility Guide (2007) provides N recommendations for corn target yields as high as 130 bu/ac, which is less than the yields currently achieved by some corn growers in Manitoba. To grow 130 bu/ac on a field with 30 lb of residual nitrate-N per acre, the Soil Fertility Guide would recommend 195 lb fertilizer N per acre or a total N supply from soil nitrate-N and fertilizer of 1.7 lb N per bushel of corn.
- The guide to Corn Production in Manitoba (2004) also provides N recommendations for corn target yields as high as 130 bu/ac. To grow 130 bu/ac on a field with 30 lb of residual nitrate-N per acre, the Soil Fertility Guide would recommend 225 lb fertilizer N per acre or a total N supply of 2.0 lb N per bushel of corn.
- The AGVISE soil testing lab in North Dakota provides N recommendations for corn target yields as high as 240 bu/ac. To grow 130 bu/ac on a field with 30 lb of residual nitrate-N per acre, AGVISE recommends 156 lb fertilizer N per acre or a total N supply of 1.2 lb N per bushel of corn.
- NDSU's guidelines are set by area and yield potential within their state; the guidelines are also affected by tillage system, soil organic matter, and prices for crop and fertilizer. For a situation such as the Eastern region of ND, which likely applies to most of MB, a 130 bu/ac crop (which is less than the 160 bu/ac average yield category), corn priced at US $3/bu and fertilizer N at US $0.30/lb on land with 30 lb of residual N, would receive a recommendation for 120 lb of fertilizer N per acre or a total N supply of 1.15 lb N per bushel of corn.

In summary, Manitoba's current recommendations of almost 2 lb N/bu of corn target yield are much higher than recommendations from other sources. This high recommendation represents a large financial risk to corn growers, as well as substantial agronomic and environmental risks (e.g., excess leaching and greenhouse gas emissions).

Nitrogen Sources

Fertilizer technology has advanced considerably since the latest fertility research was conducted with corn in Manitoba. For example, corn growers have access to fertilizer additives such as urease inhibitors (e.g., AGROTAIN™) or fertilizers that include urease inhibitors (e.g., SUPERU™) that stabilize broadcast applications of urea, to reduce ammonia volatilization losses. They also have more options for nitrification inhibitors (e.g., eNtrench™, SUPERU™, and N-Serve™) that can help to reduce N losses by leaching and denitrification. Known as enhanced efficiency fertilizers (EEF), the inhibited or coated urea N fertilizers have the potential to reduce losses and environmental problems, as well as provide agronomic benefits, especially for a crop such as corn, that requires large quantities of N over a long period.

Nitrogen Timing and Placements

Most N fertilizer is applied to Manitoba crops prior to or at planting, with approximately 40% of Manitoba's N fertilizer typically applied in the fall. The ideal placement of N fertilizer is subsurface banding instead of surface application and, for solid-seeded crops, banding N fertilizer is more practical prior to planting than at any other time during the growing season.

However, corn growers have access to several other timing and placement options for applying N fertilizer. Corn's extended growing season and N uptake pattern leads to approximately 75% of the crop N being taken up after 500 growing degree days or the V10 stage (Bender et al., 2013). Therefore, mid-season timing might be the best opportunity to match N supply with crop demand because this timing matches the period for the majority of plant N uptake. Also, since corn is row cropped there are many more N application timing and placement options than with a solid seeded crop, making in-season N fertilizer applications practical. Therefore, in-season application may be a best management practice because N is supplied closer to the time of crop uptake, decreasing the time that fertilizer N is in the soil, exposed to environmental losses.

In-season application might also enable a corn grower to adjust their N fertilizer rates in response to variable weather conditions and yield potential. One method for split application of N is to apply part of the crop's N requirement at planting, to meet the crop's early season N needs, then follow with an additional N application at approximately the V4 stage or in late June. Choosing a form of nitrogen to side-dress depends on producer preference. Urea-ammonium nitrate (UAN), anhydrous ammonia, or urea can all be banded mid-row while there is the option to also include a urease and/or nitrification inhibitor. Banding is the preference for N fertilization at these timings because it is practical for a row crop and reduces the risk of volatilization or surface stranding.

Another mid-season option for corn fertilization is to split the N between planting and the V8 growth stage. This later mid-season timing limits application to high-clearance machinery. That machinery is typically set up for handling liquid products; however, granular fertilizer can also be applied. The advanced growth stage at this time allows only surface placement of the N. Surface placement is prone to volatilization losses, so this is an excellent opportunity to use urease inhibitors. Granular products can be broadcast above the canopy, while liquid N can be "Y-dropped" - a method that uses drop hoses to penetrate below the crop canopy and place streams of liquid fertilizer adjacent to corn rows.

Predicting Nitrogen Mineralization from Soil Organic Matter

Soil N supply during the growing season is determined by two main factors, the mineral N present at planting (e.g., soil test nitrate-N) and organic N that mineralizes to plant available N during the season. Growing season mineralization is difficult to predict, but doing so would lead to refined N recommendations. Tools that have been proposed for predicting N mineralization include the pre-side dress soil nitrate test, the concentration of soil organic matter content, and an incubation test.

Decision Tools for Evaluating Nitrogen Sufficiency

A variety of tests and instruments have been developed to evaluate the N status of soil and crop. For soil, the pre-plant and pre-side dress nitrate test measure the amount of nitrate N in the soil and assist in determining N application rates (Reitsma et al., 2008). The post-harvest nitrate test is used after the growing season, where large amounts of residual nitrate-N can indicate over-fertilization and small amounts might indicate under-fertilization and soil N depletion by the crop.

Crop canopy reflectance is an evaluation of canopy density and chlorophyll content during the growing season. Measurements are taken during vegetative growth stages while there is still opportunity to apply N based on results. Instrumentation can be handheld, mounted on equipment, or mounted on an unmanned aerial vehicle (UAV or drone). Canopy reflectance technology is not commonly used across Manitoba because decision making guidelines with the collected data need to be investigated further before the information is useful for N management under our conditions.

Leaf deficiency ratings and the stalk nitrate test are two options for evaluating the plant N status near or at harvest. Leaf deficiency ratings (Gelderman et al., 2009) are based on the premise of nitrogen being a mobile nutrient and so chlorosis due to nitrogen deficiency begins showing on lower leaves and works its way up the plant, depending on severity. However, even though these ratings can be valuable for visually identifying nitrogen deficiency, there can also be other causes of chlorosis and necrosis of leaves such as drought stress. The stalk nitrate test (Blackmer and Mallarino, 2000) is a quantitative measure of the nitrate-N in the base of the corn stalk at harvest. Excess N within the plant that is not used for grain production is stored in the stalk at maturity. By testing for nitrates in the stalk, it can be determined whether N within the plants was deficient, in the optimal range, or excessive and led to accumulation within the stalk.

Project Objectives

To address these issues, the 4Rs (right rate, source, placement and timing) approach for nutrient management must be determined for these new, high-yielding corn hybrids grown under Manitoba conditions, with the following more detailed objectives:

- Determine appropriate rates for N, based on soil test reserves of N and a realistic range of yield goals for modern corn hybrids (e.g., the overall supply of N required on a per bushel basis)
- Determine the most effective and efficient combinations of timing, placement and source, especially for supplemental applications during the growing season

- Evaluate some innovative soil tests for measuring the amount of organic soil N that can be released by mineralization during the growing season
- Develop decision tools such as pre-sidedress and post-harvest soil testing, plus leaf colour ratings and stalk nitrate testing for evaluating nitrogen sufficiency at various stages throughout and after the growing season.

In total, two levels of field experiments were conducted in 2018 and 2019 to address these objectives. The results of these experiments are meant to help agronomists and producers in Manitoba to make informed management decisions regarding N fertilization of modern corn hybrids in Manitoba. This work complements other small plot research being done within the University of Manitoba and on-farm trials coordinated by the Manitoba Corn Growers Association.

2. Materials and Methods

There were two levels of field sites in this study: gold and silver level sites. Gold level sites included pre-plant, incorporated applications of N fertilizer and were entirely managed by university resources and operations. Silver level sites included only post-plant applications of N fertilizer within commercial corn fields and were managed by a combination of the cooperating producer and the university. Abbreviations for N applications and treatments in this study are listed in Table 2.1.

Table 2.1 Abbreviations for N applications and treatments used throughout the report

SPU	SUPERU™ granular fertilizer
Urea	Urea granular fertilizer
UAN	Urea ammonium nitrate liquid fertilizer
UAN&Agt	UAN fertilizer mixed with AGROTAIN™ inhibitor
Urea&ESN	ESN fertilizer mixed with Urea fertilizer 1:1 on nitrogen basis
Urea&eNt	eNtrench™ inhibitor-treated urea fertilizer
V4	V4 timing - counting fully exposed leaf collars
V8	V8 timing - counting fully exposed leaf collars and any dropped leaves
Bct	Broadcast application of the granular fertilizer
Bct&Inc	Broadcast and incorporation of the granular fertilizer
Sdr	Side-dress application of the fertilizer, sub-surface mid-row banded
Ydr	Simulated Y-drop application, dribble band on surface adjacent to row

2.1 Gold Level Site Establishment

Two gold level sites were established in each of the 2018 and 2019 growing seasons, for a total of 4 site-years. These sites are referred to as Graysville18, Stephenfield18, CarmanNorth19, and St.Claude19, named for the nearest town and crop year. Sites were planted and maintained entirely by the university within commercial farm fields that were also planted to corn. Fields were chosen on the basis of a variety of factors including low concentrations of residual nitrogen, proximity to other sites and the university, no manure history, and a uniform area for the site. The gold level sites are numbered 1, 7, 14, and 15 in Figure 2.1, Table 2.2, and Table 2.3. Each gold site used a randomized complete block design (RCBD) with 21 treatments and 4 replicates. Plots were 10 feet wide (4 x 30 inch rows) and 26 feet long with the layout being identical at each site-year. See Table 2.4 below for a complete list of treatments.

Five or less days prior to planting, the pre-plant treatments were broadcast and incorporated with a tandem disc that tilled the entire site at 2-3" soil depth. Following planting, the post-plant treatments were surface broadcast. All broadcast N was applied by hand spreading pre-measured quantities. Treatments were applied 5 feet beyond the front and rear of the plot to act as a buffer that would minimize edge effects; N fertilizer was applied with a minimum of two passes over the plot to ensure uniform broadcast application. The eNtrench™ - treated urea was treated with eNtrench™ at the label-recommended rate of 2.7 L eNtrench™ per hectare and applied within 14 days of treating the urea.

Corn was planted with a 4 row (30 inch spacing) John Deere disc vacuum planter at a target depth of 2 inches and 36 000 seeds ac^{-1}. Hybrid 33-78RIB from Dekalb was planted with side-banded phosphorus as triple super phosphate, potassium as potash, and micronutrients placed in a band 2 inches beside and 2 inches below the seed. Sulphur was broadcast to the sites either as potassium sulphate in 2018 or gypsum in 2019. See Tables 2.2 and 2.3 for further site details and background fertilizer rates. Other management by the university included herbicide applications of approved products at label-recommended rates.

2.2 Silver Level Site Establishment

Seven silver level sites were established in 2018 and six were established in 2019, for a total of 13 silver level research site-years in this project. The silver level sites are numbered 2-6, 8-13, and 16-17 on Figure 2.1, Table 2.2, and Table 2.3 below. Silver level sites were established in producer fields chosen for many of the same reasons as for the gold level sites; however, the silver level sites included a wider range of residual N and some were located further away from the university, compared to the gold level sites. Corner flags for these sites were placed in fields prior to the farmer's normal field-scale N application so the plot area did not receive spring-applied nitrogen fertilizer in addition to the research treatments in that crop year. Producers planted through the sites as part of their regular planting for the field. Producers also applied herbicides to the silver level research sites at the same time as they applied herbicides to the surrounding field.

Within 10 or less days following planting, the university established 12 treatments x 4 reps (48 plots, 4 corn rows x 26 feet each) at each silver level site. At the time of establishment post-plant SUPERU™ treatments were broadcast. Each silver site utilized an identical RCBD experimental design; see Table 2.4 for a complete treatment list.

Figure 2.1 Map of southern Manitoba and legend showing the location of gold and silver level research site-years

1	CarmanNorth19*
2	CarmanSouth19
3	CarmanWest18
4	Clearwater19
5	Elgin18
6	Elgin19
7	Graysville18*
8	Graysville19
9	Macgregor18
10	Morris19
11	Portage18
12	Rosebank18
13	Rosebank19
14	St.Claude19*
15	Stephenfield18*
16	Wellwood18
17	Winkler18

***Gold level site-years**

Table 2.2 Soil and crop characteristics of each site-year

								Starter fertilizer applied at planting (lb/ac)			
	Site & year	Prev. crop	Tillage	Soil texture to 6”	Planting date	Hybrid	Plant count per acre	N	P_2O_5	K_2O	S
1	CarmanNorth19	Soybean	Conventional	Sand	May 9/19	DK33-78RIB	34457	0	68	40	20[a]
2	CarmanSouth19	Pinto bean	Zero till	Sandy Loam	May 8/19	P7940AM	30095	0	0	0	0
3	CarmanWest18	Soybean	Zero till	Sandy Loam	May 3/18	DK33-78RIB	29952	6	20	0	0
4	Clearwater19	Canola	Conventional	Loam	May 14/19	P7455R	34355	6[b]	20[b]	0[b]	0[b]
5	Elgin18	Canola	Conventional	Clay Loam	May 8/18	A4939G2RIB	25625	35	55	15	25
6	Elgin19	Wheat	Conventional	Clay Loam	May 2/19	A4939G2RIB	30174	10	45	16	0
7	Graysville18	Black Beans	Conventional	Sandy Loam	May 15/18	DK33-78RIB	36861	0	72	50	18
8	Graysville19	Canola	Zero till	Sandy Clay Loam	May 8/19	DK35-88RIB	27882	0	0	0	0
9	Macgregor18	Wheat	Zero till	Fine Sand	May 2/18	P7527AM	29453	4	16	1	0
10	Morris19	Soybean	Conventional	Clay	May 9/19	DK29-89RIB	30401	0	0	0	0
11	Portage18	Soybean	Conventional	Silty Clay	May 3/18	MZ1633DBR	34673	6	20	0	0
12	Rosebank18	Pinto bean	Conventional	Sandy Loam	May 5/18	DK33-78RIB	28898	5	16	0	0
13	Rosebank19	Edible bean	Conventional	Sandy Clay Loam	May 8/19	DK35-88RIB	28933	5	16	0	0
14	St.Claude19	Corn	Conventional	Fine Sand	May 9/19	DK33-78RIB	33193	0	73	50	22
15	Stephenfield18	Corn	Conventional	Fine Sand	May 15/18	DK33-78RIB	34675	0	72	50	20
16	Wellwood18	Wheat	Conventional	Clay Loam	May 12/18	P7211AM	28621	9	30	0	0
17	Winkler18	Soybean	Conventional	Sandy Loam	May 3/18	P8387AM	28732	9	30	0	0

[a] plus 4 lb Zn and 2 lb Cu per acre

[b] plus 40, 80, 80, and 25 lbs N, P_2O_5, K_2O, and S per acre in fall 2018

Table 2.3 Pre-plant soil test analyses for each site-year

		Olsen	DTPA		Exch.			DTPA								
		P	Cu	EC	K	OM	pH	Zn	SO_4-S (lb/ac)		NO_3-N (lb/ac, ppmx2)			NO_3-N (lb/ac, by BD)		
	to 6”	ppm	ppm	dS m^{-1}	ppm	%		ppm	to 24"	to 48"	to 6"	to 24"	to 48"	to 6”	to 24"	to 48"
1	CarmanNorth19	16	0.38	0.115	198	2.1	7.9	0.74	18	166	9	31	72	9	31	71
2	CarmanSouth19	39	0.53	0.130	145	3.2	7.5	0.93	157	1513	14	57	87	14	55	85
3	CarmanWest18	8	0.33	0.330	133	4.3	7.2	1.53	211	990	18	64	86	18	62	85
4	Clearwater19	25	1.07	0.424	283	5.8	6.7	1.60	3422	9545	57	139	197	50	124	177
5	Elgin18	17	0.89	0.573	270	5.4	6.6	1.02	118	382	50	130	199	41	110	170
6	Elgin19	5	1.02	0.239	405	6.2	6.7	2.20	64	230	21	53	75	17	45	62
7	Graysville18	17	0.73	0.341	193	4.4	6.3	1.53	188	1515	22	80	112	21	75	104
8	Graysville19	14	0.72	0.290	213	4.0	8.3	1.33	2516	7856	26	54	108	24	51	103
9	Macgregor18	23	0.28	0.170	97	1.5	6.9	0.64	112	180	9	48	132	10	49	134
10	Morris19	20	2.30	0.416	690	6.9	8.0	0.63	317	1786	52	129	170	38	97	126
11	Portage18	19	2.73	2.225	408	6.6	7.6	2.23	8930	24130	40	91	148	30	68	112
12	Rosebank18	21	0.59	0.626	163	3.4	7.5	0.93	212	1166	30	109	185	29	104	174
13	Rosebank19	9	0.54	0.239	173	4.6	8.2	0.98	1971	6101	28	150	283	26	140	265
14	St.Claude19	45	0.42	0.105	273	1.7	7.1	1.19	19	46	6	25	70	6	25	70
15	Stephenfield18	33	0.29	0.279	200	1.5	8.2	1.63	45	92	11	37	71	11	38	72
16	Wellwood18	54	1.98	0.371	413	5.9	5.9	5.65	47	103	19	55	74	16	45	60
17	Winkler18	13	0.67	0.465	193	2.6	8.0	1.80	156	583	15	52	86	14	50	83

Table 2.4 N fertilizer treatments applied at the gold and silver sites in the study

N Applications at Planting			In-Season N Applications		
N rate lb/ac	Source	Place & time	N rate lb/ac	Source	Place & time
0		**Gold sites**			
40	Urea	Pre-plant Bct&Inc			
80	Urea	Pre-plant Bct&Inc			
120	Urea	Pre-plant Bct&Inc			
160	Urea	Pre-plant Bct&Inc			
200	Urea	Pre-plant Bct&Inc			
80	Urea&eNt	Pre-plant Bct&Inc			
80	Urea&ESN	Pre-plant Bct&Inc			
80	SPU	Pre-plant Bct&Inc			
80	SPU	Post-plant Bct			
120	Urea&eNt	Pre-plant Bct&Inc			
120	Urea&ESN	Pre-plant Bct&Inc			
120	SPU	Pre-plant Bct&Inc			
120	SPU	Post-plant Bct			
40	SPU	Post-plant Bct			
40	SPU	Post-plant Bct	40	UAN	Sdr @ V4
40	SPU	Post-plant Bct	40 or 53[a]	UAN	Ydr @ V8
40	SPU	Post-plant Bct	40 or 53[a]	UAN&Agt	Ydr @ V8
40	SPU	Post-plant Bct	80	UAN	Sdr @ V4
40	SPU	Post-plant Bct	80 or 106[b]	UAN	Ydr @ V8
40	SPU	Post-plant Bct	80 or 106[b]	UAN&Agt	Ydr @ V8
0		**Silver sites**			
40	SPU	Post-plant Bct			
80	SPU	Post-plant Bct			
120	SPU	Post-plant Bct			
160	SPU	Post-plant Bct			
200	SPU	Post-plant Bct			
40	SPU	Post-plant Bct	40	UAN	Sdr @ V4
40	SPU	Post-plant Bct	40 or 53[a]	UAN	Ydr @ V8
40	SPU	Post-plant Bct	40 or 53[a]	UAN&Agt	Ydr @ V8
40	SPU	Post-plant Bct	80	UAN	Sdr @ V4
40	SPU	Post-plant Bct	80 or 106[b]	UAN	Ydr @ V8
40	SPU	Post-plant Bct	80 or 106[b]	UAN&Agt	Ydr @ V8

[a] Due to a calculation error, the rate of N applied at V8 was 53 lb/ac in 2018

[b] Due to a calculation error, the rate of N applied at V8 was 106 lb/ac in 2018

2.3 In-season treatments and measurements

Watchdog 2000 weather stations were installed at each site. These stations continuously measured the following parameters: soil temperature at 5 cm, solar radiation, relative humidity, air temperature, rainfall, dew point, wind speed, direction, and wind gusts. Soil samples were taken in the spring from each 0 N plot; these samples were used to measure soil texture, concentrations of extractable nutrients, and potentially mineralizable nitrogen.

Spring soil samples were taken by hand with a Dutch auger, between planted rows, and partitioned into 5 depth increments: 0-6 in, 6-12 in, 12-24 in, 24-36 in, and 36-48 in. Each sample was a composite of 3 subsamples to 48 in and an additional 2 subsamples to 24 in per plot. Soil samples were kept refrigerated until dried and ground for analysis. Gravimetric soil moisture was measured by oven drying approximately 25 g of soil at 105 C for 24 hours. Spring soil samples were analyzed for nitrate-N and sulphate-S on all 5 depths to 48 in; N and S were measured by extracting 15 g of dried and ground soil with 30 mL 0.01 M $CaCl_2$ shaken for 30 minutes. Nitrate concentration was measured by automated colorimetry while water soluble S (assumed to be sulphate) was measured by inductively coupled plasma optical emission spectroscopy at Farmers Edge Laboratories in Winnipeg.

Surface soil samples (0-6 in) were also analyzed for Olsen (sodium bicarbonate) extractable phosphorus, ammonium acetate exchangeable potassium, DTPA-sorbitol extractable Cu and Zn, organic matter (loss-on-ignition), electrical conductivity, and pH of a water extract solution at Farmers Edge Laboratories in Winnipeg.

Particle size was analyzed for two composite samples from each depth of each site (block 1 & 2 blended for one sample, block 3 & 4 blended for another). Particle size was determined for a 10 g sample of dried and ground soil, using the method for particle size analysis described by Carter & Gregorich (2008). Soil samples were treated with H_2O_2 to oxidize the soil organic matter. Sand was collected with a #270 mesh screen that let the silt and clay fraction pass through. Silt and clay fractions were determined by oven drying a portion of suspension solution by pipette at specific time intervals.

Plant stand was measured once during the growing season. Established plants were counted within a 4 m length of the two central harvest rows for 25% of plots within a site.

Soil samples for pre-sidedress nitrate analysis (PSNT) were taken from each of the three sidedressed treatments immediately prior to the sidedress applications at the V4 stage of crop growth. All of these plots had received 40 lb N ac^{-1} as SUPERU™ broadcast post-plant. After the PSNT soil samples were collected, one of these treatments received no additional N and the other two received 40 or 80 lb N ac^{-1} applied immediately following the PSNT soil sampling. Samples consisted of 5 cores taken from 0-12 in randomly between rows of corn within the plot. Composite samples were refrigerated until being analyzed for nitrate-N only, using the same analytical procedure as for the pre-season soil samples.

In-season applications of UAN were applied as a sidedress at V4 or simulated Y-drop at V8 leaf collar stage. At the V4 stage, plant heights were less than 18 inches which provided sufficient clearance to apply the UAN with a tractor-drawn applicator. The applicator had three shanks spaced 30 inches apart with ¾ inch wide knife openers to enable N applications midway between the corn rows within each plot. Urea ammonium nitrate was placed 2 inches below the soil surface with drag chains to close the furrows. Half rates of fertilizer were applied as a surface dribble band immediately adjacent to guard rows on the outside edges of plots to minimize edge effects. For the simulated Y-drop application at the V8 stage, UAN was dribble banded on the surface of the soils on both sides of every corn row within the plot. These streams were placed by walking at a specific pacing rate, using a modified electric backpack sprayer outfitted with an orifice rate controller and pressure gauge. AGROTAIN™ ULTRA was mixed with UAN immediately prior to application at a rate of 1.6 L per tonne of UAN. The variability in rate for the mechanical sidedress application was probably small; however, the variability in rate for the Y-drop simulation may be greater, given variability in pace length and interval with this hand application method.

Mineralization of organic N at each site-year was estimated using measurements for the unfertilized check plots, based on a two or three step calculation. The first step was to calculate the change in soil nitrate-N reserves over the growing season; the second was to add that change to the crop's aboveground N uptake; also, at several site-years, the third step was to deduct the starter N applied as a baseline application to all plots at planting. In other words, estimated mineralization = (post-harvest soil NO_3-N – pre-plant soil NO_3-N – starter N in baseline fertilizer) + above ground N uptake.

The following soil testing methods were evaluated for their ability to predict the soil's capacity to supply plant available N by mineralizing organic N.

- "Les Henry" Incubation Test - Approximately 500 g of the 0-6 inch field-moist soil sample was used for the "Les Henry" incubation test in which fresh topsoil from each 0 N plot was packaged in a bag with air space and holes for gas exchange. The bags were kept in the dark at room temperature for 4 weeks. At the end of the incubation period the samples were dried, ground, and extracted with 0.01M $CaCl_2$ for nitrate-N concentration measured by automated colorimetry at Farmers Edge Laboratories in Winnipeg. Nitrate content after the incubation was regarded as the gross measure of N mineralization and includes the original, pre-plant nitrate-N, plus the nitrate that was mineralized during the incubation period. Net mineralization was calculated as the gross mineralization minus pre-incubation nitrate concentrations that were measured in the same samples.
- Sodium bicarbonate extraction - Another method to estimate the soil's nitrogen supplying capability was the $NaHCO_3$ extraction and ultraviolet absorbance method developed by Fox and Piekielek (1973). The extract's absorbance at 205 nm and 260 nm is a measurement of labile fraction of the organic matter. Therefore, this method was expected to predict increased concentrations of mineralizable organic N in the soil from greater absorbance in the extract. The extraction for this analysis was performed on dried and ground surface soil from each control plot.
- Soil nitrate tests - Pre-plant soil nitrate-N analyses for 6, 24, and 48 inch depths were also used to determine if there was any relationship between the pre-plant nitrate-N and growing season mineralization. The pre-sidedress nitrate-N test (PSNT) was also evaluated for a potential indicator of N mineralization. For predicting N mineralization, gross and net values for the PSNT were used, with gross PSNT being the average nitrate-N from the PSNT samples and net PSNT is the gross PSNT average (lb N/ac) minus the pre-plant nitrate-N measured at the site (lb N/ac).

- Soil organic matter concentration - For the final predictor of N mineralization, soil organic matter (SOM) content was measured on the 0-6 inch depth of each pre-plant soil sample, using the loss-on-ignition method that was mentioned previously. For all of these soil tests that might predict N mineralization, linear regression was used to test for a significant relationship between the soil test value and an estimate for N mineralization during the growing season.

Spectral reflectance was measured in the crop canopy at several times throughout the season and with multiple instruments. The instruments used were a Trimble Greenseeker and Holland Scientific Crop Circle with active reflectance, and an unmanned aerial vehicle (UAV) which measured passive reflectance. We intended to use the spectral reflectance measurements to calibrate canopy reflectance measurements with the crop's nitrogen status. However, the analysis of imagery data is a part of this project that was not completed by our research team and is being conducted by Dr. Mario Tenuta's and Dr. Paul Bullock's research teams.

2.4 Harvest and fall soil and plant sampling

Visual green leaf assessment ratings were taken on all plots at the R4 dough to R5 dent stages. Green leaves were evaluated for signs of chlorosis and necrosis on ten consecutive plants within a harvest row. Evaluation on a plant began at the leaf adjacent to the lowest productive ear which is regarded as leaf 1, and then proceeded down the stalk until encountering a leaf that showed symptoms of yellowing and senescence (N deficiency). The leaf number for the symptomatic leaf was recorded for each of the ten plants. For example, if leaf 5 was reached and that leaf was healthy, then the leaf assessment rating was leaf 5+ or non-deficient.

The stalk nitrate test was completed on all research plots (Blackmer and Mallarino, 2000). The samples were taken after black layer formation on the cob and prior to crop harvest. A sample of corn stalk 8 inches long was taken from 6 to 14 inches above the soil surface, from 8 plants per plot to create a composite sample. Two plants were sampled from the front and two from the rear of each of the two harvest rows. Stalks were oven dried at 65 C and ground through a 1 mm screen before extraction and analysis for nitrate-N content at AGVISE Laboratories.

Total biomass of corn was harvested on all 0 N plots to determine crop N uptake from soil for the control treatments. Immediately prior to grain harvest, consecutive plants from the first 39 inches of each harvest row were cut at the soil surface and processed into separate samples for corn grain, corn cob, and stalk material. Data collected included total biomass yield, biomass moisture content, biomass N content, cob core yield and N content, grain yield, grain moisture content and grain N content.

Grain yield was measured by one of two strategies depending on the site conditions and logistics. Where soil moisture was not excessive at harvest and distance from the university was not far (9 of the 17 site-years), the entire two rows by plot length were harvested directly with a Wintersteiger plot combine. At the remaining 8 sites where excess soil moisture or travel distance prevented direct harvesting by the plot combine, cobs were handpicked and bagged from 2 rows by 13 feet, then threshed through the stationary combine. All grain yields were adjusted and reported at 15.5% moisture. A subsample of grain from each plot was kept and oven dried at 65 C before being finely ground and analyzed for N content by combustion at AGVISE Laboratories.

Detailed post-harvest soil sampling was in the original protocol for all site-years and plots. However, poor weather and delayed harvests in fall 2018 and fall 2019 resulted in many sites where soil sampling could not be completed as planned, due to excess moisture and ground freezing before samples could be collected. Therefore, soil sampling was completed as planned at only four site-years. The complete soil sampling protocol that was planned for each plot was to use a tractor mounted hydraulic sampler to collect two cores to 48 in and an additional two cores to 24 in on each plot, with all samples taken between corn rows and partitioned into 5 depths (0-6 in, 6-12 in, 12-24 in, 24- 36 in, and 36-48 in). Due to the problems mentioned earlier, this sampling procedure was amended by sampling only the 0 N plots to 48 in at a site (by Dutch auger or hydraulic probe) or by sampling 0 N plots to 48 in and additionally sampling the rate treatments to only 24 in by Dutch auger. Post-harvest gravimetric soil moisture samples were collected, processed, and analyzed in the same manner as for the pre-plant soil moisture samples. However, post-harvest soil moisture measurements were performed on 0 N and 160 lb N/ac plots only if they received post-harvest soil sampling for nitrate analysis.

2.5 Statistical analyses

All data were collected and calculated using Microsoft Excel and statistical analyses were conducted with Statistical Analysis Software (SAS). A general linear model in SAS, PROC GLIMMIX, was used to model yield and profitability responses to the treatments in question. The Coefficient of Variation (C.V.) from PROC UNIVARIATE was used to assess variability within the study.

When a global analysis was performed, data from all 17 site-years were analyzed together. The type III global Analysis of Variance (ANOVA) is reported with degrees of freedom, *F*-value, and the *P*-value (*Pr>F*); which is the probability that our treatment applied had no effect and differences in observations were a result of random variation or other factors. Blocks were considered to be random and nested within each site-year, so global ANOVA tests were used to determine treatment effect, site-year effect, and the treatment x site-years interaction for factors where the independent variable was consistent across sites. When there were significant interactions between treatments and site-years, the data were sliced to identify specific responses at individual sites. Also, in situations where the independent variable was not consistent across sites (e.g., the total N supply rate, including soil test residual nitrate-N for each site and the N fertilizer applications) an ANOVA was completed for each individual site-year. In all cases, treatment means were compared by least squares means (LSmeans) and Tukey's honest significant difference for multiple comparisons. An alpha of 0.05 was used as the *P* level to determine statistical significance throughout the entire report.

2.6 Calculations for soil nitrate-nitrogen

The amount of nitrate-nitrogen in the soil, expressed as lb/ac or kg/ha at the various site-years was calculated using two different methods:

a) PPM x 2 method – Most commercial soil test labs convert the soil test analyses concentrations in "parts per million" or "ppm" to lb/acre using the common rule of thumb that there are approximately 2 million pounds of soil in a 6" slice of soil per acre, regardless of soil texture. Therefore, in this report, critical soil test thresholds and estimates for total N supply based on soil test analyses from commercial soil testing labs (e.g., Sections 3 and 4 of this report) are calculated using this simple technique and displayed as "ppmx2"

b) Bulk density (BD) method - For calculations related to mass balances (e.g., estimated mineralization of soil N at each site in Section 5 of this report), the concentrations of nitrate-N were converted to lb/ac or kg/ha using estimated bulk densities, based on soil texture and are indicated as amounts of N (or S) "by bulk density"

Example for the PPMx2 method:

This method simply multiplies lab analyses in mg/kg (ppm) by 2 to convert to lb/ac for a 6 inch slice, regardless of soil texture and bulk density:

$$\frac{lab\ mg\ NO3-N}{kg\ of\ soil} x\ 2 = \frac{lb\ NO3-N}{6"\ slice\ of\ acre}$$

Example for the bulk density (BD) method:

This method accounts for the bulk density of each soil at each site-year. For example, at the CarmanNorth19 site-year, nitrate-nitrogen (NO_3-N) and sulphate-sulphur (SO_4-S) "by bulk density" are based on the particle size analysis performed on each sample depth from each site (Table 2.5).

Table 2.5. Example of 0-15 cm texture analysis and assumed bulk density values of particles

Site	Depth	Sand	Silt	Clay
CarmanNorth19	0-15 cm	89%	4%	7%
Reference bulk density[a]		**1.55 g/cm^3**	**1.15 g/cm^3**	**1.05 g/cm^3**

[a] Reference bulk densities from University of Saskatchewan (1991) Basic Soil Science

Determine average bulk density at that depth, based on the proportions in each textural class:

$$Average\ bulk\ density = (0.89 * 1.55) + (0.04 * 1.15) + (0.07 * 1.05) = 1.50\frac{g}{cm^3}$$

Determine kg of soil per hectare (ha) for that sample depth:

$$1.50\frac{g}{cm^3}\,x\,\frac{\frac{1500000000\ cm^3}{15\ cm\ slice\ of\ a\ ha}}{\frac{1\ kg}{1000g}} = \frac{2250000\ kg\ soil}{15\ cm\ slice\ of\ a\ ha} = \frac{2000000\ lb\ of\ soil}{6\ inch\ slice\ of\ an\ acre}$$

Since this sandy soil has 2,000,000 lb of soil per 6 inch slice of an acre, the following formula converts lab analyses in mg/kg (ppm) to lb/ac:

$$\frac{lab\ mg\ of\ NO3 - N}{kg\ of\ soil}\,x\ 2.00 = \frac{lb\ NO3 - N}{6"\ slice\ of\ acre}$$

In this soil, which has a very high sand content and a very high bulk density, both methods give similar results. However, at sites with medium or high silt or clay content the bulk density of the sample decreases and as a result the “ppmx2” method typically used by commercial soil test labs would overestimate available nitrate.

Nevertheless, for sections 3 and 4 of this report, all spring and fall soil nitrate-N values are based on the “ppm x2” calculation method, to be consistent with commercial soil testing laboratory reports and agronomist calculations for determining soil inorganic N. However, in part 5, where estimated rates of N mineralization are reported, all soil N calculations are by the bulk density method to more accurately represent the amount of residual nitrate-N at each site, before and after growing the corn crop.

3. Nitrogen rate: Determine appropriate nitrogen fertilizer rates for modern corn hybrids in Manitoba

The appropriate rate of N fertilization was determined with the yield data from treatments where 0, 40, 80, 120, 160, and 200 lb N/ac was applied as conventional urea that was broadcast and incorporated before planting at the four gold level site-years and as SUPERU™ broadcast post-plant at the 13 silver level site-years. Those six treatments represent the rate of fertilizer N that was applied consistently at all site-years.

Two overall strategies were used to determine the most appropriate rate of N fertilization. One strategy simply compared yield responses at each rate of N fertilizer applied, without any consideration for residual soil test nitrate-N that was present at each site prior to establishing the trial. The other strategy accounted for the N supplied from soil and fertilizer at each site as the sum of the rate of fertilizer N applied plus the site's pre-plant soil test NO_3-N plus any starter N applied with the seed at planting. Most important, the calculation of total N supply accounts for variation in the amount of spring soil test nitrate at each site, which was highly variable across the site-years. This calculation is also very important for establishing the calibration data which support recommendations that are based on soil test nitrate analyses. However, this estimate of total N supply does not account for N losses or mineralization of soil organic N during the growing season.

As expected, when averaged across all site-years, N fertilizer rates increased corn yield (Table 3.1). Thirteen individual site-years responded to N fertilizer rate, and 12 of those site-years reached the statistically highest group of yields with 80 lb N/ac or less applied. However, the increase in yield varied significantly among site-years, varying from no increase (e.g., Elgin18) to an increase of almost 100 bu/ac (e.g., CarmanNorth19)(Figures 3.1 and 3.2). The site-year by treatment interaction indicates that site-year factors affected the response to N fertilizer rate. One of those factors was the amount of spring nitrate-N in the top 2 feet of soil at planting, which varied between 25 and 140 lb N/ac across the various site-years, as shown in Table 2.3. Such a wide range of soil N in the spring resulted in a wide range of total N supply to treatments that employed identical rates of fertilizer N.

In addition, the mean yields were also significantly different across site-years (62 to 157 bu/ac), indicating that site-specific conditions, including heat and precipitation, also affected the growth and yield potential of corn. Overall, the growing seasons in 2018 and 2019 in Southern Manitoba were generally dry, especially for corn production. However, growing season weather varied greatly across sites and between years; therefore, the crop's yield potential and demands for N were also variable across sites and years. In section 3.3 where N required per bushel of corn production is determined, site-years are separated into high and low yielding groups with high yielding site-years being characterized as those achieving a yield of at least 130 bu/ac for at least one of the N rates.

3.1 Effect of nitrogen fertilizer application rate on corn grain yield

Table 3.1 Effect of N fertilizer application rate on corn grain yield

			---------- Fertilizer N Rate ----------						
Site-Year	Trt *Pr>F*	Baseline N[a]	0 lb/ac	40 lb/ac	80 lb/ac	120 lb/ac	160 lb/ac	200 lb/ac	Site Mean[c]
		lb/ac			Yield (bu/ac)[b]				
CarmanNorth19	<0.0001	31	61 D	96 C	121 BC	133 AB	141 AB	153 A	118 cde
CarmanSouth19	0.3124	57	142	154	152	151	162	157	153 ab
CarmanWest18	<0.0001	70	104 B	129 AB	139 A	143 A	149 A	149 A	135 abc
Clearwater19	0.2482	145	149	147	160	164	156	164	157 a
Elgin18	0.9630	165	114	121	120	117	117	120	118 cde
Elgin19	<0.0001	63	76 B	96 AB	117 A	110 A	117 A	114 A	105 def
Graysville18	0.0168	80	107 B	128 AB	132 AB	134 A	117 AB	132 AB	125 bcd
Graysville19	0.0183	54	111 B	129 AB	142 A	135 AB	136 AB	131 AB	130 abcd
MacGregor18	<0.0001	52	73 C	135 B	148 AB	166 A	159 AB	156 AB	139 abc
Morris19	<0.0001	129	88 B	118 A	129 A	117 A	123 A	123 A	116 cde
Portage18	<0.0001	97	91 B	111 AB	122 A	129 A	113 AB	130 A	116 cde
Rosebank18	0.0118	114	112 B	135 AB	132 AB	146 A	132 AB	136 AB	132 abcd
Rosebank19	0.2224	155	140	149	153	156	158	160	153 ab
StClaude19	<0.0001	25	19 B	38 B	66 A	81 A	83 A	85 A	62 g
Stephenfield18	<0.0001	37	28 C	73 B	101 A	124 A	117 A	110 A	92 ef
Wellwood18	<0.0001	64	49 B	79 A	95 A	76 A	79 A	88 A	78 fg
Winkler18	<0.0001	61	89 C	133 B	158 AB	155 AB	160 A	151 AB	141 abc
Mean for all site-years	<0.0001	82	91 C	117 B	129 A	132 A	130 A	132 A	
Global ANOVA	df	*Pr>F*							
Trt	5	<0.0001							
Siteyr	16	<0.0001							
Siteyr*Trt	80	<0.0001							
C.V. (%)		28							

[a] Baseline N includes pre-plant soil test NO_3-N to 24” by PPMx2 plus starter N applied at planting

[b] Across fertilizer rates in each row, means followed by the same upper case letter are not significantly different at $P<0.05$

[c] Within the column for site means, means followed by the same lower case letter are not significantly different at $P<0.05$

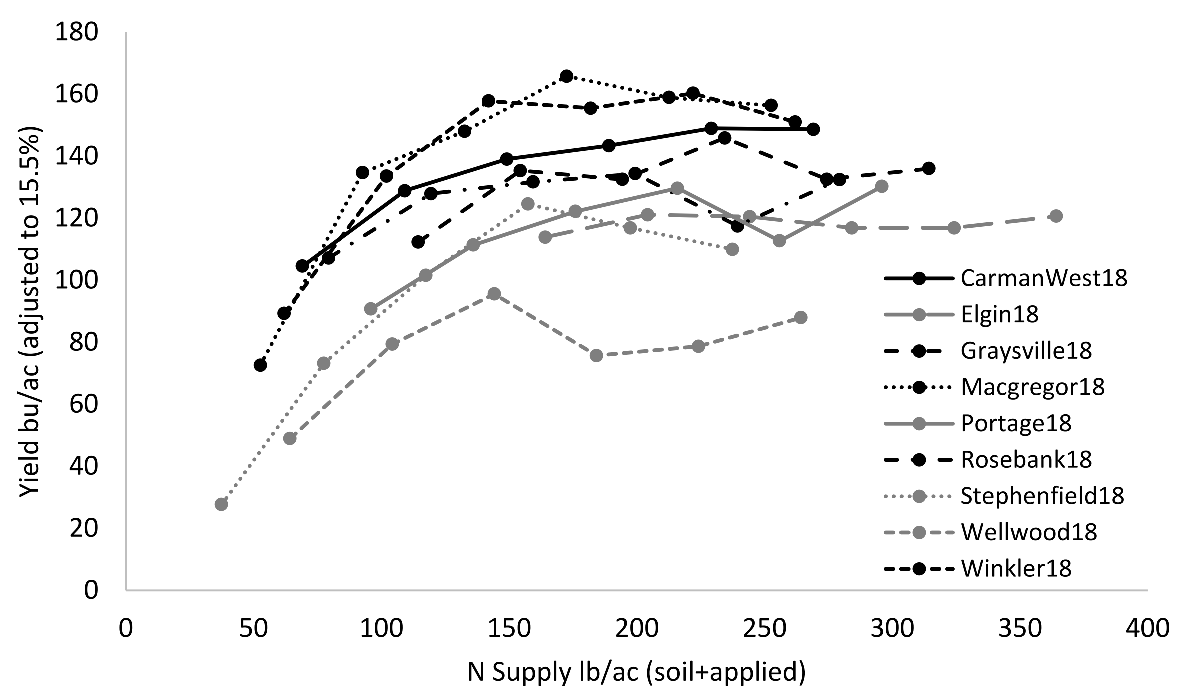

Figure 3.1 Effect of total N supply (baseline N plus fertilizer N) on corn grain corn yield at the 9 research sites used in 2018

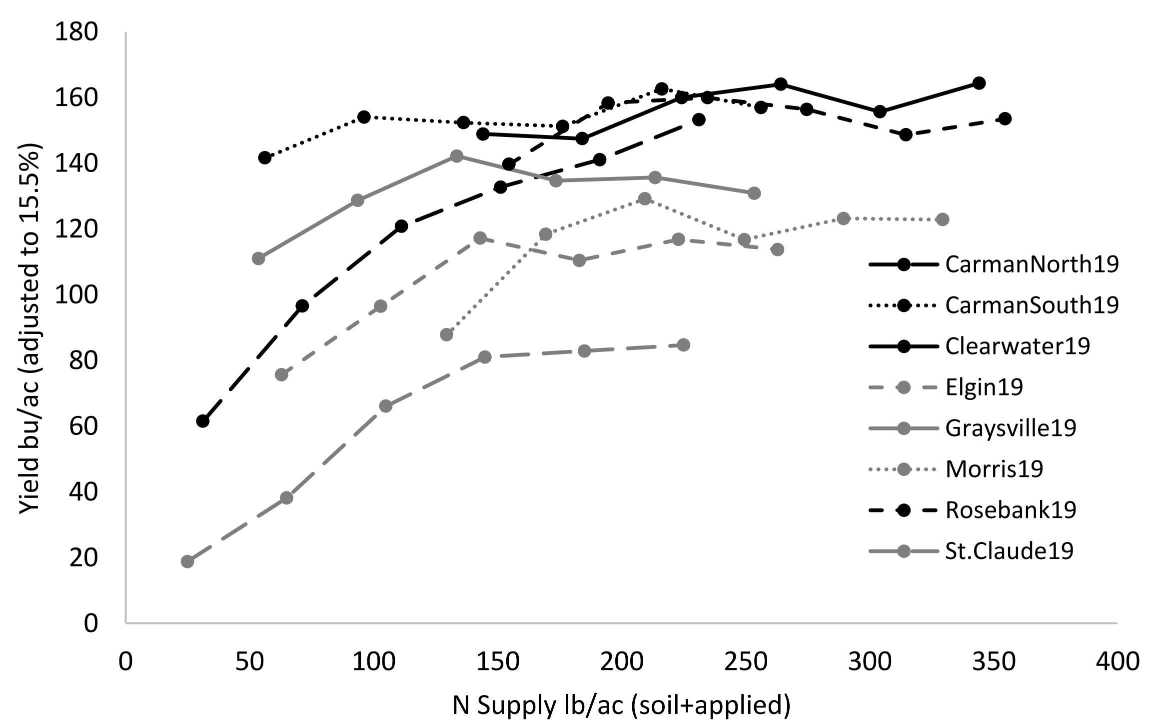

Figure 3.2 Effect of total N supply (baseline N plus fertilizer N) on corn grain corn yield at the 8 research sites used in 2019

3.2 Yield response and optimum economic return to nitrogen supply

The maximum return to nitrogen (MRTN) supply can be defined as the total N supply (fertilizer N application rate plus pre-plant soil test residual nitrate-N) at which the net economic return to fertilizer N is the greatest. Mathematically, this is where (yield x corn price) minus (N application rate x cost of N fertilizer) is maximized. The cost of N was calculated only for N applied as fertilizer within the fertilizer rate treatments and not for spring soil test nitrate-N or for N applied as starter or baseline fertilizer across all treatments. In this economic analysis, profitability is calculated by using pre-set grain corn and fertilizer N prices and/or prices that represent a ratio between the cost of N fertilizer and price of grain corn. The results presented in this study will hold true at any market values that equal the ratios in Table 3.2. For this study, the MRTN was calculated using three methods:

a) identify numerically greatest economic return to total N supply for each site-year, without any statistical analysis
b) use statistical comparisons of fertilizer rate treatment means to identify the mean total N supply for the group of treatments that generated the highest returns at each site-year
c) use quadratic yield response models to characterize response to N supply and maximum economic return to N at each individual site-year

Table 3.2 Fertilizer and corn prices and price ratios used for N profitability analysis

	Ratio of Price for Fertilizer N vs. Corn		
	Low N Price Ratio	Medium N Price Ratio	High N Price Ratio
Price of N fertilizer per lb	\$0.35	\$0.45	\$0.55
Price of corn per bu	\$4.50	\$4.50	\$4.50
Price ratio \$N:\$ Corn	0.08:1	0.10:1	0.12:1

a) Numerically greatest economic return to N supply

The numerically greatest return to N fertilizer is a non-statistical method to evaluate the yield response data where the rate treatment with the high numerical value for return is identified from tables of mean values for each site-year (Appendix Tables 6.1-6.17). As the fertilizer:corn price ratios increase from low to high, the cost of N fertilizer increases relative to the price of corn, decreasing the profitability of applying N fertilizer.

The numerical maximum return to the total nitrogen supply rate (including residual soil test nitrate at the beginning of the growing season) at the medium fertilizer:corn price ratio varied from 97 to 265 lb N/ac with the mean being 179 lb N/ac (Table 3.3). The economic MRTN supply rate was less than the N supply rate to achieve maximum yield at only 7 of the 17 site-years.

Table 3.3 Total N supply (baseline N plus fertilizer N) for the numerically maximum yielding treatment and maximum economic return to N fertilizer for each site-year at each fertilizer:corn price ratio

	For maximum yield	For maximum return to N fertilizer		
		Low price ratio[a]	Medium price ratio	High price ratio
Site-year	Total N supply (lb N/ac)			
CarmanNorth19	231	231	231	231
CarmanSouth19	217	97	97	97
CarmanWest18	230	230	230	230
Clearwater19	265	265	265	225
Elgin18	205	205	205	205
Elgin19	223	143	143	143
Graysville18	200	160	120	120
Graysville19	134	134	134	134
MacGregor18	172	172	172	172
Morris19	209	209	209	209
Portage18	297	217	217	217
Rosebank18	234	234	234	234
Rosebank19	235	195	195	195
StClaude19	225	145	145	145
Stephenfield18	157	157	157	157
Wellwood18	144	144	144	144
Winkler18	221	141	141	141
mean	208	181	179	176

[a] Fertilizer:corn price ratios are defined in Table 3.2

Within the economic analysis, increasing the cost of N fertilizer from \$0.35 to \$0.55 /lb reduced the average MRTN rate by only 5 lb N/ac. The numerical maximum return to N fertilizer application rate was 40 lb N/ac at 4 of the 17 site-years and as high as 160 and 200 lb N/ac at others. The most frequent rate of N application for the numerical MRTN was 120 lb N/ac at 6 of the 17 site-years.

b) Statistical comparisons of means to identify optimum N supply for highest returns

Statistical comparisons of means were used to evaluate the effect of total N supply on corn grain yield and profitability at three scenarios for fertilizer:corn price ratios, with the mean total N supply for the group of treatments that generated the highest economic returns at each site-year being the MRTN.

At 9 of the 17 site-years, statistical comparisons of means indicated that the N supply rate for the MRTN was the same as the rate for achieving a yield equivalent to the highest yielding group of treatments, regardless of the fertilizer:corn price ratio (Table 3.4). To achieve maximum yield as determined by statistical comparison of means, the range of total N supply required was from 54 to 217 lb N/ac with a mean of 147 lb N/ac across the 17 site-years.

Table 3.4 Mean total N supply (baseline N plus fertilizer N) for the treatment group with the maximum yield and maximum economic return to N fertilizer determined for each site-year by statistical comparison of means at each fertilizer:corn price ratio. For site-years with no statistically significant responses to N fertilizer, baseline N supplies are reported for maximum yields and economic returns.

	For yield equivalent to maximum yield[a]	For maximum return to N fertilizer		
		Low price ratio[b]	Medium price ratio	High price ratio
Site-year	Total N supply (lb N/ac)			
CarmanNorth19	171	171	171	151
CarmanSouth19	57	57	57	57
CarmanWest18	190	190	190	190
Clearwater19	145	145	145	145
Elgin18	165	165	165	165
Elgin19	183	183	183	63
Graysville18	200	180	167	167
Graysville19	54	54	54	54
MacGregor18	172	172	172	172
Morris19	249	129	129	129
Portage18	217	217	217	207
Rosebank18	234	114	114	114
Rosebank19	155	155	155	155
StClaude19	165	165	165	165
Stephenfield18	177	177	177	177
Wellwood18	184	184	64	64
Winkler18	201	201	181	181
mean	172	156	147	139

[a] Mean N supply required for yield to match the highest yielding group of treatments according to statistical comparisons of means

[b] Fertilizer:corn price ratios are defined in Table 3.2

Over all site-years, the average N supply rate for MRTN decreased only 17 lb N/ac as the fertilizer:corn price ratio increased from low to high. For the medium fertilizer:corn price ratio, 8 of 17 site-years had no statistically significant differences in yield or profitability between the zero N control and any N fertilizer application rate; those site-years were CarmanSouth19, Clearwater19, Elgin 18, Graysville19, Morris19, Rosebank18, Rosebank19, and Wellwood 18. For site-years with significant economic responses to N fertilizer, no site required an average of more than 140 lb fertilizer N/ac to be in the highest profitability group at the medium fertilizer:corn price ratio (Appendix Tables 6.1-6.17).

c) Quadratic yield response models for each site-year to estimate overall average response to N supply

Quadratic response models (or response "curves") were used to describe the yield response to total N supply at each site-year. The MRTN for these quadratic response models occurs at the highest rate of N where the revenue benefit from an additional unit of N is greater than or equal to the cost of applying an additional unit of N fertilizer. As N rates increase beyond the MRTN to maximum yield, the revenue from further increases in yield due to applied N is less than the cost of that additional N fertilizer.

The range of total N supply from soil plus fertilizer required to achieve maximum yield varied from 176 to 347 lb/ac and the average was 228 lb N/ac (Table 3.5). The average N supply for the MRTN at the high fertilizer:corn price ratio for N fertilizer was 180 lb N/ac, which was 18 lb/ac less than the recommendation of 198 lb/ac when the price ratio was lowest.

Overall, the quadratic models based on responses for each individual site-year indicated that N supply should be reduced by an average of 39 lb N/ac when targeting the MRTN at a medium fertilizer:corn price ratio (189 lb N/ac) compared to targeting absolute maximum yield (228 lb N/ac).

Table 3.5 Total N supply (baseline plus fertilizer N) for the maximum yield and maximum economic return to N fertilizer determined by quadratic response equations for each site-year at each fertilizer:corn price ratio

	For maximum yield	For maximum return to N fertilizer		
		Low price ratio[a]	Medium price ratio	High price ratio
Site-year	Total N supply (lb N/ac)			
CarmanNorth19	240	220	215	209
CarmanSouth19	242	150	123	97
CarmanWest18	234	209	202	195
Clearwater19	347	241	211	181
Elgin18	na[b]	na[b]	na[b]	na[b]
Elgin19	207	187	182	176
Graysville18	208	176	167	158
Graysville19	176	154	148	142
MacGregor18	193	184	182	179
Morris19	262	242	236	231
Portage18	249	221	213	206
Rosebank18	243	218	211	204
Rosebank19	266	233	223	214
St.Claude19	205	187	181	176
Stephenfield18	182	173	171	169
Wellwood18	199	177	171	165
Winkler18	198	188	185	182
mean	228	198	189	180

[a] Fertilizer:corn price ratios are defined in Table 3.2

[b] Virtually no response to N fertilizer at Elgin18, so quadratic response model did not fit well (R^2= 0.17)

d) Comparison of N rate recommendations developed from the three methods

For the numerical analysis of mean yields and returns to N, the average N supply for the 17 site-years was 208 lb N/ac when targeting maximum yield (Table 3.3). The N rate decreased to 179 lb N/ac when targeting the MRTN at the medium fertilizer:corn price ratio, or 29 lb N/ac less than for maximum yield.

Equivalent N supply values for the statistical comparisons of mean yields and returns to N were lower than for those determined by the numerical or quadratic response methods. An average N supply of 172 lb N/ac was required for the highest yielding group of treatments within each site (Table 3.4). An average total N supply of 147 lb N/ac was required to achieve the optimum return to N at the medium price ratio, 25 lb N/ac less than to achieve the maximum yield.

One of the possible explanations why the economically optimum N supply determined by this method was lower than the other methods is that the highest rates of N applied were generally not high enough to result in significant reductions in returns. Therefore, the full range of statistically similar returns to N for the various rates of N supply might not be fully represented and the mean rate of N supply for the statistical group with the highest returns might have been slightly biased towards low rates of N.

Average N requirements for maximum yield and MRTN were greatest when quadratic equations were used to model yield responses to N. Quadratic responses predicted an average N supply of 228 lb N/ac to achieve absolute maximum yield and 189 lb N/ac to achieve the MRTN at medium ratio, or 39 lb N/ac less than for maximum yield (Table 3.5).

The numerical method showed the largest effect of site-year on the MRTN for the medium fertilizer:corn price ratio, with an N supply range of 97-265 lb N/ac, compared to 54-217 lb N/ac and 123-236 lb N/ac for the quadratic and statistical comparisons of means methods, respectively. However, the quadratic method of describing N response for each site-year showed the largest effect of N fertilizer cost on the MRTN, compared to the two other methods. The average difference between the MRTN for the lowest compared to highest ratio of fertilizer:corn prices was 18 lb N/ac for the quadratic method, but only 5 lb N/ac for the numerical method and 17 lb N/ac for the statistical comparisons of means.

3.3 Nitrogen required per bushel of corn for site-years with low and high yield potential

One method that soil testing labs use for N fertilizer recommendations is to use a farmer's target yield, then multiply that yield by a standard measure of N needed per unit of production of the crop, e.g., lb N/bushel. In the Northern Great Plains, the total supply of N required per unit of yield is determined from the results of fertilizer rate treatments and analyses of spring residual nitrate-N at each site. In our study, N supply per unit of production was determined from the numerically MRTN, MRTN determined by statistical comparisons of means, and quadratic response models. For each method of determining the MRTN, we calculated the N supplied per bushel of corn production at each site-year by dividing the total N supply (pre-plant soil test nitrate to 2 feet + starter N + applied N) by the average yield of that treatment at the MRTN. Average N supply values were determined for two groups of site-years, separated into high- and low-yielding groups, with high-yielding site-years being characterized as those achieving a yield of at least 130 bu/ac in at least one of the N rate treatments.

a) Nitrogen required at the numerically greatest economic return for low- and high-yielding site-years

At lower yielding site-years (<130 bu/ac), the mean N supply at MRTN was 167 lb/ac for an average yield of 111 bu/ac and an average optimum N supply of 1.52 lb N/bu (Table 3.6). Higher yielding site-years (>130 bu/ac), required an average of an additional 18 lb N/ac at the numerically MRTN, while they yielded 39 bu/ac more. Therefore, high yielding site-years required less N per bushel (1.24 lb N/bu) than low yielding site-years (1.52 lb N/bu) at their respective economically optimum N supply. This suggests that corn becomes more efficient at utilizing N as yield potential increases, rather than following a linear demand for N based on crop yield goal, alone. However, there was also substantial variability in the optimum rate of N supply among site-years with similar yield potential, probably due to variability in N mineralization from one site-year to another. For example, the economically optimum N supply for Carman North19 was 1.51 lb N/bu for 153 bu/ac, but in the same year and same region, the optimum N supply for Carman South19 for 154 bu/ac was only 0.62 lb N/bu.

The optimum N supply of 1.24 lb N/bu for high yielding site-years is similar to the recommendations that are provided by AGVISE Labs in North Dakota, which recommends a total N supply of 1.2 lb N per bushel to grow a 130 bu/ac corn crop.

Table 3.6 Total N supply (baseline plus fertilizer N) per bushel of corn yield at the numerically optimum economic N rate for site-years with low and high yield potential

Site-year	Baseline N[a] lb N/ac	N supply at MRTN[b] lb N/ac	Yield at MRTN[b] bu/ac	N supply/bu lb N/bu grain corn
		Site-years with yield potential <130 bu/ac		
Elgin18	165	205	121	1.69
Elgin19	63	143	117	1.22
Morris19	129	209	129	1.62
St.Claude19	25	145	81	1.79
Stephenfield18	37	157	124	1.27
Wellwood18	64	144	94	1.52
mean	81	167	111	1.52
		Site-years with yield potential ≥130 bu/ac		
CarmanNorth19	31	231	153	1.51
CarmanSouth19	57	97	154	0.62
CarmanWest18	70	230	149	1.54
Clearwater19	145	265	164	1.61
Graysville18	80	120	128	0.93
Graysville19	54	134	142	0.94
MacGregor18	52	172	166	1.04
Portage18	97	217	129	1.67
Rosebank18	114	234	146	1.60
Rosebank19	155	195	158	1.23
Winkler18	61	141	158	0.90
mean	83	185	150	1.24

[a] Baseline N includes pre-plant soil test NO_3-N to 24” by PPMx2 plus starter N applied at planting

[b] MRTN, maximum return to nitrogen, the numerically most profitable N treatment using the medium fertilizer:corn price ratio of $0.45/lb of N and $4.50/bu of corn

b) Nitrogen required according to statistical comparisons of means to identify optimum N supply for highest returns for low- and high-yielding site-years

According to the statistical comparisons of means, the average N requirement per bushel at lower yielding site-years (<130 bu/ac) to obtain the optimum yield was 1.59 lb N/bu, which was 0.5 lb N/bu greater than the 1.09 lb N/bu needed to obtain the optimum yield at higher yielding site-years (≥130 bu/ac)(Table 3.7). Once again, this suggests that corn becomes more efficient at utilizing N as yield potential increases, rather than following a linear demand for N based on crop yield, alone. However, as was the case for the numerically optimum N rates, there was also substantial variability among site-years with similar yield potential. For example, the economically optimum N supply for Rosebank19 was 1.1 lb N/bu for 140 bu/ac, but in the same year and same region, the optimum N supply for Carman South19 for 142 bu/ac was only 0.4 lb N/bu.

Table 3.7 Mean total N supply (baseline plus fertilizer N) per bushel of corn yield at the economic optimum N rate for the medium fertilizer:corn price ratio, determined by statistical comparisons of means for site-years with low and high yield potential. For site-years with no statistically significant responses to N fertilizer, baseline N supplies are reported for maximum yields and economic returns.

Site-year	Baseline N[a]	Mean N supply for the means group with the highest MRTN[b]	Mean yield for the means group with the highest MRTN[b]	Mean N supply/bu for the means group with the highest MRTN[b]
	lb N/ac	lb N/ac	bu/ac	lb N/bu corn
		Site-years with yield potential <130 bu/ac		
Elgin18	165	165	114	1.45
Elgin19	63	183	111	1.65
Morris19	129	129	88	1.47
St.Claude19	25	165	79	2.10
Stephenfield18	37	178	113	1.57
Wellwood18	64	64	49	1.31
mean	81	147	92	1.59
		Site-years with yield potential ≥130 bu/ac		
CarmanNorth19	31	171	137	1.25
CarmanSouth19	57	57	142	0.40
Carman West18	70	189	142	1.34
Clearwater19	145	145	149	0.97
Graysville18	80	168	127	1.33
Graysville19	54	54	111	0.49
MacGregor18	52	172	153	1.13
Portage18	97	217	121	1.79
Rosebank18	114	114	112	1.02
Rosebank19	155	155	140	1.11
Winkler18	61	181	158	1.15
mean	83	148	136	1.09

[a] Baseline N includes pre-plant soil test NO_3-N to 24” by PPMx2 plus starter N applied at planting

[b] MRTN, maximum return to nitrogen, the most profitable N treatment using the medium fertilizer:corn price ratio of $0.45/lb of N and $4.50/bu of corn

These N requirements are much smaller than those recommended in the current edition of the Manitoba Soil Fertility Guide (Appendix Table 6.9), where with 30 lb/ac of pre-plant nitrate-N to 2 feet, the Guide recommends applying 195 lb N/ac for a yield goal of 130 bu/ac. That equates to a total N supply of 1.73 lb N/bu of corn yield, which is greater than 1.09 lb N/bu, which is the average N requirement determined by the statistical comparison of means for site-years yielding 130 bu/ac or more.

c) Nitrogen required according to the quadratic model to identify optimum N supply for highest returns for low- and high-yielding site-years

Using the quadratic model for yield response, the average N supply required was similar for the low and high yielding site-years at 188 and 189 lb/ac, respectively (Table 3.8). The average yield, however, was 40 bu/ac greater for the high yielding site-years, leading to an average optimum N requirement of 1.76 lb/bu at low yielding site-years and 1.29 lb/bu at site-years yielding greater than 130 bu/ac. This once again suggests that as yield potential increases, corn becomes more efficient at using nitrogen.

Table 3.8 Total N supply (baseline plus fertilizer N) per bushel of corn yield at the economic optimum N rate determined by quadratic yield response model for individual site-years with low and high yield potential

Site-year	Baseline N[a] lb/ac	N supply at MRTN[b] lb/ac	Yield at MRTN[b] bu/ac	N supply/bu lb N/bu corn
		Site-years with yield potential <130 bu/ac		
Elgin18	na[c]	na[c]	na[c]	na[c]
Elgin19	63	182	117	1.56
Morris19	129	236	126	1.87
St.Claude19	25	181	84	2.15
Stephenfield18	37	171	122	1.40
Wellwood18	65	171	87	1.97
mean	64[c]	188	107	1.76
		Site-years with yield potential ≥130 bu/ac		
CarmanNorth19	31	215	149	1.44
CarmanSouth19	57	123	152	0.81
CarmanWest18	70	202	148	1.36
Clearwater19	145	211	155	1.36
Graysville18	80	167	130	1.28
Graysville19	54	148	138	1.07
MacGregor18	52	182	167	1.09
Portage18	97	213	125	1.70
Rosebank18	114	211	139	1.52
Rosebank19	155	223	156	1.43
Winkler18	61	185	163	1.13
mean	77	189	147	1.29

[a] Baseline N includes pre-plant soil test NO_3-N to 24” by PPMx2 plus starter N applied at planting

[b] Maximum return to nitrogen using the medium fertilizer:corn price ratio of $0.45/lb of N and $4.50/bu of corn

[c] Elgin18 had virtually no response to N fertilizer, so the quadratic response model did not fit well (R^2= 0.17) and the N supply and response data for this site are not included in this analysis

As a complement to the quadratic response models developed for individual site-years, nitrogen response models were developed for the pooled or composite response data for each yield group. This approach is meant to account for overall differences in yield potential across groups of site-years, similar to the approach used by North Dakota State University for corn N recommendations (Figure 3.3, Table 3.9).

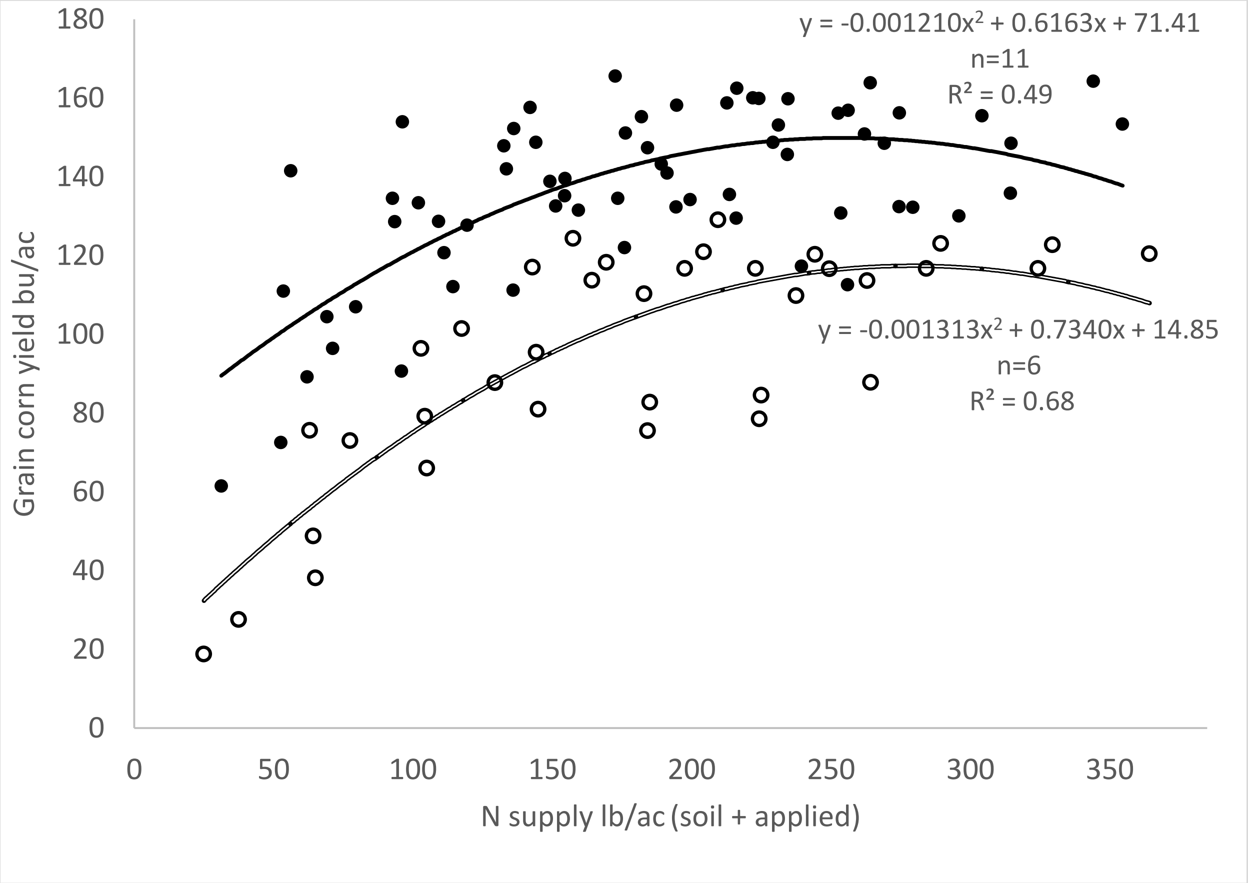

Figure 3.3 Quadratic model for grain yield response to N supply for two groups of site-years, with potential yields over or under 130 bu/ac

A summary of MRTN developed from two quadratic models for grouped site-years of low and high yield potential (Table 3.9) indicates that the site-years with a yield potential <130 bu/ac required 2.09 lb N/bu which is 0.65 lb more N per bushel than when the yield potential was >130 bu/ac (1.44 lb N/bu). Both of these groups' N requirements per bushel were higher than some current recommendations, such as those from AGVISE Labs which recommends 1.2 lb N/bu.

The low and high yielding groups of site-years also required more N/bu with this approach to determining MRTN, compared to using the mean of quadratic models for the individual low- and high-yielding site-years within each group (1.76 and 1.29 lb N/bu respectively). The most likely reason for the higher N recommendation in the quadratic equations for the two groups of sites is that an unusually large response to N at a few individual site-years had a substantial influence on the upward slope and peak yield estimate by the quadratic model, whereas when site-years were analyzed individually for their quadratic responses, atypically large N responses from a few site-years did not skew the overall average yield potential and MRTN upwards as much.

Table 3.9 Total N supply (baseline plus fertilizer N) per bushel of corn yield at the economic optimum N rate determined by two quadratic yield response models, one for the group of low-yielding site-years and one for the group of high-yielding site-years

Site-year group	Baseline N lb/ac	N supply at MRTN[b] lb/ac	Yield at MRTN[b] bu/ac	N supply/bu lb N/bu corn
yield potential <130 bu/ac	81	241	115	2.09
yield potential >130 bu/ac	77	213	148	1.44

[a] Baseline N is a calculation of pre-plant NO3-N to 24” by PPMx2 plus starter N applied at planting

[b] Maximum return to nitrogen using $0.45/lb N and $4.50/bu corn

d) Comparison of N rate recommendations per bushel for low- and high-yielding site-years developed from the different methods of determining MRTN

Overall, yield potential and the method of determining the N supply rate for MRTN had a large effect on the recommendation for optimum rate of N supply (Table 3.10). Lower yielding site-years generally had much higher N requirements per bushel for optimum economic yield. However, even when site-years had similar yield potential, there were large differences in the economically optimum N supply, indicating soil organic N reserves and management history as additional factors for determining optimum N rates.

If a corn crop was expected to yield 120 bu/ac, following the single quadratic response model developed for the low-yielding group of site-years would lead to recommending a total N supply of 251 lb N/ac for MRTN, compared to the statistical comparison of means recommending a total N supply of 161 lb N/ac, the numerically greatest MRTN method recommending 182 lb N/ac, and the average for individual quadratic response models recommending 215 lb N/ac. Therefore, the quadratic models recommend the largest rates of N supply while the statistical comparisons of means recommend the smallest rates of N supply. Furthermore, grouping the site-years for the quadratic model results in a much greater N supply recommendation compared to the average of quadratic models for individual site-years.

Site-years with a greater yield potential were more efficient at using N. Regardless of the method used to determine the optimum supply of N, there was at least a 0.28 lb N/bu improvement in N efficiency when site-years had a yield potential greater than 130 bu/ac compared to site-years yielding less than 130 bu/ac.

As mentioned previously, the method of determining N supply rate for MRTN has a large impact on the N supply recommendations (Table 3.10). Nevertheless, the overall average optimum rate of N for all four methods for high-yielding site-years was 1.27 lb N/bu, nearly identical to AGVISE Labs, where 1.2 lb N/bu of corn is used. However, the AGVISE recommendations on a per bushel basis could lead to undersupplying N on site-years that have a yield goal less than 130 bu/ac. The 2007 version of the Manitoba Soil Fertility Guide recommends 1.7 lb N/bu which is a greater N supply recommendation than six of the eight N MRTN determinations reported in this study.

Table 3.10 Summary of total N supply (baseline plus fertilizer N) and corn yield at the economic optimum N supply (MRTN) for each method of determination at the medium fertilizer:corn price ratio

	Low yielding site-years (<130 bu/ac)		High yielding site-years (>130 bu/ac)	
Method of determining economic optimum nitrogen supply	N supply (lb N/ac)	Yield (bu/ac)	N supply (lb N/ac)	Yield (bu/ac)
Average of numerically greatest return to N for each site-year	167	111	185	150
	1.52 lb N/bu		1.24 lb N/bu	
Average of statistical comparison of means for each site-year	147	92	148	136
	1.59 lb N/bu		1.09 lb N/bu	
Average of quadratic response models for each individual site-year	188	107	189	147
	1.76 lb N/bu		1.29 lb N/bu	
One quadratic response model for each entire group of site-years	241	115	213	148
	2.09 lb N/bu		1.44 lb N/bu	

3.4 Indicators of N sufficiency

a) Pre-sidedress nitrate test (PSNT)

The purpose of the pre-sidedress nitrate soil test is to enable corn growers to adjust the rate of N that they normally apply at the V4 stage, after accounting for early season disappearance of N (e.g., leaching and denitrification losses in a wet spring) or appearance of N (e.g., due to mineralization of organic N). Generally, a low rate of side-dressed N would be recommended if pre-sidedress nitrate concentrations were high (e.g., if there was a large amount of residual soil nitrate from the previous crop year, plus N mineralization from soil organic matter).

Preliminary analysis of the PSNT test shows very little response to additional N fertilizer in plots where concentrations of PSNT exceeded 40 mg N/kg soil (equivalent to approximately 160 lb N/acre in the top foot of soil) (Figure 3.4, Table 3.11). This measurement in the PSNT includes the 40 lb N/ac applied at planting. Where the concentrations of PSNT were 30-40 mg N/kg soil (~120-160 lb N/ac in the top foot of soil), application of an additional 40 lb N/acre at V4 appeared to increase yield above the base treatment of 40 lb N/ac applied at planting and matched the yield of the 200 lb N/ac treatment. For plots where PSNT concentrations were less than 30 mg N/kg soil (<120 lb N/ac), an additional 80 lb N/acre was required at V4 to match the yield for the 200 lb N/ac treatment. However, further statistical analysis of the PSNT data is required.

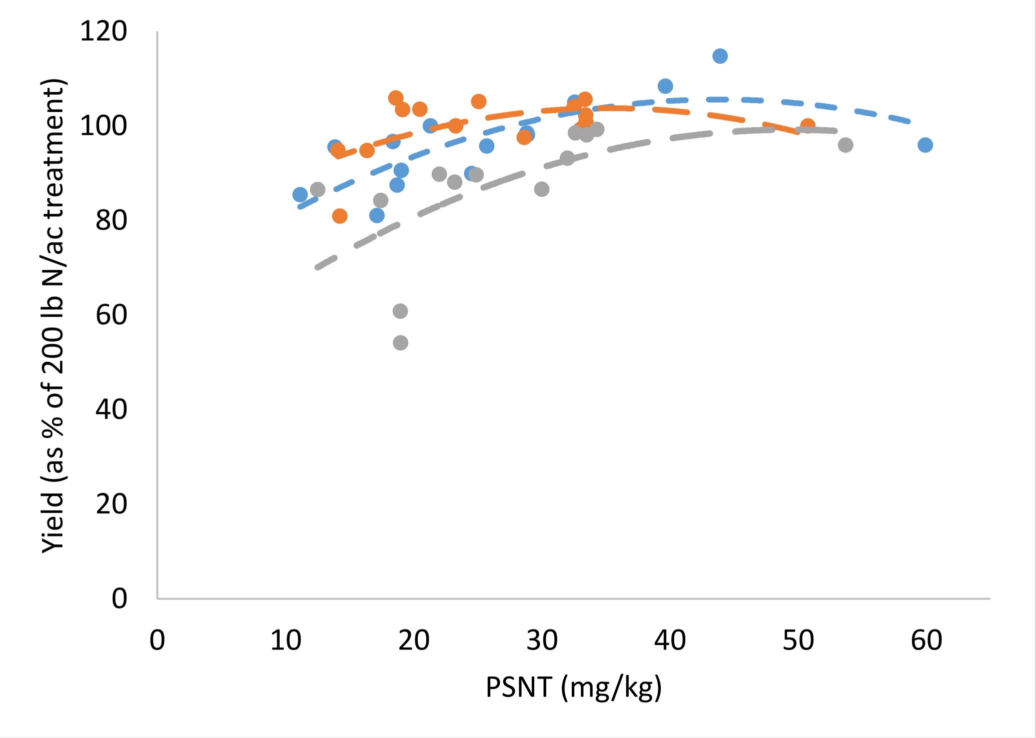

Figure 3.4 Quadratic models for indexed yield to PSNT test of plots that received 40 lb N at planting (grey), or 40 lb N at planting plus 40 (blue) or 80 (orange) lb N at V4.

Table 3.11 Quadratic equations and r^2 of treatments that received PSNT testing at 15 site-years

Grey	40 lb/ac at planting	$y = -0.0215x^2 + 2.12x + 46.9$	$R^2 = 0.36$
Blue	40 lb/ac at planting + 40 at V4	$y = -0.0213x^2 + 1.87x + 64.7$	$R^2 = 0.59$
Orange	40 lb/ac at planting + 80 at V4	$y = -0.0231x^2 + 1.62x + 75.2$	$R^2 = 0.35$

b) Leaf colour ratings

Rating leaf greenness at physiological maturity has been identified as a potential tool to predict whether or not there will be a yield loss resulting from N deficiency. In South Dakota, researchers found that when the third and fourth leaves below the primary ear leaf were completely green, yield was not limited due to lack of N (Gelderman et al., 2009).

Preliminary regression analyses of the leaf colour ratings in our study show that this indicator has some potential to predict N deficiency for corn in Manitoba, but these ratings were not reliable where other plant stresses such as drought stress might have caused chlorosis. Figures 3.6 and 3.7 show the analyses of yield response to N vs. leaf colour ratings for the third and fourth leaves below the ear. These analyses confirm the South Dakota findings: when the third and fourth leaves are green and not chlorotic, yield loss due to N deficiency is highly unlikely. Similar to the study in South Dakota, these figures also show that yield loss due to N deficiency is greater when a greater proportion of leaves show deficiency. These figures plus Figure 3.5 also show that N deficiency symptoms are greatest on basal leaves and travel up the plant with increasing degree of N deficiency.

However, the frequency of chlorosis was not a reliable or accurate predictor of N deficiency in our study. Indexed yields did not fall below 90% of yield for the 200 lb N/ac treatment until more than 60% of the third leaves or 80% of the fourth leaves within the plot showed chlorosis (Figures 3.6 and 3.7). For the first two leaves below the ear, yields were generally at least 90% of the 200 lb N/ac treatment unless at least 40% of the leaves were chlorotic (Figure 3.5). Within the site-years presented, relationships between yield loss due to N deficiency and frequency of chlorosis were poor and inconsistent, with R^2 values that varied from 0.00 to 0.86 (Tables 3.12-3.14) and a very wide range of slope coefficients. Therefore, the relationship between yield response to N and leaf colour was highly variable and unreliable across site-years.

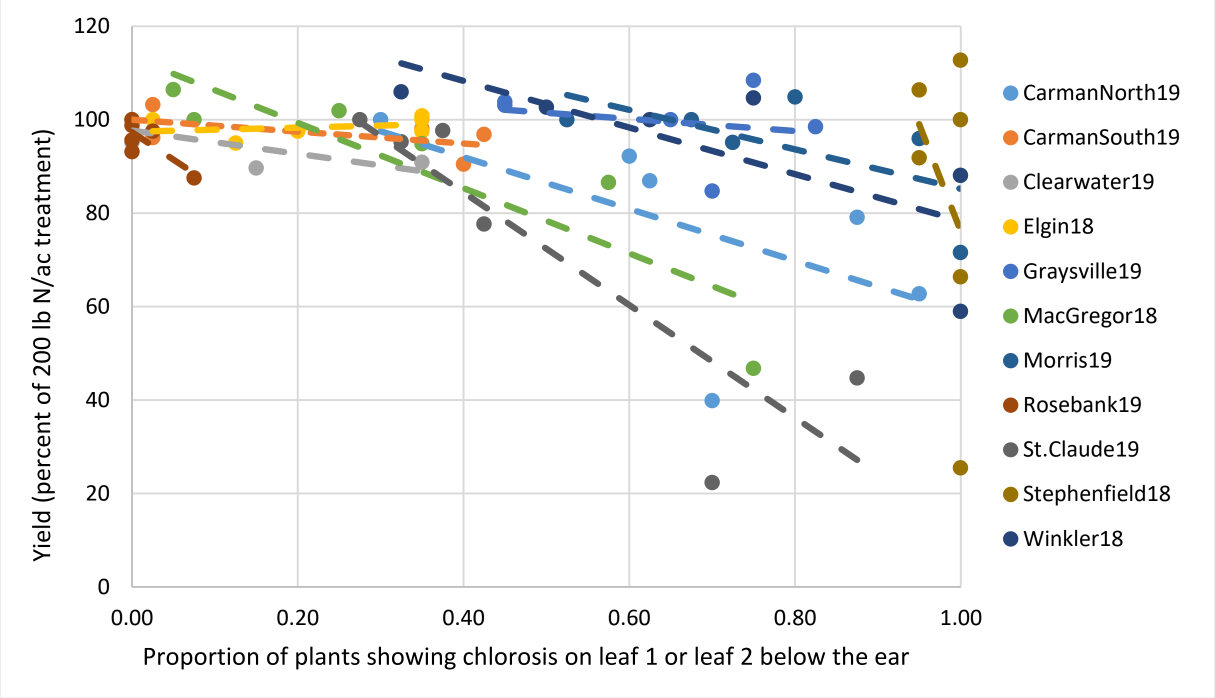

Figure 3.5 Linear models for the relationship between yield as a % of yield for the 200 lb N/ac treatment and proportion of the first and/or second leaves below the ear that displayed chlorosis or necrosis.

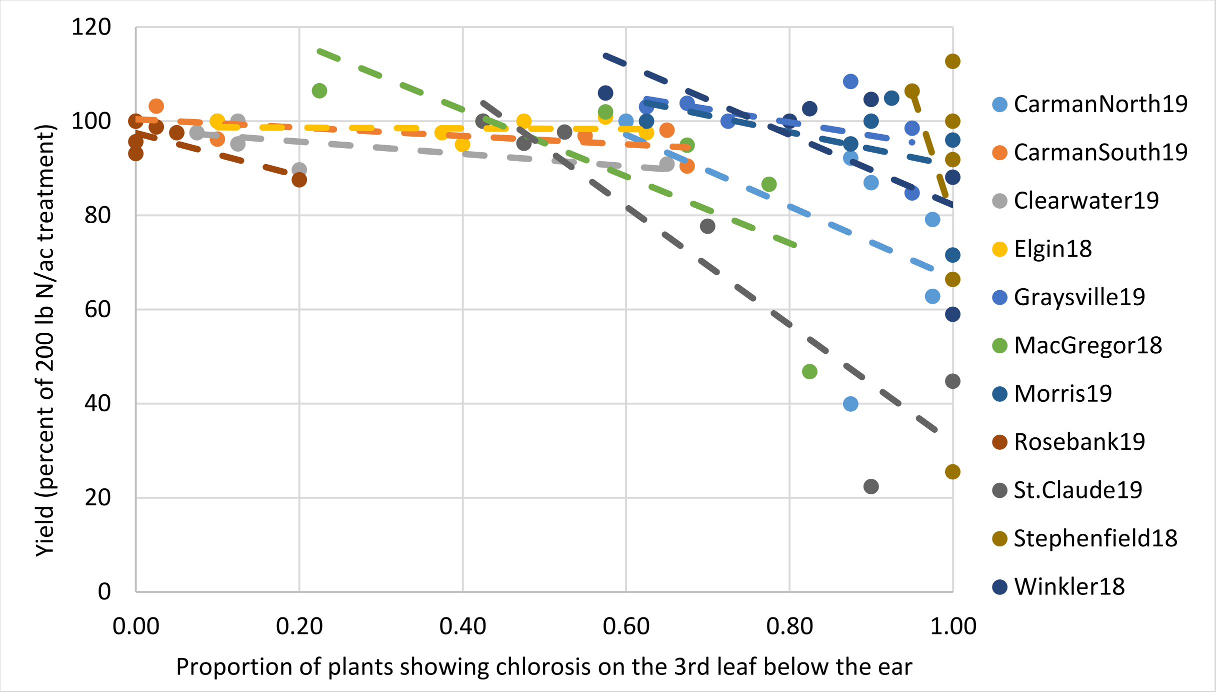

Figure 3.6 Linear models for the relationship between yield as a % of yield for the 200 lb N/ac treatment and proportion of the third leaves below the ear that displayed chlorosis or necrosis.

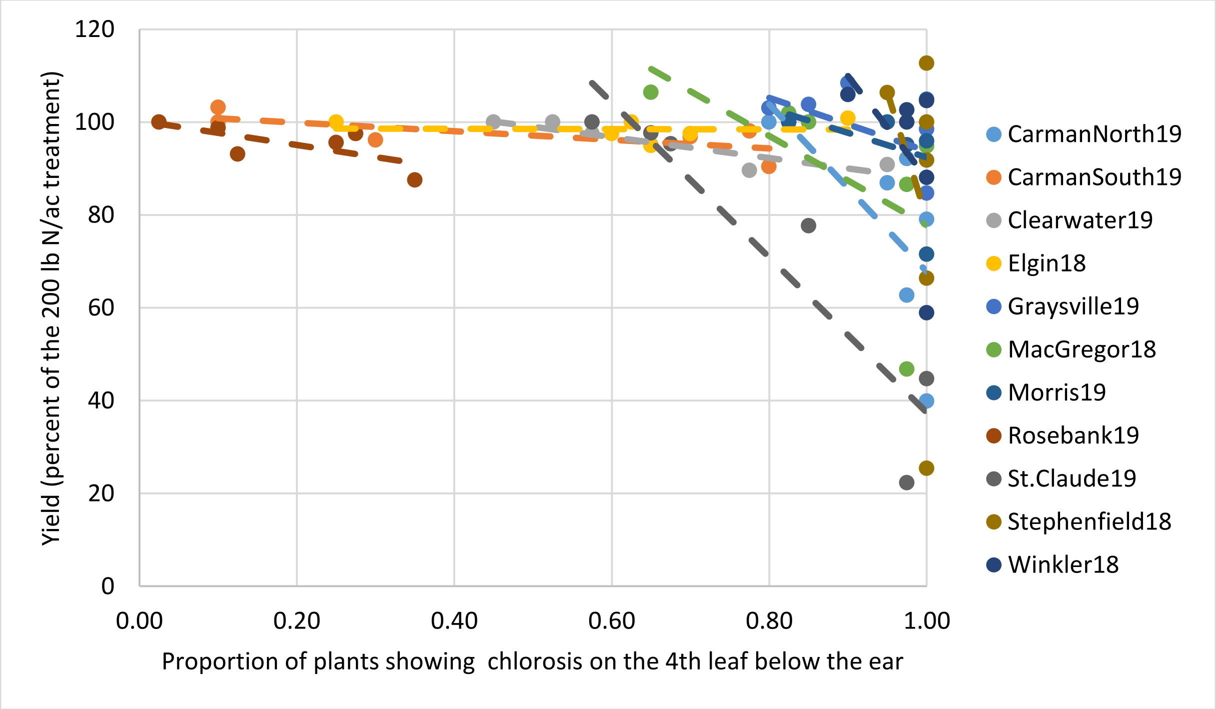

Figure 3.7 Linear models for the relationship between yield as a % of yield for the 200 lb N/ac treatment and proportion of the fourth leaves below the ear that displayed chlorosis or necrosis.

Table 3.12 Linear regression parameters for the relationship between yield as a percentage of yield for the 200 lb N/acre treatment and proportion of plants showing chlorosis on first and second leaves below the ear

CarmanNorth19	$y = -55.4x + 114$	$R^2 = 0.33$
CarmanSouth19	$y = -12.8x + 100$	$R^2 = 0.40$
Clearwater19	$y = -24.8x + 98$	$R^2 = 0.61$
Elgin18	$y = 4.44x + 97$	$R^2 = 0.08$
Graysville19	$y = -13.0x + 108$	$R^2 = 0.06$
MacGregor18	$y = -70.0x + 113$	$R^2 = 0.78$
Morris19	$y = -42.2x + 127$	$R^2 = 0.40$
Rosebank19	$y = -118.2x + 97$	$R^2 = 0.61$
StClaude19	$y = -121x + 133$	$R^2 = 0.79$
Stephenfield18	$y = -459x + 535$	$R^2 = 0.13$
Winkler18	$y = -50.0x + 128$	$R^2 = 0.57$
All Sites	$y = -22.7x + 101$	$R^2 = 0.17$

Table 3.13 Linear regression parameters for the relationship between yield as a percentage of yield for the 200 lb N/acre treatment and proportion of plants showing chlorosis on third leaf below the ear

CarmanNorth19	$y = -76.2x + 143$	$R^2 = 0.23$
CarmanSouth19	$y = -8.86x + 100$	$R^2 = 0.45$
Clearwater19	$y = -13.0x + 98$	$R^2 = 0.40$
Elgin18	$y = -0.72x + 99$	$R^2 = 0.00$
Graysville19	$y = -28.3x + 122$	$R^2 = 0.25$
MacGregor18	$y = -70.9x + 131$	$R^2 = 0.54$
Morris19	$y = -35.6x + 126$	$R^2 = 0.17$
Rosebank19	$y = -45.7x + 98$	$R^2 = 0.61$
StClaude19	$y = -126x + 157$	$R^2 = 0.85$
Stephenfield18	$y = -542x + 621$	$R^2 = 0.11$
Winkler18	$y = -74.6x + 157$	$R^2 = 0.43$
All Sites	$y = -20.2x + 103$	$R^2 = 0.14$

Table 3.14 Linear regression parameters for the relationship between yield as a percentage of yield for the 200 lb N/acre treatment and proportion of plants showing chlorosis on fourth leaf below the ear

CarmanNorth19	y = -180x + 248	$R^2 = 0.38$
CarmanSouth19	y = -9.17x + 102	$R^2 = 0.52$
Clearwater19	y = -22.5x + 110	$R^2 = 0.83$
Elgin18	y = -0.26x + 99	$R^2 = 0.00$
Graysville19	y = -57.4x + 151	$R^2 = 0.38$
MacGregor18	y = -96.1x + 174	$R^2 = 0.34$
Morris19	y = -52.8x + 145	$R^2 = 0.09$
Rosebank19	y = -26.1x + 100	$R^2 = 0.50$
StClaude19	y = -167x + 204	$R^2 = 0.86$
Stephenfield18	y = -542x + 621	$R^2 = 0.11$
Winkler18	y = -221x + 309	$R^2 = 0.22$
All Sites	y = -20.6x + 106	$R^2 = 0.10$

c) Pre-harvest stalk nitrate concentrations

Stalk nitrate sampling is another technique to evaluate whether the crop had sufficient supplies of available N late in the growing season (Blackmer and Mallarino, 2000). The mean stalk nitrate concentration increased at every site-year as N application rate increased. Using reference values from Iowa State University as guidelines, Elgin18, St.Claude19 and Stephenfield18 maintained marginal N status at fertilizer rates as high as 160 or 200 lb N/ac. At 13 of the 17 site-years, applying 120 lb N/ac resulted in optimal or excess N within the corn plants. At an application rate of 80 lb N/ac, optimal or excess N was found at only 6 of the site-years and at 40 lb N/ac, all but one site was ranked low or marginal. Using the Iowa State guidelines, the optimum fertilizer N application rate would appear to be between 80 and 120 lb N/ac, which is equivalent to a total N supply of approximately 150-200 lb N/ac, after accounting for pre-plant soil test NO_3-N.

However, the stalk nitrate concentrations at optimum rates of fertilizer N determined by numerical and statistical comparisons of means did not match well with the stalk nitrate guidelines used for corn production in Iowa (Table 3.15). According to the guidelines for Iowa, stalk nitrate concentrations were low to marginal for optimum rates of N at 10 of the 17 site-years, including 7 site-years where the optimum rate of fertilizer N was zero. Stalk nitrate concentrations were rated optimal at or near the economic optimum rate of fertilizer N for only 7 of the 17 site-years. For optimum rates of N determined by numerical maximum returns, corn grown at those rates would be regarded as having optimal stalk nitrate status at only 6 of the 17 site-years, according to the Iowa guidelines, but would be regarded as low to marginal at 8 site-years and as having excess N at 3 site-years. Therefore, the stalk nitrate test guidelines for Iowa do not seem to be a reliable indicator of N sufficiency for corn grown under Manitoba conditions.

Table 3.15 Corn stalk nitrate concentrations by site-year and N fertilizer rate

Site-year	0 lb N/ac	40 lb N/ac	80 lb N/ac	120 lb N/ac	160 lb N/ac	200 lb N/ac	site-year mean
	stalk NO_3 concentration (ppm)[a]						
CarmanNorth19	64	46	196	644*[b]	1267*[b]	1937**	692
CarmanSouth19	229*	313**	467	1818	2021	2222	1178
CarmanWest18	44	36	164	742*	1571**	1642	700
Clearwater19	203*	576	2698	3566**	4743	4819	2767
Elgin18	226*	336**	645	742	699	992	607
Elgin19	107	58	409**	1133*	2879	2933	1253
Graysville18	80	66**	801*[b]	2039*[b]	2522	3110	1436
Graysville19	123*	573	2819**	4677	5580	4408	3030
MacGregor18	83	167	553	1173*/**	1475	2108	926
Morris19	83*	236	1045**	4186	8222	9191	3827
Portage18	42	59	242	824*/**	3905	5783	1809
Rosebank18	656*	661	1809	2494**	3918	4181	2286
Rosebank19	870*	1913**	2678	3213	3938	4585	2866
St.Claude19	138	80	136	158*/**[b]	151*[b]	545	201
Stephenfield18	43	18	22	55*/**[b]	392*[b]	789	220
Wellwood18	98*	665	636**	3012	4941	6691	2674
Winkler18	45	41	42**	364*	1257	2140	648
All site-years	184	344	903	1814	2910	3416	

*Indicates stalk NO_3 concentration at the nearest economic optimum rate of fertilizer N application determined by statistical comparisons of means for the medium fertilizer:corn price ratio

**Indicates stalk NO_3 concentration at the numerical economic optimum rate of fertilizer N for the medium fertilizer:corn price ratio

[a] Interpretation guidelines for the stalk nitrate test to evaluate the crops N late season N status according to Iowa State University:

Stalk NO_3 concentration (ppm)	Nitrogen status interpretation
<250 ppm	Low
250-700 ppm	Marginal
700-2000 ppm	Optimal
>2000 ppm	Excess

[b] Optimum rate of N determined by statistical comparison of means was exactly midway between these two rates of N

d) Post-harvest soil test nitrate-N

On the Prairies, post-harvest fall nitrate-N tests are commonly used to determine N fertilizer requirements for the next crop. A post-harvest soil test can also be used as an evaluation of the nitrogen fertilization program for the crop that was recently harvested. In our study, post-harvest soil samples were collected from N fertilizer rate treatments at 8 of the 17 site-years, with an additional 5 site-years having only the check plots post-harvest soil sampled.

After harvesting the corn plots, there was an average of 31 lb/ac of residual soil test nitrate-N in the top 24 inches at the optimum N rate determined by statistical comparisons of means and 37 lb/ac at the numerically MRTN rate (Table 3.16). The maximum amount of post-harvest soil nitrate at an optimum N rate determined by statistical comparisons of means was at Graysville18 with 38-71 lb N/ac and the minimum was at StClaude19 with 15-17 lb N/ac. For the numerically optimum N rates, the maximum residual nitrate-N was 103 at Rosebank18 and the minimum was at 15 at StClaude19.

Table 3.16 Effect of pre-plant N rate on post-harvest mean residual soil nitrate-N

	Rate of fertilizer N applied (lb N/ac)					
Site-Year	0	40	80	120	160	200
	Residual soil NO_3-N after harvest lb/ac NO_3-N to 24 inches					
CarmanNorth19	13	13	16	18*[b]	21*[b]	26**
CarmanSouth19	26*	27**	24	38	36	54
CarmanWest18[a]	54			*	**	
Clearwater19[a]	33*			**		
Elgin19[a]	36		**	*		
Graysville18	31	29**	38*[b]	71*[b]	117	146
Graysville19	23*	41	36**	37	33	54
MacGregor18[a]	19			*/**		
Morris19[a]	43*		**			
Rosebank18	40*	38	53	103**	173	183
Rosebank19	32*	37**	38	42	44	37
StClaude19	17	14	17	15*/**[b]	17*[b]	20
Stephenfield18	11	11	19*	23*/**[b]	38*[b]	43
Mean	29	26	30	43	60	70

	Summary	
	MRTN by means comparison	Numerical MRTN
Observations	10	8
Mean	31 lb N/ac	37 lb N/ac

*Indicates the residual NO_3-N at the nearest economic optimum rate of fertilizer N application determined by statistical comparisons of means for the medium fertilizer:corn price ratio

**Indicates the residual NO_3-N at the numerical economic optimum rate of fertilizer N application for the medium fertilizer:corn price ratio

[a] Residual NO_3-N at these site-years was not measured across all N treatments due to frozen soil

[b] Optimum rate of N determined by statistical comparison of means was exactly midway between these two rates of N

Of the control (0 N) plots that were post-harvest soil sampled (i.e., at 13 of 17 site-years) the mean post-harvest residual NO_3-N was 29 lb N/ac, which is only slightly less than the mean post-harvest N found for the optimum rate of N determined by statistical comparisons of means (n=10) of 31 lb N/ac. This is partly because the optimum rate determined by statistical comparisons of means was the 0 N rate at 6 of the site-years that were sampled. The control treatments averaged 26 lb residual N/ac at the remaining 7 site-years where there were statistically significant N responses, indicating that this amount of residual nitrate-N is lower than optimum for corn. The smallest amount of residual N was 11 lb N/ac at Stephenfield18, an extremely N deficient site-year, so corn is unlikely to deplete soil nitrate-N below this amount.

Considering these values and the economic impacts of an insufficient N supply to a corn crop, a post-harvest NO_3-N test from 20-50 lb N/ac to 24" probably indicates that the previous corn crop was not excessively fertilized. Residual nitrate concentrations exceeding 50 lb N/ac probably indicate that there was excess nitrogen available for the crop.

Comparing the mean N supply at the optimum rate of N determined by statistical comparisons of means to the N supply for the numerically highest return for high yielding site-years (Table 3.10), the mean N supply increased from 148 lb N/ac to 185 lb N/ac. That increase of 37 lb/ac of N supply led to 14 more bu/ac of production and left an additional 6 lb of NO_3-N in the soil post-harvest.

4. Nitrogen source, time, and placement

4.1 Comparison of enhanced efficiency fertilizers applied pre-plant

At the four gold level site-years, additional treatments applied at planting included urea-based products with a physical coating (ESN™) or chemical inhibitors (eNtrench™-treated urea and SUPERU™). The five treatments were 1) pre-plant broadcast and incorporated ESN™:Urea in a 1:1 blend, 2) pre-plant broadcast and incorporated SUPERU™, 3) pre-plant broadcast and incorporated eNtrench™-treated urea, 4) post-plant broadcast SUPERU™, and 5) the standard management practice treatment of pre-plant urea broadcast and incorporated. Each of these treatments was applied at 80 and 120 lb N/ac.

Within a similar rate of N fertilization application, there were no significant differences in corn grain yield among different sources and placements (Table 4.1). This lack of difference between sources was not surprising, given the relatively dry soil conditions and, therefore, low risk of nitrate-N losses by leaching or denitrification across most site-years in 2018 and 2019. Also, the lowest rate of N used in these comparisons was close to the optimum N rate determined in the rate study, which meant that yield response differences between sources would be difficult to detect. Lastly, the C.V. for these data was large (27%) adding to the challenge of detecting differences between treatments.

Nevertheless, there might have been some subtle but inconsistent effects of the enhanced efficiency fertilizers. For example, when comparing across N rates, SUPERU™ broadcast post-plant was the only treatment applied at 80 lb N/ac that achieved a yield that was statistically similar to all of the treatments in which 120 lb N/ac were applied. Conversely, conventional urea applied at 120 lb N/ac was the only treatment at that rate that matched the statistically lowest yielding group of treatments in which 80 lb N/ac was applied.

Table 4.1 Effects of N fertilizer sources and placements applied at planting on corn grain yield at gold level site-years.

Global ANOVA	df	*Pr>F*
Trt	9	<.0001
Site-year	3	0.0002
Site-year*Trt	27	0.1216
C.V.		27

Site-year	pre-plant NO_3-N lb/ac	mean bu/ac[a]
Graysville18	80	136 A
Stephenfield18	37	120 A
CarmanNorth19	31	133 A
St.Claude19	25	77 B

Site-Year	80 lb N/ac Urea Bct&Inc	80 lb N/ac Urea&eNt Bct&Inc	80 lb N/ac Urea&ESN Bct&Inc	80 lb N/ac SPU Bct&Inc	80 lb N/ac SPU Bct	120 lb N/ac Urea Bct&Inc	120 lb N/ac Urea&eNt Bct&Inc	120 lb N/ac Urea&ESN Bct&Inc	120 lb N/ac SPU Bct&Inc	120 lb N/ac SPU Bct
	Yield bu/ac									
Graysville18	132	131	137	130	141	134	141	144	140	125
Stephenfield18	101	110	105	110	103	124	137	143	124	140
CarmanNorth19	121	112	122	131	141	133	139	138	143	149
St.Claude19	66	68	57	64	92	81	82	84	92	86
All site-years	105 C	105 C	105 C	109 BC	120 ABC	118 ABC	125 AB	127 A	125 AB	125 AB

[a] Means within a column or row followed by the same letter are not significantly different (*P*<0.05)

4.2 Comparison of nitrogen application timings

Split application of N fertilizer was evaluated by a using six treatments from each site, although across site-years there was some variability in crop staging, in-season rates of application, and placement. In spite of these small differences within treatments, the general strategies of applying the full rate of N at planting vs. splitting the applications between planting and in-season applications at V4 and V8 were evaluated with a global ANOVA (Table 4.2).

The site-year*treatment interaction shows that only 3 of the 17 site-years had statistically significant yield differences between applying the full rate of N at planting vs. split application, those being Carman North19, St. Claude19, and Stephenfield18. At Stephenfield18, the 120 lb N/ac applied as SUPERU™ at planting yielded significantly more than every other timing and rate combination, whereas at Carman North19 every treatment belonged to the top yielding group except the split application at the low rate and late stage (40 lb N/ac at planting + 40 lb N/ac at V8). At St. Claude19, any treatment applied early (at planting or at planting plus at V4 stage) was able to achieve yields that were equivalent to the highest yielding group, while treatments applied at the V8 stage belonged exclusively to the low yielding groups. There were no situations in these three site-years or the other 14 site-years where split application of N out-yielded full rate applications of N at planting. Once again, the dry soil conditions during the 2018 and 2019 growing seasons probably contributed to this lack of benefit for split applications, because the risk of losing N applied at planting was very low and perhaps also due to inadequate moisture as a limitation for yield.

However, these three site-years also illustrate that there is a risk of yield loss with split N applications if the corn crop is not supplied with sufficient N in the early part of the growing season. One of the reasons why large amounts of N fertilizer were required early in the growing season at these site-years was that all three site-years had less than 40 lb NO_3-N/ac to 2 feet at planting. These were the three site-years with the least pre-plant soil N in the study. These results indicate that there is a risk of yield loss for late application or even for split application overall when soil N reserves are initially low. Applying more than 40 lb N/ac at planting would be another way to mitigate the risks of early season N deficiency when planning for split application on soils with low levels of pre-plant N. Furthermore, in these trials the N at planting was surface broadcast; it may also be beneficial to improve the positional availability of early season N by banding near the seed row.

Table 4.2 Effect of N fertilizer application timing on grain corn yield

Site-Year	Site-Year *Pr>F*	df	80 lb N/ac @planting	40 lb N/ac @planting + 40 lb N/ac @V4	40 lb N/ac @planting + 40 or 53 lb N/ac @V8[a]	120 lb N/ac @planting	40 lb N/ac @planting + 80 lb N/ac @V4	40 lb N/ac @planting + 80 or 106 lb N/ac @V8[a]
			Yield bu/ac[b]					
CarmanWest18	0.3333	5	139	134	139	143	155	143
Elgin18	0.5684	3	120	n.a.[c]	112	117	n.a.[c]	125
Graysville18	0.5527	5	132	130	130	134	135	136
MacGregor18	0.1800	5	148	149	143	166	148	143
Portage18	0.8312	3	122	n.a.[d]	122	129	n.a.[d]	124
Rosebank18	0.1419	5	132	156	144	146	135	144
Stephenfield18	<0.0001	5	101 B	94 B	92 B	124 A	89 B	99 B
Wellwood18	0.0594	5	95	77	75	76	91	93
Winkler18	0.7200	5	158	146	145	155	151	151
CarmanNorth19	<0.0001	5	121 A	124 AB	100 B	133 A	145 A	127 A
CarmanSouth19	0.7031	5	152	154	149	151	165	157
Clearwater19	0.7602	5	160	157[e]	166	164	160[e]	152
Elgin19	0.5888	5	117	114	112	110	118	103
Graysville19	0.7485	5	142	141	133	135	132	141
Morris19	0.3353	5	129	118[e]	122	117	123[e]	108
Rosebank19	0.4237	5	153	168	171	156	169	157
St.Claude19	0.0002	5	66 A	77 ABC	62 BC	81 AB	90 A	58 C
All site-years			129	129	125	132	134	127

Global ANOVA	df	*Pr>F*
Trt	5	0.0002
Siteyr	16	<0.0001
Siteyr*Trt	76	0.0001
C.V.		23%

[a] In 2018 the N rate applied at V8 was 53 or 106 lb/ac while in 2019 the N rate applied at V8 was 40 or 80 lb/ac

[b] Means within the same row that are followed by the same letter are not statistically different at *P<0.05*

[c] In-season treatments at V4 were not applied at this site due to recent hail damage and poor plant stand; however, this site recovered later

[d] In-season treatments at V4 were not applied due to narrow row spacing that was not compatible with our applicator

[e] The V4 treatment was surface applied rather than injected

4.3 Comparison of enhanced efficiency fertilizers applied mid-season

Mid-season applications of N fertilizer included a comparison of UAN treatments applied with and without AGROTAIN™ urease inhibitor. The mid-season treatments were applied at V8 stage (mid to late July) and Y-drop simulated application of 53 or 106 lb N/ac in 2018 and 40 or 80 lb N/ac in 2019, in addition to 40 lb N/ac applied at planting. The global ANOVA analysis of the four treatments at all 17 site-years can be found below (Table 4.3).

The only significant effect in the global ANOVA was site-year, which reveals that the mean yield of some site-years was significantly different than others. The analysis shows that there was no advantage to adding a urease inhibitor such as Agrotain™ when mid-season N was surface applied. There was a high C.V. of 25% which could contribute to an inability for the statistical analysis to detect differences. However, the numerical values of the overall means for Agrotain™ and non-Agrotain™ treatments were very similar, showing that there was likely no treatment effect.

A more important factor that probably contributed to the lack of yield difference was the insignificant difference in yield response to N at these two rates. In the portion of the study focused on effect of N rates, the average numerical difference in yield between the 80 and 120 or 200 lb N/ac fertilizer rate treatments applied at planting was only 3 bu/ac, which was not statistically significant (Table 3.1). This shows that the response to N fertilizer application at rates at or above 80 lb/ac was generally minimal. Therefore, a response to the Agrotain™ treated UAN fertilizer compared to untreated urea would be unlikely because the untreated urea treatment probably provided sufficient N to achieve near maximum yield for these site-years.

Table 4.3 Effect of supplemental mid-season N application source and rate on grain corn yield at each site-year. All treatments also received 40 lb N/ac as SuperU broadcast at planting.

Site-year	Trt *Pr>f*	df	40 or 53 lb N/ac as UAN @V8[a]	40 or 53 lb N/ac as UAN with Agrotain™@ V8[a]	80 or 106 lb N/ac as UAN @V8[a]	80 or 106 lb N/ac as UAN with Agrotain™ @ V8[a]	Mean[b]	
			---------- Yield (bu/ac) ----------					
CarmanWest18	0.7887	3	139	147	143	147	144	ABC
Elgin18	0.0418	3	112	111	125	101	112	DEF
Graysville18	0.3937	3	130	126	136	139	133	BCD
Macgregor18	0.9787	3	143	146	144	146	145	ABC
Portage18	0.5014	3	122	115	124	127	122	CDE
Rosebank18	0.8706	3	144	144	144	149	145	ABC
Stephenfield18	0.8311	3	92	95	99	92	94	EF
Wellwood18	0.0263	3	75	84	93	99	88	FG
Winkler18	0.3605	3	145	151	151	161	152	AB
CarmanNorth19	0.0004	3	100	100	127	125	113	DEF
CarmanSouth19	0.6996	3	149	158	157	151	154	AB
Clearwater19	0.3086	3	166	166	152	159	161	AB
Elgin19	0.4401	3	112	115	103	105	108	DEF
Graysville19	0.6773	3	133	137	141	132	136	ABCD
Morris19	0.4131	3	122	114	108	118	115	CDEF
Rosebank19	0.1451	3	171	155	157	168	163	A
StClaude19	0.0489	3	62	51	58	74	61	G
All site-years			125	124	127	129		

Global ANOVA	df	*Pr>F*
Trt	3	0.0701
Siteyr	16	<.0001
Siteyr*Trt	48	0.0660
C.V.		25%

[a] In 2018 the rate of N applied at V8 was 53 or 106 lb/ac while in 2019 the rate of N applied at V8 was 40 or 80 lb/ac

[b] Means within the same column that are followed by the same letter are not statistically different at *P<0.05*

5. Mineralization

A simple and common method for recommending the rate of N fertilizer application in Manitoba is to subtract the soil's plant available nitrate-N reserve from the crop's estimated N requirement, i.e., the recommended rate of N fertilizer = crop N demand – pre-plant soil nitrate N. However, mineralization of soil organic N provides an additional source of N for crops and predicting the contribution of N mineralization would improve the accuracy for N fertilizer rate recommendations.

Currently there is no well-proven way to predict growing season N mineralization for Manitoba soils and environmental conditions. Therefore, one of the objectives for our study was to evaluate soil testing methods that might provide that information.

5.1 Estimated mineralization of soil organic N within site-years

This method provides an estimate of N mineralization only if N losses by leaching or denitrification are small, which was assumed to be the case during the relatively dry growing seasons for these site-years. In addition, none of our measurements accounted for the amount of fertilizer N immobilized in the fertilized plots. Therefore, the estimated amount of mineralized N cannot be simply added to the fertilizer N and pre-plant nitrate-N to account for the contribution of organic N transformations to the total N supply for fertilized treatments.

Estimated growing season N mineralization was the least at Stephenfield18 with only 12 lb/ac and the greatest at CarmanSouth19 with 95 lb/ac (Table 5.1). Stephenfield18 was also the site-year with smallest overall N uptake on check plots at 40 lb/ac, indicating that a low rate of mineralization was an important factor that contributed to the severe N deficiency in the check plots at this site-year, along with small amounts of pre-plant nitrate-N.

This variability in mineralization was also one of the reasons for differences in the optimum rate of N fertilization from one site-year to another. For example, the average rate of N mineralization was 63 lb N/ac in the high yielding site-years, compared to 30 lb N/ac in the low yielding group of site-years. Therefore, part of the reason for the smaller apparent N requirement per bushel at the higher yielding site-years was due to more mineralization of soil organic N during the growing season at the higher yielding site-years.

5.2 Evaluating soil test indicators for predicting mineralization

As shown in Table 5.1, N mineralization was extremely variable across site-years. Pre-plant and in-season soil tests were taken from each site to assess their ability for predicting soil N mineralization. Analytical results for seasonal changes in soil N and plant uptake of N for each replicate of the 0 N check treatment at each site-year were averaged to represent N mineralization at each site-year. The ability of the soil tests to predict N mineralization was then evaluated using simple linear regression. The independent variables tested were soil organic matter (SOM), pre-plant NO_3-N for three depths, gross and net Les Henry incubation NO_3-N, gross and net pre-sidedress NO_3-N soil test (PSNT) for the 0-30 cm soil depth, $NaHCO_3$ extract absorbance at 205 nm, and $NaHCO_3$ extract absorbance at 260 nm.

Table 5.1 Soil test nitrate-N, crop N uptake and estimated N mineralization from the 0 N treatment at each site.

Site-Year	Baseline N[a]	Plant N uptake	Post-harvest NO_3-N to 24" as BD	Estimated N mineralization
	lb/ac			
CarmanNorth19	31	65	13	47
CarmanSouth19	55	125	25	95
CarmanWest18[b]	68	105	53	89
Clearwater19[b]	130	143	30	43
Elgin18[bc]	145	132		
Elgin19[b]	55	83	30	59
Graysville18	75	104	29	58
Graysville19	51	96	22	67
Macgregor18[b]	53	85	19	51
Morris19	97	82	32	17
Portage18[bc]	74	87		
Rosebank18[b]	109	148	52	92
Rosebank19[b]	145	137	30	22
StClaude19	25	40	17	32
Stephenfield18	38	40	10	12
Wellwood18[bc]	54	56		
Winkler18[bc]	59	96		
Maximum	145	148	53	95
Median	55	96	29	51
Mean	74	96	28	53
Minimum	25	40	10	12

[a] Baseline N includes pre-plant NO_3-N to 24" by BD plus starter N applied at planting

[b] Additional starter N applied at planting as a baseline application to all plots, was also accounted for in the calculation for mineralization

[c] Post-harvest soil samples were not collected from these sites due to frozen soils; therefore, estimated mineralization could not be calculated

None of the soil test indicators were significantly related to estimated mineralization when measured across the site-years (Appendix Table 6.19). The strongest relationship was the net Les Henry mineralization test, with an R^2 of 0.11 (Figure 5.1), but that relationship was not statistically significant (*p*-value of 0.27). The Les Henry mineralization test is designed to simulate ideal mineralization conditions for the soil, and should therefore be a measure of the soils mineralization potential. The next strongest relationship was for gross PSNT (Figure 5.1). The PSNT soil samples were the only samples taken during the growing season (V4 growth stage), whereas all of the other measurements were obtained from pre-plant soil tests. The PSNT samples were also from plots that received 40 lb/ac of SUPERU™ post-plant broadcast, whereas samples from the 0 N plots were used for all other soil test indicators.

Of the three common depths for pre-plant nitrate-N (0-6, 0-24, and 0-48 inch), none were significantly related to observed mineralization. The 0-24" depth is most commonly taken by agronomists and producers; however, these samples would not be useful for predicting N mineralization with an R^2 of 0.01 (Figure 5.1). Pre-plant nitrate tests may have potential for detecting soils with large mineralization potential because increased concentrations of nitrate within the soil at planting could indicate that mineralization has occurred in the short term (e.g., between harvesting the previous crop and sampling the soil) or long term (e.g., in fields where N mineralization has exceeded expectations and resulted in consistently high concentrations of residual soil nitrate-N).

Soil organic matter and $NaHCO_3$ absorbance measure different pools of organic matter within the soil; once again these measurements were not related to observed mineralization across site-years (R^2 of 0.00005 and 0.0266, respectively). Therefore, even though soil organic matter is an important source of N for mineralization, these simple measurements of soil organic matter did not predict the amount of N that mineralized during the growing season under field conditions.

It is important to consider that Manitoba experienced relatively dry growing seasons in 2018 and 2019, reducing microbial activity, reducing N mineralization. Therefore, these estimates of N mineralization might be smaller than normal. The poor relationships between soil tests for potential N mineralization and measured estimates of mineralization could be attributed to fundamental inadequacies of the tests to measure potential mineralization and/or that the degree to which potential mineralization was realized under field conditions that varied greatly with environmental conditions across the site-years. Inclusion of environmental data such as soil moisture and temperature might improve the ability to track mineralization and growing season crop N demand; however, the inability to forecast these conditions will probably limit the value of any pre-plant or early season soil test for estimating mineralization of soil organic N.

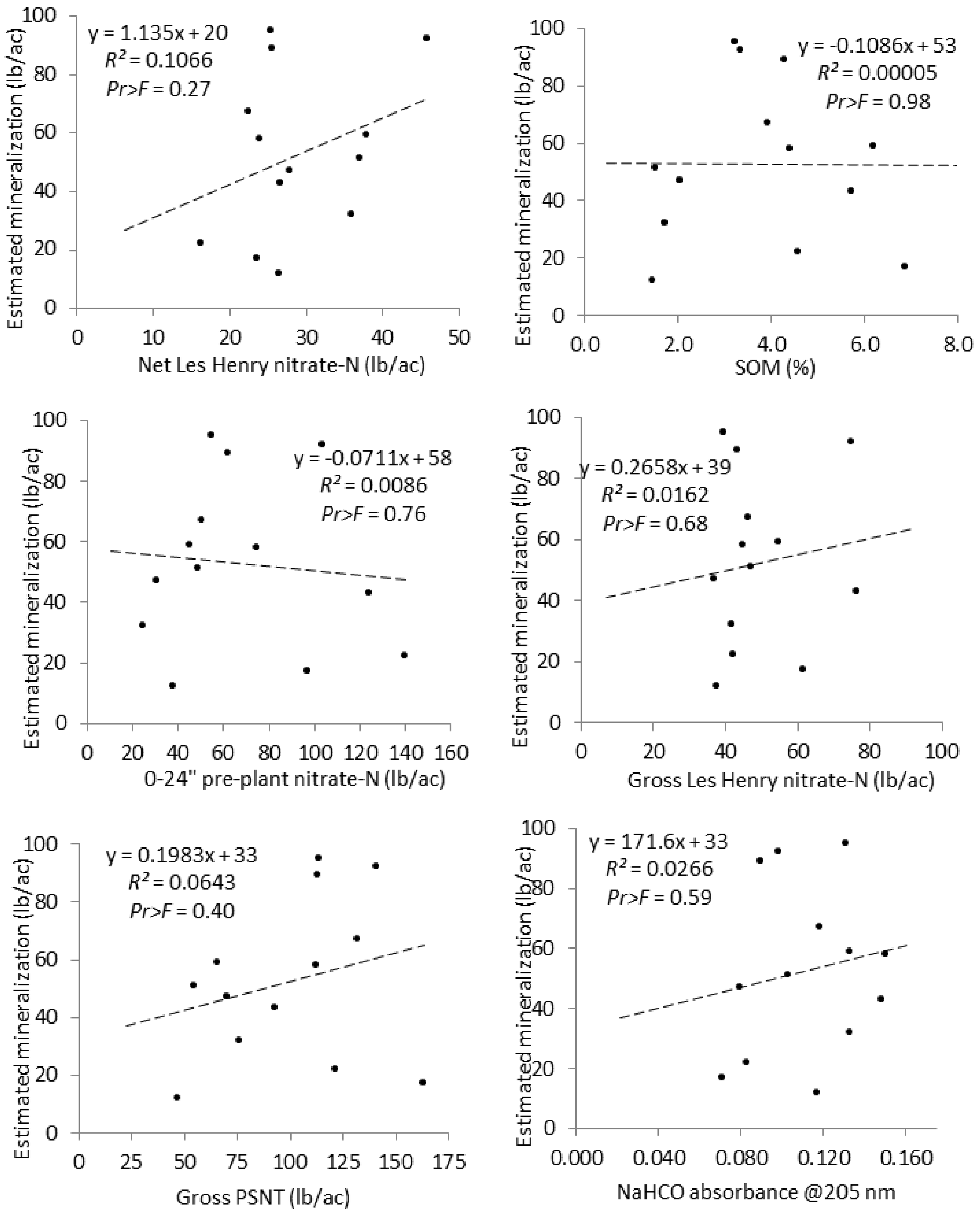

Figure 5.1 Relationship between estimated growing season N mineralization to 2 feet and the site-year averages of potential soil tests for predicting mineralization.

6. Appendices

Table 6.1 CarmanNorth19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]		Low ratio[a]		Medium ratio[a]		High ratio[a]	
——lb/ac——		——bu/ac——		——return $/ac——					
0	31[b]	61	C	$277	C	$277	C	$277	B
40	71	96	BC	$420	BC	$416	BC	$412	AB
80	111	121	AB	$515	AB	$507	AB	$499	A
120	151	133	A	$555	AB	$543	AB	$531	A
160	191	141	A	$578	AB	$562	AB	$546	A
200	231	**153**[c]	A	**$619**[c]	A	**$599**[c]	A	**$579**[c]	A
Pr>F		**<.0001**		**<.0001**		**<.0001**		**0.0002**	
df		5		5		5		5	
C.V.		29		27		27		25	

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.2 CarmanSouth19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield	Low ratio	Medium ratio	High ratio
——lb/ac——		——bu/ac——	——return $/ac——		
0	57[a]	142	$637	$637	$637
40	97	154	**$679**[b]	**$675**[b]	**$671**[b]
80	137	152	$657	$649	$641
120	177	151	$638	$626	$614
160	217	**162**[b]	$675	$659	$643
200	257	157	$636	$616	$596
Pr>F		0.2787	0.7310	0.6562	0.2995
df		5	5	5	5
C.V.		9	9	9	10

[a] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[b] Indicates numerically highest yield or economic return to N

Table 6.3 CarmanWest18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]	Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac	return $/ac		
0	70[b]	104 B	$470 B	$470 B	$470 B
40	110	129 A	$565 AB	$561 AB	$557 AB
80	150	139 A	$597 A	$589 A	**$581**[c] A
120	190	143 A	$602 A	$590 A	$578 AB
160	230	**149**[c] A	**$613**[c] A	**$597**[c] A	$581 AB
200	270	149 A	$598 A	$578 A	$558 AB
Pr>F		**<.0001**	**0.0024**	**0.0063**	**0.0332**
df		5	5	5	5
C.V.		13	11	11	10

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*
[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N
[c] Indicates numerically highest yield or economic return to N

Table 6.4 Clearwater19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield	Low ratio	Medium ratio	High ratio
lb/ac		bu/ac	return $/ac		
0	145[a]	149	$669	$669	$669
40	185	147	$649	$645	$641
80	225	160	$691	$683	**$675**[b]
120	265	**164**[b]	**$696**[b]	**$684**[b]	$672
160	305	156	$646	$630	$614
200	345	164	$669	$649	$629
Pr>F		0.0950	0.4810	0.4174	0.1381
df		5	5	5	5
C.V.		7	7	7	8

[a] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N
[b] Indicates numerically highest yield or economic return to N

Table 6.5 Elgin18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield	Low ratio	Medium ratio	High ratio
lb/ac		bu/ac	return $/ac		
0	165[a]	114	$512	$512	$512
40	205	**121**[b]	**$530**[b]	**$526**[b]	**$522**[b]
80	245	120	$513	$505	$497
120	285	117	$486	$474	$462
160	325	117	$469	$453	$437
200	365	120	$472	$452	$432
Pr>F		0.9677	0.6664	0.4263	0.1094
df		5	5	5	5
C.V.		13	14	15	17

[a] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[b] Indicates numerically highest yield or economic return to N

Table 6.6 Elgin19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]	Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac	return $/ac		
0	63[b]	76 B	$340 B	$340 B	$340
40	103	96 AB	$420 AB	$416 AB	$412
80	143	**117**[c] A	**$499**[c] A	**$491**[c] A	**$483**[c]
120	183	110 A	$455 AB	$443 AB	$431
160	223	117 A	$469 A	$453 AB	$437
200	263	114 A	$441 AB	$421 AB	$401
Pr>F		**0.0009**	**0.0148**	**0.0270**	0.0601
df		5	5	5	5
C.V.		18	16	16	16

[a] Means within a column followed by the same letter are not significantly different $(P<0.05)$

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.7 Graysville18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]		Low ratio[a]		Medium ratio[a]		High ratio[a]	
lb/ac		bu/ac		return $/ac					
0	80[b]	107	B	$482	A	$482	AB	$482	AB
40	120	128	AB	$561	A	**$557**[c]	A	**$553**[c]	A
80	160	132	A	**$564**[c]	A	$556	AB	$548	A
120	200	**134**[c]	A	$562	A	$550	AB	$538	A
160	240	117	AB	$472	A	$456	B	$440	B
200	280	132	A	$525	A	$505	AB	$485	AB
Pr>F		**0.0074**		**0.0214**		**0.0180**		**0.0070**	
df		5		5		5		5	
C.V.		17		18		18		19	

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.8 Graysville19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield	Low ratio	Medium ratio	High ratio
lb/ac		bu/ac	return $/ac		
0	54[a]	111	$499	$499	$499
40	94	129	$565	$561	$557
80	134	142	**$611**[b]	**$603**[b]	**$595**[b]
120	174	135	$564	$552	$540
160	214	**136**[b]	$554	$538	$522
200	254	131	$519	$499	$479
Pr>F		0.0566	0.1561	0.1487	0.0857
df		5	5	5	5
C.V.		12	12	12	13

[a] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[b] Indicates numerically highest yield or economic return to N

Table 6.9 MacGregor18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]	Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac	return $/ac		
0	52[b]	73 B	$326 B	$326 B	$326 B
40	92	135 A	$591 A	$587 A	$583 A
80	132	148 A	$637 A	$629 A	$621 A
120	172	**166**[c] A	**$703**[c] A	**$691**[c] A	**$679**[c] A
160	212	159 A	$658 A	$642 A	$626 A
200	252	156 A	$633 A	$613 A	$593 A
Pr>F		**<0.0001**	**0.0001**	**0.0002**	**0.0004**
df		5	5	5	5
C.V.		26	25	25	25

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.10 Morris19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]	Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac	return $/ac		
0	129[b]	88 B	$395	$395	$395
40	169	118 AB	$518	$514	$510
80	209	**129**[c] A	**$553**[c]	**$545**[c]	**$537**[c]
120	249	117 AB	$483	$471	$459
160	289	123 A	$498	$482	$466
200	329	123 AB	$482	$462	$442
Pr>F		**0.0226**	0.0882	0.1063	0.1130
df		5	5	5	5
C.V.		17	17	17	18

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.11 Portage18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]		Low ratio[a]		Medium ratio[a]		High ratio[a]	
lb/ac		bu/ac		return $/ac					
0	97[b]	91	B	$408	B	$408	B	$408	B
40	137	111	AB	$487	AB	$483	AB	$479	AB
80	177	122	A	$521	A	$513	A	$505	AB
120	217	129	A	**$541**[c]	A	**$529**[c]	A	**$517**[c]	A
160	257	113	A	$451	AB	$435	AB	$419	B
200	297	**130**[c]	A	$515	A	$495	AB	$475	AB
Pr>F		**0.0002**		**0.0040**		**0.0070**		**0.0124**	
df		5		5		5		5	
C.V.		15		14		14		14	

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.12 Rosebank18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]		Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac		return $/ac		
0	114[b]	112	B	$505	$505	$505
40	154	135	AB	$594	$590	$586
80	194	132	AB	$568	$560	$552
120	234	**146**[c]	A	**$614**[c]	**$602**[c]	**$590**[c]
160	274	132	AB	$540	$524	$508
200	314	136	AB	$541	$521	$501
Pr>F		**0.0255**		0.0969	0.0977	0.0590
df		5		5	5	5
C.V.		13		13	13	14

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.13 Rosebank19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield	Low ratio	Medium ratio	High ratio
lb/ac		bu/ac	return $/ac		
0	155[a]	140	$628	$628	$628
40	195	**158**[b]	**$698**[b]	**$694**[b]	**$690**[b]
80	235	153	$691	$683	$675
120	275	156	$661	$649	$637
160	315	149	$612	$596	$580
200	355	153	$620	$600	$580
Pr>F		0.4588	0.3712	0.2720	0.1063
df		5	5	5	5
C.V.		13	13	14	15

[a] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[b] Indicates numerically highest yield or economic return to N

Table 6.14 St.Claude19 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]		Low ratio[a]		Medium ratio[a]		High ratio[a]	
lb/ac		bu/ac		return $/ac					
0	25[b]	19	B	$85	B	$85	C	$85	C
40	65	38	B	$158	B	$154	BC	$150	BC
80	105	66	A	$269	A	$261	AB	$253	AB
120	145	81	A	**$322**[c]	A	**$310**[c]	A	**$298**[c]	A
160	185	83	A	$317	A	$301	A	$285	A
200	225	**85**[c]	A	$311	A	$291	A	$271	AB
Pr>F		**<.0001**		**<.0001**		**<.0001**		**<.0001**	
df		5		5		5		5	
C.V.		53		54		55		56	

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.15 Stephenfield18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]	Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac	return $/ac		
0	37[b]	28 C	$124 C	$124 C	$124 C
40	77	73 B	$315 B	$311 B	$307 B
80	117	101 A	$429 AB	$421 AB	$413 AB
120	157	**124**[c] A	**$518**[c] A	**$506**[c] A	**$494**[c] A
160	197	117 A	$469 A	$453 A	$437 AB
200	237	110 A	$424 AB	$404 AB	$384 AB
Pr>F		**<.0001**	**<.0001**	**<.0001**	**<.0001**
df		5	5	5	5
C.V.		41	40	40	40

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.16 Wellwood18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]	Low ratio[a]	Medium ratio[a]	High ratio[a]
lb/ac		bu/ac	return $/ac		
0	64[b]	49 B	$220 B	$220	$220
40	104	79 AB	$343 AB	$339	$335
80	144	**95**[c] A	**$401**[c] A	**$393**[c]	**$385**[c]
120	184	76 AB	$298 AB	$286	$274
160	224	79 AB	$298 AB	$282	$266
200	264	88 A	$325 AB	$305	$285
Pr>F		**0.0133**	**0.0446**	0.0522	0.0539
df		5	5	5	5
C.V.		26	27	28	29

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.17 Winkler18 Effect of N supply on corn grain yield and economic return to N fertilizer for low, medium and high fertilizer N:corn price ratios

N fertilizer rate	Total N supply	Yield[a]		Low ratio[a]		Medium ratio[a]		High ratio[a]	
lb/ac		bu/ac		return $/ac					
0	61[b]	89	C	$401	C	$401	C	$401	C
40	101	133	B	$586	B	$582	B	$578	B
80	141	158	A	**$681**[c]	A	**$673**[c]	A	**$665**[c]	A
120	181	155	A	$657	AB	$645	AB	$633	AB
160	221	**160**[c]	A	$664	AB	$648	AB	$632	AB
200	261	151	AB	$609	AB	$589	B	$569	B
Pr>F		**<.0001**		**<.0001**		**<.0001**		**<.0001**	
df		5		5		5		5	
C.V.		19		17		17		16	

[a] Means within a column followed by the same letter are not significantly different *(P<0.05)*

[b] Initial rate of N supply in this column includes pre-plant soil nitrate-N plus starter fertilizer N

[c] Indicates numerically highest yield or economic return to N

Table 6.18 Quadratic response equations, maximum yield, and MRTN rates for each individual site-year and for grouped yield responses

Site-year	Second order polynomial response equation	R^2 value	Maximum yield (vertex)	N supply at maximum yield	Yield at MRTN medium ratio	N supply at MRTN medium ratio	N supply at MRTN low ratio	N supply at MRTN high ratio
			bu/ac	lb/ac	bu/ac		lb/ac	
CarmanNorth19	$y = -0.001985x^2 + 0.9524x + 36.01$	$R^2 = 0.9897$	150	240	149	215	220	209
CarmanSouth19	$y = -0.000422x^2 + 0.2041x + 133.39$	$R^2 = 0.6756$	158	242	152	123	150	97
CarmanWest18	$y = -0.001575x^2 + 0.7368x + 63.21$	$R^2 = 0.9787$	149	234	148	202	209	195
Clearwater19	$y = -0.000368x^2 + 0.2558x + 117.85$	$R^2 = 0.6408$	162	347	155	211	241	181
Elgin18	$y = -0.000165x^2 + 0.0997x + 104.10$	$R^2 = 0.1667$	119	302	104	-1	66	-68
Elgin19	$y = -0.001972x^2 + 0.8174x + 33.35$	$R^2 = 0.9246$	118	207	117	182	187	176
Graysville18	$y = -0.001243x^2 + 0.5163x + 78.21$	$R^2 = 0.4995$	132	208	130	167	176	158
Graysville19	$y = -0.001807x^2 + 0.6356x + 83.85$	$R^2 = 0.8788$	140	176	138	148	154	142
MacGregor18	$y = -0.004507x^2 + 1.7395x - 0.26$	$R^2 = 0.9537$	168	193	167	182	184	179
Morris19	$y = -0.001921x^2 + 1.0082x - 4.93$	$R^2 = 0.7468$	127	262	126	236	242	231
Portage18	$y = -0.001409x^2 + 0.7015x + 39.23$	$R^2 = 0.7417$	127	249	125	213	221	206
Rosebank18	$y = -0.001561x^2 + 0.7581x + 48.78$	$R^2 = 0.7438$	141	243	139	211	218	204
Rosebank19	$y = -0.001186x^2 + 0.6303x + 74.58$	$R^2 = 0.5408$	158	266	156	223	233	214
St.Claude19	$y = -0.002141x^2 + 0.8765x - 4.22$	$R^2 = 0.9859$	85	205	84	181	187	176
Stephenfield18	$y = -0.004532x^2 + 1.6500x - 27.85$	$R^2 = 0.9925$	122	182	122	171	173	169
Wellwood18	$y = -0.001772x^2 + 0.7060x + 17.70$	$R^2 = 0.5784$	88	199	87	171	177	165
Winkler18	$y = -0.003850x^2 + 1.5236x + 13.20$	$R^2 = 0.9626$	164	198	163	185	188	182
Grouped sites with yield potential < 130 bu/ac	$y = -0.001313x^2 + 0.7340x + 14.85$	$R^2 = 0.6808$	117	279	115	241	250	233
Grouped sites with yield potential >130 bu/ac	$y = -0.001210x^2 + 0.6163x + 71.41$	$R^2 = 0.4850$	150	255	148	213	222	204

Table 6.19 Linear regression relationships between potential indicators of N mineralization and estimated mineralization

Site-year	Estimated mineralization	SOM (%)	Pre-plant NO_3-N (lb/ac by BD)			Les Henry Incubation NO_3-N (lb/ac by BD)		PSNT NO_3-N (lb/ac by BD)		$NaHCO_3$ extract absorbance	
						gross NO_3-N	net NO_3-N	gross NO_3-N	net NO_3-N	@260 nm	@205 nm
	lb/ac to 24in.	to 6in.	to 6in.	to 24 in.	to 48in.						
CarmanNorth19	47	2.1	9	31	71	37	28	70	52	0.116	0.080
CarmanSouth19	95	3.2	14	55	85	39	25	114	86	0.207	0.131
CarmanWest18	89	4.3	18	62	85	44	26	114	72	0.132	0.090
Clearwater19	43	5.8	50	124	177	77	27	93	12	0.240	0.148
Elgin19	59	6.2	17	45	62	55	38	66	36	0.210	0.133
Graysville18	58	4.4	21	75	104	45	24	113	73	0.224	0.151
Graysville19	67	4.0	24	51	103	47	23	132	93	0.210	0.118
Macgregor18	51	1.5	10	49	134	47	37	55	32	0.160	0.103
Morris19	17	6.9	38	97	126	62	24	163	101	0.122	0.071
Rosebank18	92	3.4	29	104	174	75	46	141	45	0.143	0.099
Rosebank19	22	4.6	26	140	265	42	16	122	68	0.132	0.083
St.Claude19	32	1.7	6	25	70	42	36	76	64	0.195	0.133
Stephenfield18	12	1.5	11	38	72	38	27	47	26	0.166	0.117
mean	53	3.8	21	69	118	50	29	100	58	0.173	0.112
Y-intercept[a]		53	56	58	62	39	20	33	43	33	33
slope[a]		-0.1086	-0.1638	-0.0711	-0.0806	0.2658	1.135	0.1983	0.1685	112.6	171.6
Pr>F		0.98	0.81	0.76	0.58	0.68	0.27	0.40	0.59	0.57	0.59
R^2		0.00005	0.0054	0.0086	0.0284	0.0162	0.1066	0.0643	0.0272	0.0294	0.0266

[a] Simple linear regression with estimated mineralization to 60 cm as the response (Y) variable

7. References

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