Project title: Long-term effect of nitrogen rates on corn – Year 5 (2013) Interim Report

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Executive Summary

This report summarizes results from year 5 of a 10 year field trial designed to evaluate the long-term effect of timing and rate of fertilizer N on grain corn yield and associated economics. The trial also evaluates the long-term impact of duration (over years) of various fertilizer N rates on corn yield potential, natural N supply and soil organic matter levels. The 2013 growing season represented the fifth year that the various N rate treatments were imposed at this trial. Economic estimates presented in this summary are based on a Nitrogen:Corn price ratio of 8.1 with a corn price of $177/tonne ($4.50/bu) and fertilizer N cost of $1.43/kg-N ($0.65/lb-N).

Fertilizer N rate history (uniform 145 kg-N/ha applied the previous year or the same fertilizer N rates (30, 58, 87, 145 and 218 kg-N/ha) applied yearly starting in 2009) had minimal effects on corn development, growth, yield and N uptake in 2013. This may suggest that short-term history (4 years) of less than adequate fertilizer N application does not substantially affect current year's corn fertilizer N requirements in Ontario.

Maximum economic rate of nitrogen (MERN) in 2013 was not affected by timing of application (planting or sidedress), averaging 240 kg-N/ha with a grain yield of 13.4 Mg/ha. In 2010, applying N sidedress reduced MERN by 19% (Planting MERN was 221 kg-N/ha and sidedress MERN was 180 kg-N/ha). Similarly in 2011, applying N sidedress reduced MERN by 12% (Planting MERN was 200 kg-N/ha and sidedress MERN was 177 kg-N/ha). In 2009 and 2012 application timing had small effects on MERN, with average MERN across application timings that were 150 kg-N/ha in 2009 and 134 kg-N/ha in 2012. For each of the 5 years of this study, timing of N application did not substantially affect maximum economic yield which was always at least 98% of the non-N limited yields.

Timing of N application did not affect the rate of grain yield increase per unit of N applied between the starter and maximum economic rates of N in 2013, with an average rate that was 34 kg-grain/kg-N. The 2013 rates were the highest observed over the 5 years of this trial (23 kg-grain/kg-N in 2009, 31 kg-grain/kg-N in 2010, 29 kg-grain/kg-N in 2011 and 16 kg-grain/kg-N in 2012).

Applying 115 kg-N/ha over the starter rate increased total above-ground corn N uptake by 83 kg-N/ha in 2013 with an apparent fertilizer N recovery of 72%. Fertilizer N recoveries to applying 115 kg-N/ha were 53% in 2009, 59% in 2010,61% in 2011 and 41% in 2012. Similarly, applying 188 kg-N/ha over the starter rate increased total above-ground N uptake by 119 kg-N/ha in 2013 with an apparent fertilizer N recovery of 64%. Fertilizer N recoveries associated with applying 188 kg-N/ha were 49% in 2009, 50% in 2010, 56% in 2011 and 27% in 2012.

General N recommendations under estimated fertilizer N requirements in 2013 by 105 kg-N/ha when applied at planting and 125 kg-N/ha when applied sidedress. Ontario's general N recommendations at this site were based on a 10 Mg/ha yield goal for a silt-loam soil in a 2650 CHU area following grain corn. Similarly, the soil N test underestimated corn N requirements in 2013 by 91 kg-N/ha when applied at planting and 104 kg-N/ha applied sidedress. rainfall from April 1 to August 31 at this site in 2013 was 31% higher than the 5 year average and yield was 32% higher than average. The higher than average 2013 yields increased corn N demand for N which accounted for most of the unusually high requirement for fertilizer N observed in 2013.

Over the 5 years of this study corn N requirements, yield potential and total rainfall from April 1 to August 31 were closely related. Seasonal rainfall totals had a greater impact at this trial on N demand needed to meet yearly yield potential than on natural N supply which did not vary much over the 5 years. When more years of data are available from this site, attempts to correlate fertilizer N requirements to weather events will be made to determine if recommendation models can be improved based on known, and perhaps, anticipated weather events or trends.

Introduction and Description of Production Practices

A long-term trial was initiated at the Elora Research Station (Elora ON CA) in 2008 to evaluate the effect that duration (over years), timing of application (close to date of planting or sidedress about 5-7 weeks after planting) and rate of nitrogen fertilizer has on long-term corn yields and associated economics. The actual N fertilizer treatments were first imposed in 2009, so 2013 results represent the fifth year of corn response to the various N fertilizer treatments. The fertilizer N treatments were duplicated so that the same application rate and timing combination is applied on some plots continuously for the entire duration of the trial and on other plots the fertilizer N rate treatments are applied on plots which received a uniform 145 kg-N/ha rate the previous year. Comparison of the continuous fertilizer N treatments to those imposed on plots with uniform 145 kg-N/ha application the previous year will enable the evaluation of long-term effects of various fertilizer N application rates and timings on organic matter levels, natural N supply and corn yield response. Continuous fertilizer N treatments (including the continuous starter N only treatments) recieved the same fertilizer N rate for the fifth consecutive year in 2013.

2013 production practices:
Previous Crop: Grain Corn
Tillage: Fall Moldboard plow with spring secondary tillage (switched from Fall Chisel plow used in 2009 and 2010 production years)
Corn: Pioneer 38B14 was planted on May 8, 2013 in 0.76 m rows at 79,000 seeds/ha
Fertility: Fall broadcast phosphorous (0-46-0) was applied on October 18, 2012 at 50 kg-P2O5/ha and was incorporated using a moldboard plow.
Fall broadcast potassium (0-0-60) was applied on October 19, 2012 at 200 kg- K2O/ha and was incorporated using a moldboard plow.
Spring broadcast potassium sulphate (0-0-50) was applied on May 6, 2013 at 125 kg-K_2O/ha and incorporated just prior to planting using a field cultivator.
Starter 200 kg/ha of 15-15-15-2Zn starter was banded through the planter 5 cm beside, 5 cm below seeding depth (Nutrient rates of 30 kg/ha of N, P2O5 and K2O plus 4 kg-Zn/ha).
Early application timing (planting) of fertilizer N was injected mid-row as UAN on May 9, 2013 at treatment related rates of 0, 28, 57, 115, 188, and 230 kg-N/ha.
The late application timing (sidedress) was June 26, 2013 with N application methods and treatments that were the same as described for the early date.
Following corn harvest (October 2013), phosphorous and potassium were broadcast applied and incorporated with a moldboard plow at rates of 50 kg- P2O5/ha as 0-46-0 and 200 kg-K_2O/ha as 0-0-60.

Site Fertility

Soil pH, phosphorous, potassium, and magnesium levels in the surface 15 cm for years 2008-2013 are presented in Table 1. Soil test phosphorous and potassium levels in fall 2013 were rated as “moderately responsive” and efforts will continue in 2014 to increase phosphorous and potassium fertility at this site.

Soil ammonium and nitrate concentrations in the surface 30cm for the planting (May 9) and sidedress (June 24) sample dates were not affected by the length of time (duration) that fertilizer N treatments had been imposed (Table 2). This suggests that previous years’ N rate history had minimal residual (carry over) effect on spring mineral soil N concentrations at this site in 2013.

The soil ammonium and nitrate concentrations shown in table 2 were obtained from plots where the same fertilizer N rate (30, 87 or 218 kg-N/ha) was applied each year since 2009)4 years).

Site average spring soil NO_3-N concentration in the surface 30cm for the planting sample date (May 9) averaged 6.2 ppm (Standard Error=0.16, Sample Number=56) and for the sidedress sample date (June 24) soil nitrate-N concentration averaged 9.3 ppm (Standard Error=0.16, Sample Number=56). Soil NO_3-N test recommendations for Ontario are 148 kg-N/ha preplant based on the May 9 sample and 136 kg-N/ha sidedress based on the June 26 sample.

Spring soil nitrate concentrations in 2013 tended to be slightly lower when compared to earlier years (5-year range is 6.2 – 8.6 ppm at planting and 9.0 to 12.9 ppm at sidedress). Spring soil nitrate concentrations over years varied within a relatively narrow range (3-4 ppm) suggesting that natural N supply did not substantially vary at this site over the first 5 years of this trial.

Impact on Timing and Previous Years' Rate of Fertilizer N on Corn Development, Yield and N Uptake

This section utilizes 2 statistical analyses because of an imbalance in fertilizer N treatments. The trial does contain a balanced assortment of N fertilizer treatments consisting of 1) 5 total N rates (30, 58, 87, 145 and 218 kg-N/ha); 2) 2 application dates (close to when corn was planted or sidedress 4-6 weeks after corn planting) and 3) 2 fertilizer N application histories (uniform N application of 145 kg-N/ha the previous year or where the same N rate has been applied continuously starting in 2009). This analysis was used to identify the impact that timing of N application and fertilizer N history has on corn response to the various fertilizer N rates.

There also was a continuously applied 260 kg-N/ha rate which was applied close to corn planting or sidedress. Comparisons between the continuously applied 218 and 260 kg-N/ha rates were included in summary tables to evaluate the potential corn response to N rates exceeding 218 kg-N/ha with significance of corn response to applying 260 kg-N/ha based on a statistical analysis that only included the continuously applied N treatments.

Some plots that had received yearly fertilizer N application of either 30, 87 or 218 kg-N/ha from 2009 to 2012 had the fertilizer N rate switched to either 30 or 218 kg-N/ha. This was done in order to evaluate the effect of previous year's fertilizer N rate on corn performance and response to current year fertilizer N application.

Previous years' N rate (30, 87 or 218 kg-N/ha) or timing of application did not significantly affect corn development, growth or yield when either 30 or 218 kg-N/ha was applied in 2013 (Table 3). Similarly, previous year's N rate and timing of application usually did not affect corn N concentrations or uptake when either 30 or 218 kg-N/ha was applied in 2013 (Table 4). Minimal corn growth, yield and N uptake response to historic N rates of 30, 87 and 218 kg-N/ha where only 30 kg-N/ha was applied in 2013 indicates that there was minimal residual (carry over) effect of previous years' (2009-2012) fertilizer N application. Similarly, the minimal corn growth, yield and N uptake response to previous years' N management where a high rate of fertilizer N (218 kg-N/ha) was applied in 2013 suggests that previous year's N management has minimal effect on corn growth, yield and N uptake when economic or non-N limiting rates of fertilizer N are applied.

Slightly lower grain N concentration and content were observed in plots that received 145 kg-N/ha (Uniform) in 2012 when compared to where 218 kg-N/ha had been applied continuously since 2009 (Table 5). There was also a tendency at the 218 kg-N/ha rate to have slightly lower grain N contents when applied at planting compared to sidedress in 2013. Reasons for relatively

low grain N contents following last year's 145 kg-N/ha rate (Table 5) is not clear since grain N contents were similar for the previous year's 30, 87 and 218 kg-N/ha rates (Table 4).

Nitrogen rate history and timing of application effects on grain N concentration and content for the lower rates (30, 58, 87 145 kg-N/ha) were not as consistent and usually not significant.

Except for grain N concentration and removal, corn development, growth and yield response to rate of fertilizer N application in 2013 was not affected by either Timing (Planting vs. sidedress) or previous N application history (Uniform 145 kg-N/ha in 2012 vs. continuous application of the same N rate for 5 years (2009-2013). Timing of N application and duration of N rates also did not have significant effects on corn development, growth, yield and N uptake in earlier years of this study.

The remainder of this section discusses the average effect of rate history, application timing and N rate on corn development, growth, yield and N uptake in 2013. Except for grain N (summarized in table 5), generally application timing or N rate history did not affect corn development, growth, yield or N uptake response to rate of fertilizer N applied in 2013.

Corn development (days to 50% silking, harvest grain moisture) and final biomass (Grain, stover, total above ground and harvest index) were not affected by fertilizer N history or timing of application (Table 6). Fertilizer N rate history and timing of application also did not affect corn development and final biomass in 2010, 2011 or 2012.

Corn silked 2 days earlier where higher N rates (145, 218 & 260 kg-N/ha) were applied compared to the starter only (30 kg-N/ha) rate in 2013 (Table 6). Similarly, higher N rates silked about 2 days earlier in 2009, 2010 and 2011.

Applying N rates over 200 kg-N/ha was associated with harvest moisture content in 2013 that was more than 1% higher than when fertilizer N rates were less than 150 kg-N/ha (Table 6). Higher fertilizer N rates were also associated with similar relative increases in harvest moisture in previous years.

Harvest index, the percentage of total corn plant biomass which is grain, increased as total N rate increased in 2013 with the highest harvest indices' associated with fertilizer N rates of 145, 218 and 260 kg-N/ha (Table 6). Similar N rate effects on harvest index were observed in earlier years.

Grain yield, stover biomass and total corn biomass responded to increasing fertilizer N rates up to the 218 and/or 260 kg-N/ha rates in 2013 (Table 6). Grain yields were more than doubled where fertilizer N rates exceeded 200 kg-N/ha. Stover yields were increased by about 70% where fertilizer N rates exceeded 200 kg-N/ha. Above ground biomass in Table 6 was estimated based on a calculation using the dry grain corn yield (0% moisture) and harvest index. The Stover yield in Table 6 represents the mass, at 0% moisture) of the above ground plant material not including the grain or cobs.

Years with maximum yields exceeding 11 Mg/ha (2010, 2011 and 2013) produced the highest yields, stover biomass and total biomass when fertilizer N rate was 218 kg-N/ha and/or 260 kg-N/ha. For the other 2 years, yield and stover biomass for the 218 kg-N/ha rate was not significantly higher than the 145 kg-N/ha rate.

Grain and Stover N concentration in 2013 steadily increased, as fertilizer N rate increased from the starter rate (30 kg-N/ha) to 218 kg-N/ha (Table 7). Applying 218 kg-N/ha increased grain N

concentration by a factor of about 1.3 and stover N concentration by a factor of about 1.5 over where just the 30 kg-N/ha starter rate was applied. Applying 260 kg-N/ha did not significantly increase stover or grain N concentration. Fertilizer N rate effects on stover and grain N concentrations in 2013 were similar to those observed in 2010 and 2011 and about 2 times larger than the stover and grain N concentration increases in 2012 (a year with relatively low fertilizer N requirement).

Total N content, which represents total N uptake in the above ground portion of the plant, was increased by a factor of about 2.7 at the 218 kg-N/ha rate when compared to the starter only (30 kg-N/ha) rate (Table 7). Grain N content, which represents N removal, increased by a factor of about 3.1 for the 218 kg-N/ha rate when compared to the starter only rate. Stover N content, which represents the amount of N remaining in the corn residue after harvest, increased by a factor of about 1.9 for the 218 kg-N/ha rate when compared to the starter only rate. Highest stover and grain N contents were also observed in the 218 kg-N/ha rate in 2010 and 2011; but in 2012 N contents did not significantly increase for rates above 145 kg-N/ha.

The highest grain and total N contents in 2013 occurred in the 260 kg-N/ha rate where grain N content was increased by 12 kg-N/ha (8%) and total N content by 15 kg-N/ha (7%) over where 218 kg-N/ha was applied continuously.

Applying the recommended fertilizer N rate (145 kg-N/ha) increased total N content (Grain & Stover) by about 83 kg-N/ha with an apparent fertilizer N recovery of about 72% for the 115 kg-N/ha that was applied in addition to the starter N (Table 7). Apparent fertilizer N recovery at the 115 kg-N/ha rate (145 kg-N/ha total N rate) was the highest observed over the 5 years of this trial (previous 4-years (2009 – 2012) ranged between 41 – 61%.

Applying the 218 kg-N/ha rate in 2013 increased total N content by 119 kg-N/ha over the starter rate of 30 kg-N/ha with an apparent fertilizer N recovery of 64%. (Table 7). The N recovery for the 218 kg-N/ha rate in 2013 was also the highest observed in this trial which ranged between 27 to 50% in the previous 4 years.

The high fertilizer N recoveries observed in 2013 can be attributed to adequate rainfall amounts that was evenly distributed throughout the growing season which resulted in high yields and demand for N.

Late Season Soil N.

Soil mineral N content in the surface 30 cm in 2013, measured shortly following black layering of corn (early October), was not affected by fertilizer N application history or application timing (Table 8). Also the rate of N applied continuously in the previous 4 years (2009-2012) did not affect end of season (early October) soil ammonium or nitrate concentrations (Table 2). Nitrogen rate history or application timing also usually did not affect fall soil mineral N content in earlier years of this trial.

Early October soil mineral N content was also not affected by the N rate applied in 2013 (Table 8). Differences in end of season (fall) soil N among N rate treatments usually occur only when some rates are in excess of corn requirements. In 2013, none of the N rates applied significantly exceeded corn N demands and as a consequence fall soil N differences among the various N rates were small. Only in 2012, when fertilizer N requirements were about 140 kg-N/ha, were fall soil mineral N contents higher in the 218 and 260 kg-N/ha rates.

Grain Corn Yield and Economic Response to Fertilizer N

Ontario Corn general N recommendations for this site following grain corn with a 10 Mg/ha expected yield and a Nitrogen:Corn price ratio of 8.1 are 136 kg-N/ha preplant and 115 kg-N/ha sidedress. Economic estimates presented in this summary are based on a Nitrogen:Corn price ratio of 8.1 with a corn price of $177/tonne ($4.50/bu) and fertilizer N cost of $1.43/kg-N ($0.65/lb-N).

Four yield response equations to applied fertilizer N were initially fitted to the 2013 grain corn yield data which were based on fertilizer N application timing (planting or sidedress) and previous year fertilizer N rate (uniform 145 kg-N/ha rate applied in 2012 or continuous application of the same rate over years).

Three of the 4 response curves fitted in 2013 were similar with estimated 0-N yields (Intercept) within a range of 4.4-5.1 Mg/ha; N rate that produces maximum yields within a range of 270-287 kg-N/ha and maximum (plateau) yield within a range of 13.6 to 13.8 Mg/ha. However, the response curve based on preplant applied N following a uniform 145 kg-N/ha rate in 2012 had maximum N estimated at 219 kg-N/ha and associated plateau yield of 12.5 mg/ha. The primary reason for low preplant response to fertilizer N following an uniform 145 kg-N/ha application in 2012 is probably because of a design constraint in the experiment where a 260 kg-N/ha rate is not included. There was a clear yield response to applying 260 kg-N/ha in 2013 (Table 6) and the absence of the 260 kg-N/ha rate was probably the primary reason for low maximum N and plateau yield estimates for preplant N applied following an uniform (145 kg-N/ha) rate that was applied in 2012. Previous N history (uniform vs. continuous) had minimal effects on corn grain yield response to the various N rates when applied sidedress in 2013.

Over time, continuous applications of less than adequate fertilizer N rates may reduce grain corn yield because of reduced residual (carry over) N and/or readily mineralizable organic N. The lack of consistent and significant yield reductions associated with continuous application of less than adequate fertilizer N rates at this trial in 2010 - 2013 suggest that shorter-term (1-5 years) of less than adequate N fertility may have minimal impact on natural soil N supply and subsequent corn grain yield potential in Ontario.

Since previous years' N rate history probably did not affect soil N supply in 2013, even where lower fertilizer N rates were applied in earlier years , discussion of 2013 grain corn yield response to fertilizer N rates and application timing will be based on development of regression equations using yield data pooled across fertilizer N application history.

Timing of N application (at planting or sidedress) did not affect corn grain yield response to fertilizer N in 2013 (Table 9. The average N rate that maximized yield in 2013 was estimated at 273 kg-N/ha with an average maximum yield of 13.6 Mg/ha. The average estimated maximum economic N rate (MERN) was 240 kg-N/ha and the maximum economic yield (MEY) was 13.4 Mg/ha (99% of the non-N limited yield). Maximum economic N rates and associated yields in 2013 were the highest observed in the 5 year history of this trial (Appendix 1). Over the 5-year history of this trial timing of N application significantly affected mearn only in 2 years where sidedress MERN was 41 kg-N/ha (23%) less than preplant in 2010 and 27 kg-N/ha (13%) less than preplant in 2011 (Appendix 1).

Applying the maximum economic rate of N increased corn yields in 2013 by 7.1 Mg/ha when compared to the yields obtained where only starter N was applied (30 kg-N/ha) (Table 9). The 2013 yield increase was the Highest observed in the 5-year history of this trial (Appendix 1.

In 2013 timing of fertilizer N application did not effect the rate of grain yield increase per unit of applied fertilizer N between the starter rate (30 kg-N/ha) and MERN, which averaged 33.8 kg-grain/kg-N (Table 9). The 2013 rate of grain yield increase per unit of applied fertilizer N was 2 times higher when compared to 2012 rates and similar to the rates observed in 2010 and 2011 (Appendix 1). Over years, there is a clear trend for more efficient conversion of applied fertilizer N to grain yield during years with higher yield potentials. The average rate of grain yield increase was calculated by determining the estimated yield response between the starter N rate (30 kg-N/ha) and MERN and then dividing by the amount of fertilizer N required over the starter rate to obtain MERN.

Net returns to applying N fertilizer, over the starter rate, averaged about $957/ha in 2013 (Table 9). This was the largest return increase observed over the 5 years of this trial, which was about 3, 1.4, 1.6 and 6.4 times greater than returns for years 2009-2012, respectively (Appendix 1).

General N Recommendations grossly under estimated corn N requirements in 2013 by 105 kg-N/ha for the planting recommendation and 125 kg-N/ha for the sidedress recommendation (Table 9). Applying the general N recommended rate in 2013 reduced planting applied N yields by 2.2 Mg/ha and for sidedress applied N by 3.0 Mg/ha. The associated losses in profits in 2013 were $236/ha when N was applied at planting and $343/ha when applied sidedress. Historically, the general recommended N rates have resulted in estimated losses in potential profits of more than $100/ha for 3 of the 5 years; years when economic N rates were 60 to 125 kg-N/ha greater than the general recommended N rate (Appendix 2. General N recommendations are based on a 10 Mg/ha yield goal using a nitrogen:corn price ratio of 8.1.

Ontario soil NO_3-N test recommendations in 2013 also grossly underestimated corn N requirements by 91 kg-N/ha for the planting recommendation and 104 kg-N/ha for the sidedress recommendation (Table 9). Loss in potential yield was 1.8 Mg/ha and profit of $184/ha for planting recommendation. Similarly, loss in potential yield was 2.2 Mg/ha and profit was $236/ha when applied sidedress (Appendix 2)

Ontario's soil N test recommendations underestimated corn N requirements for each of the 5 years of this trial; especially in years with yield potentials that exceeded 10 Mg/ha (2010, 2011 and 2013 (Appendix 2)). For the 3 higher yielding years, soil N test recommendations were substantially less than actual N requirements (ranging between 41 – 104 kg-N/ha with an associated profit loss ranging between $52/ha to $236/ha (Appendix 2).

Consistent under prediction of corn fertilizer N requirements by the soil nitrate-N test suggests that the trial site may have lower than average capacity to supply natural N and(or) the soil N test is not correctly calibrated. General N recommendations also have a strong tendency to under predict N requirements at this site (Appendix 2); also suggesting that this site also probably has a less than average capacity to supply natural N.

Grain yield response to sidedress applied N for years 2009 to 2013 are presented in Figure 1. At low fertilizer N rates there is little variation in yields over years suggesting that there was little variation in natural N supply at this trial during these 5 years. This is supported by a relatively small range in PSNT soil nitrate concentrations (surface 30 cm) measured at this site over years (Table 10). There is a tendency for lower soil nitrate concentration in years with higher April 1 to PSNT sample date rainfall amounts, however, the relatively small PSNT soil N differences over years can not account for the relatively large differences in MERN observed over these 5 years.

There was a 106 kg-N/ha variation in sidedress MERN over the 5 years of this trial (Table 10). The sidedress MERN yields also varied by 6.5 Mg/ha over years with an increase that was closely

related to variation in MERN. The relationship between Maximum Economic N Rate and yearly yield potential over the 5 years at this site can be described by the following equation: MERN= 7 + 16.5*Yield R^2=0.95.

There was a tendency for higher yields at this site during years with higher April 1 to August 31 rainfall totals provided that sufficient nitrogen fertilizer was applied. In 2013, April 1 to August 31 rainfall was 132% of the 5-year average for this site, yield potential was 132% of average and economic N requirement was 136% of average (Table 10). In contrast, 2012 April 1 to August 31 rainfall was 59% of average, yield potential was 69% of average and economic N requirement was 76% of average. The other 3 years had rainfall amounts, yield potentials and economic N rates that were closer to the 5-year average.

The first 5 years of this trial have shown that yearly variation in MERN is not exclusively due to yearly variations in natural N supply. In fact figure 1 clearly shows, at least for this site, that the majority of the yearly variation in MERN was due to yearly changes in corn N demand (yield) which appears to be mostly driven by seasonal differences in April 1 to August 31 rainfall totals (Table 10). Efforts will continue in the following years to better understand and hopefully improve the ability of fertilizer N recommendation models to better predict corn N demand as well as soil N supply.

Table 1. Surface 15 cm soil nutrient test history for the IPNI long-term nitrogen response trial located near Elora ON (2008-2013).

	pH		Phosphorous		Potassium		Magnesium	
Date	Avg	Range	Avg	Range	Avg	Range	Avg	Range
			- ppm-P_2O_5 -		-- ppmK_2O --		-- ppm-Mg --	
9-May-2008	7.6	7.4-7.8	14	11-15	88	85-93	444	409-498
17-Apr-2009	7.7	7.6-7.8	13	11-15	71	66-74	407	372-447
19-May-2009	7.7	7.6-7.7	19	15-25	82	75-87	399	374-413
15-Apr-2010	7.6	7.5-7.7	14	10-16	82	77-86	417	398-447
5-Apr-2012	7.4	7.3-7.5	11	9-13	81	76-85	387	360-423
9-Oct-2012	7.7	7.6-7.7	14	10-17	94	89-101	377	359-386
5-Nov-2013	7.8	7.7-7.8	12	10-13	85	78-94	311	287-330

Table 2. Effect of yearly fertilizer N application at rates of 30, 87 and 218 kg-N/ha from 2009 to 2012 on soil ammonium and nitrate concentrations on 3 sample dates at Elora (2013).

Current N Rate[+]	Early May		Late June		Early October	
Previous N Rate[++]	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
30 kg-N/ha	---------- ppm ----------					
30 kg-N/ha	2.4	6.4	2.8	9.3	3.1	7.4
87 kg-N/ha	2.0	5.6	2.5	8.7	3.8	7.4
218 kg-N/ha	2.1	6.3	2.4	9.5	3.3	7.2
218 kg-N/ha						
30 kg-N/ha	2.1	5.4	2.5	8.9	3.3	6.6
87 kg-N/ha	2.3	6.0	3.1	9.1	3.4	7.0
218 kg-N/ha	2.2	5.8	2.4	9.8	3.8	7.5
Se	0.28	0.50	0.33	0.58	0.47	0.72
LSD(P=0.05)+++	ns	ns	Ns	ns	ns	ns

+ Ffertilizer N rate applied in the current year (2013). Rates are bolded.
++ Fertilizer N rates applied each year from 2009 to 2012.
+++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.

Table 3. Effect of yearly fertilizer N application at rates of 30, 87 and 218 kg-N/ha from 2009 to 2012 on **days required to reach 50% silking, harvest grain moisture, and final yields at Elora (2013).**

Group Treatment	50% Silking - Days -	Grain Moisture - % -	Grain Yield -Mg/ha @ 15.5% -	Harvest Index+ - % -	Total Biomass Mg/ha @ 0% -	Stover Biomass++ Mg/ha @ 0% -
Timing						
Planting	79.3	25.4	9.58	51.0	15.56	6.02
Sidedress	78.9	25.4	9.84	51.4	15.87	6.08
Se	0.14	0.12	0.173	0.27	0.259	0.102
LSD(P=0.05)+++	ns	ns	ns	ns	ns	ns
N Rate++++						
30 kg-N/ha						
30 kg-N/ha	80.6	24.8	6.31	48.3	11.00	4.79
87 kg-N/ha	80.6	24.7	6.09	48.0	10.72	4.71
218 kg-N/ha	80.1	24.8	6.44	47.2	11.56	5.14
218 kg-N/ha						
30 kg-N/ha	77.6	26.1	13.18	54.3	20.53	7.31
87 kg-N/ha	77.9	26.0	13.12	55.2	20.07	7.04
218 kg-N/ha	77.8	26.0	13.10	54.3	20.41	7.30
Se	0.25	0.21	0.178	0.46	0.327	0.177
LSD(P=0.05)+++	0.7	0.6	0.51	1.3	0.93	0.50

+ Total biomass yields (at 0% moisture content) were calculated by dividing grain yield at 0% moisture by the harvest index expressed as a proportion (50% expressed as a proportion is 0.5).

++ Stover yields at 0% moisture were estimated by subtracting estimate of total ear yield at 0% moisture from the total dry biomass yield. Therefore, Stover yields do not include cobs.

+++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.

++++ Fertilizer N rates in bold are the current year (2013) fertilizer N rates and the not bolded rates were the fertilizer N rates that were applied yearly from 2009 to 2012.

Table 4. Effect of yearly fertilizer N application at rates of 30, 87 and 218 kg-N/ha from 2009 to 2012 **on concentration and content of N in grain and Stover at Elora (2013).**

Group Treatment	Stover[+] N Concentration - % -	Stover[+] N Content - kg-N/ha -	Grain N Concentration - % -	Grain N Content - kg-N/ha -	Total N Content - kg-N/ha -
Timing					
Planting	0.64	39	1.04	90	129
Sidedress	0.63	40	1.06	96	136
Se	0.022	1.4	0.012	2.0	2.7
LSD(P=0.05)[++]	ns	ns	ns	ns	ns
N Rate[+++]					
30 kg-N/ha					
30 kg-N/ha	0.53	25	0.83	44	70
87 kg-N/ha	0.56	26	0.82	42	68
218 kg-N/ha	0.54	28	0.84	46	73
218 kg-N/ha					
30 kg-N/ha	0.75	55	1.27	142	197
87 kg-N/ha	0.74	52	1.23	137	189
218 kg-N/ha	0.71	52	1.32	146	198
Se	0.026	2.1	0.020	2.3	3.7
LSD(P=0.05)[++]	0.07	6	0.06	7	11

+ Stover N concentration and content includes all above ground plant parts except grain and cobs.

++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.

+++ Fertilizer N rates in bold are the current year (2013) fertilizer N rates and the not bolded rates were the fertilizer N rates that were applied yearly from 2009 to 2012.

Table 5. Fertilizer nitrogen application history and timing effects on concentration and content of N in grain and Stover where 218 kg-N/ha was applied in 2013 at Elora.

Group Treatment	Stover+ N Concentration - % -	Stover+ N Content - kg-N/ha -	Grain N Concentration - % -	Grain N Content - kg-N/ha -	Total N Content - kg-N/ha -
History					
Continuous	0.71	52	1.32	146	198
Uniform	0.70	49	1.24	135	184
Se	0.030	1.8	0.021	2.3	2.8
LSD(P=0.05)++	ns	ns	0.06	6	8
Timing					
Planting	0.68	46	1.25	134	181
Sidedress	0.73	54	1.32	147	201
Se	0.030	1.8	0.021	2.6	2.8
LSD(P=0.05)++	ns	5	0.06	8	8

+ Stover N concentration and content includes all above ground plant parts except grain and cobs.

++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.

Table 6. Fertilizer nitrogen application history, timing and rate effects on days required to reach 50% silking, harvest grain moisture, and final yields at Elora (2013).

Group Treatment	50% Silking - Days -	Grain Moisture - % -	Grain Yield -Mg/ha @ 15.5% -	Harvest Index+ - % -	Total Biomass Mg/ha @ 0% -	Stover Biomass++ Mg/ha @ 0% -
History						
Continuous	78.7	25.1	9.67	51.5	15.73	6.08
Uniform	79.0	25.1	9.67	51.4	15.73	6.11
Se	0.13	0.08	0.086	0.21	0.143	0.073
LSD(P=0.05)+++	ns	ns	ns	ns	ns	ns
Timing						
Planting	79.1	25.0	9.49	51.2	15.50	6.04
Sidedress	78.6	25.2	9.85	51.7	15.96	6.16
Se	0.13	0.08	0.140	0.21	0.217	0.073
LSD(P=0.05)+++	0.4	ns	ns	ns	ns	ns
N Rate						
30 kg-N/ha	80.3	24.9	6.34	47.9	11.15	4.89
58 kg-N/ha	79.1	24.8	7.98	49.8	13.54	5.63
87 kg-N/ha	78.8	24.8	9.36	51.0	15.51	6.16
145 kg-N/ha	78.0	25.0	11.70	53.8	18.39	6.69
218 kg-N/ha	78.0	26.0	12.97	54.6	20.07	7.11
Se	0.21	0.13	0.137	0.32	0.226	0.115
LSD(P=0.05)+++	0.6	0.4	0.39	0.9	0.64	0.33
Continuous N Rate++++						
218 kg-N/ha	77.8	26.0	13.10	54.3	20.41	7.30
260 kg-N/ha	78.3	27.1	13.88	55.3	21.21	7.37
Se	0.25	0.21	0.178	0.46	0.327	0.177
LSD(P=0.05)+++	Ns	0.6	0.51	ns	ns	ns

+ Total biomass yields (at 0% moisture content) were calculated by dividing grain yield at 0% moisture by the harvest index expressed as a proportion (50% expressed as a proportion is 0.5).

++ Stover yields at 0% moisture were estimated by subtracting estimate of total ear yield at 0% moisture from the total dry biomass yield. Therefore, Stover yields do not include cobs.

+++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.

++++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the fifth year in 2013 averaged over Planting and sidedress application timing.

Table 7. Fertilizer nitrogen application history, timing and rate effects on concentration and content of N in grain and Stover at Elora (2013).

Group Treatment	Stover+ N Concentration - % -	Stover+ N Content - kg-N/ha -	Grain N Concentration - % -	Grain N Content - kg-N/ha -	Total N Content - kg-N/ha -
History					
Continuous	0.59	36	1.02	87	123
Uniform	0.60	37	1.01	85	122
Se	0.013	0.8	0.009	1.0	1.3
LSD(P=0.05)++	ns	ns	ns	ns	Ns
Timing					
Planting	0.60	36	1.01	84	120
Sidedress	0.59	37	1.02	88	125
Se	0.014	0.8	0.009	1.7	1.3
LSD(P=0.05)++	ns	ns	ns	ns	4
N Rate					
30 kg-N/ha	0.53	26	0.85	45	71
58 kg-N/ha	0.53	30	0.86	58	88
87 kg-N/ha	0.56	35	0.93	74	108
145 kg-N/ha	0.63	42	1.13	112	154
218 kg-N/ha	0.70	50	1.28	141	191
Se	0.021	1.3	0.015	1.6	2.0
LSD(P=0.05)++	0.06	4	0.04	5	6
Continuous N Rate+++					
218 kg-N/ha	0.71	52	1.32	146	198
260 kg-N/ha	0.74	54	1.35	158	213
Se	0.026	2.1	0.020	2.3	3.7
LSD(P=0.05)++	ns	ns	ns	7	11

+ Stover N concentration and content includes all above ground plant parts except grain and cobs.

++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.

+++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the fifth year in 2013 averaged over Planting and sidedress application timing.

Table 8. Fertilizer nitrogen application history, timing and rate effects on total soil mineral N content in the surface 30cm shortly after corn black layer at Elora (early October, 2013).

Group Treatment	Mineral N+
History	- kg-N/ha -
Continuous	43
Uniform	42
Se	1.2
LSD(P=0.05)++	Ns
Timing	
Planting	44
Sidedress	42
Se	2.0
LSD(P=0.05)++	Ns
N Rate	
30 kg-N/ha	43
58 kg-N/ha	42
87 kg-N/ha	43
145 kg-N/ha	43
218 kg-N/ha	42
Se	1.6
LSD(P=0.05)++	Ns
Continuous N Rate+++	
218 kg-N/ha	45
260 kg-N/ha	53
Se	2.9
LSD(P=0.05)++	Ns

+ Soil mineral N content was calculated by multiplying the total mineral soil N concentration (NO3-N+NH4-N) by 4 to obtain an estimate in kg-N/ha units.
++ Least Significant Difference at the 5% level of probability. The symbol ns indicates that differences were not significant.
+++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the fifth year in 2013 averaged over Planting and sidedress application timing.

Table 9. Summary of corn yield response equations for planting and sidedress fertilizer N applied at a long-term fertilizer N rate trial located at Elora (2013). Summary includes estimates of net returns and losses associated with applying fertilizer N rates based on Ontario general recommendations and the soil nitrate-N test.

Parameter	Unit	Planting	Sidedress
Response Equations			
Intercept	kg/ha	4321	4582
Linear		66.4	67.2
Quadratic		-0.1212	-0.1231
Model C.V.	%	4.6	5.1
Maximum N	kg-N/ha	274	273
Plateau Yield	Mg/ha	13.4	13.7
Maximum Economic N Rate	kg-N/ha	241	240
Maximum Economic Yield	Mg/ha	13.3	13.6
Economic Yield Increase	Mg/ha	7.1	7.1
Net Return	$/ha	951.87	962.02
General Recommendations			
Recommended N Rate	kg-N/ha	136	115
Estimated Yield	Mg/ha	11.1	10.7
Estimated Net Return	$/ha	715.98	618.87
Estimated Loss	$/ha	-235.90	-343.15
Nitrate-N Test Recommendations			
Recommended N Rate	kg-N/ha	148	136
Estimated Yield	Mg/ha	11.5	11.4
Estimated Net Return	$/ha	767.66	725.93
Estimated Loss	$/ha	-184.22	-236.09

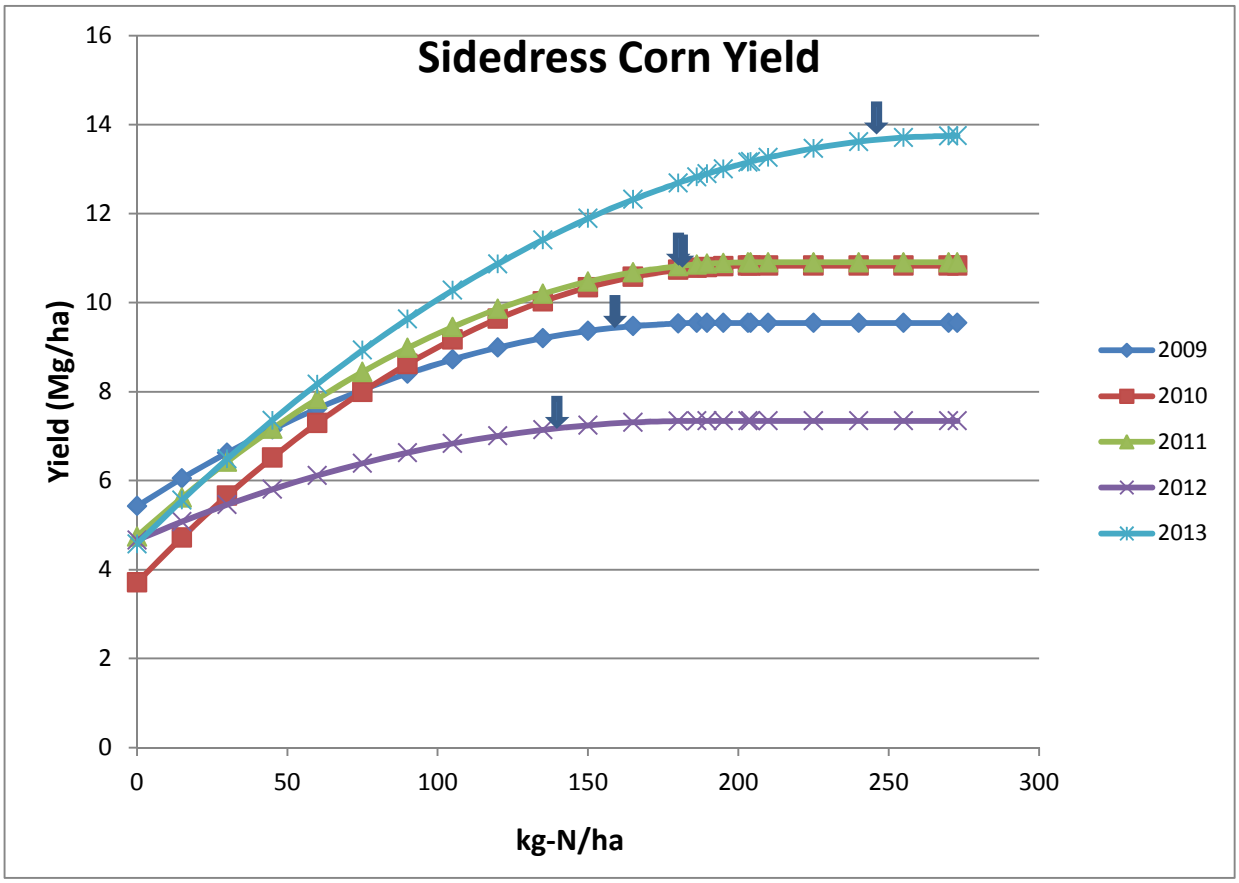
+ Estimated net return is calculated as the value of the yield ($177/Mg, $4.50/bu) increase associated with applying fertilizer N in excess of the 30 kg-N/ha starter rate less the cost of the nitrogen fertilizer ($1.43/kg-N, $0.65/lb-N).

++ Estimated loss represents an estimate of the reduction in profit associated with applying recommended rates instead of the maximum economic rate of N.

Table 10. Summary of sidedress sample soil nitrate concentration (PSNT), rainfall received from April 1 to sidedress sample date and August 31 and maximum economic N rate and associated yield at a Nitrogen:Corn price ratio of 8.1 (Elora 2009-2013).

	PSNT		Rain		Max. Economic	
Year	Date	Nitrate	Apr. 1 - PSNT	Apr. 1 - Aug. 31	N Rate	Yield
		ppm	mm	mm	kg-N/ha	Mg/ha
2009	24-Jun	10.1	222	427	154	9.4
2010	14-Jun	9.0	238	425	180	10.7
2011	14-Jun	11.3	267	492	177	10.8
2012	8-Jun	12.9	104	215	134	7.1
2013	24-Jun	9.3	311	559	240	13.6
Average		10.5	229	424	177	10.3

Figure 1. Grain corn yield response to fertilizer N applied at sidedress at Elora (2009-2013). The arrow associated with each years' response curve is MERN at a Nitrogen:Corn price ratio of 8.1.



Appendix 1. Yearly summary of planting and sidedress Maximum Economic N Rates (MERN), Yield (MEY), associated N Use Efficiency and Net Returns assuming a corn price of $177/tonne ($4.50/bu) and fertilizer N cost of $1.43/kg-N ($0.65/lb-N) (Nitrogen:Corn price ratio of 8.1).

Parameter		Planting	Sidedress
MERN (kg-N/ha)			
	2009	145	154
	2010	221	180
	2011	200	177
	2012	133	134
	2013	241	240
	Average	188	177
MEY (Mg/ha)			
	2009	9.2	9.4
	2010	10.9	10.7
	2011	10.9	10.8
	2012	7.0	7.1
	2013	13.3	13.6
	average	10.3	10.3
Yield Response to N (mg/ha)			
	2009	2.8	2.8
	2010	5.5	5.1
	2011	5.0	4.4
	2012	1.7	1.7
	2013	7.1	7.1
	average	4.4	4.2
Net Return ($/ha)			
	2009	328.72	313.28
	2010	692.28	684.70
	2011	640.65	563.73
	2012	150.41	147.79
	2013	951.87	962.02
	Average	552.79	534.30
N Use Efficiency (MERN) (kg/kg-N)			
	2009	24.3	22.3
	2010	28.6	33.9
	2011	29.3	29.8
	2012	16.4	16.1
	2013	33.6	33.9
	Average	26.4	27.2

Note Estimated net return in Appendix 1 is calculated as the value of the yield ($177/Mg, $4.50/bu) increase associated with applying fertilizer N in excess of the 30 kg-N/ha starter rate less the cost of the nitrogen fertilizer ($1.43/kg-N, $0.65/lb-N). Yield response to N and N use efficiency is based on the yield increase to adding N to the MERN rate over the starter N rate of 30 kg-N/ha.

Appendix 2. Yearly summary of planting and sidedress general and soil N-test N recommendations and associated yield increases, net returns and potential losses at a Nitrogen:Corn price ratio of 8.1. Planting general N recommendation each year at planting was 136 kg-N/ha and at sidedress was 115 kg-N/ha.

Parameter		Planting	Sidedress
Gen Rec Yield (Mg/ha)			
	2009	9.1	8.9
	2010	9.5	9.5
	2011	9.9	9.7
	2012	7.1	6.9
	2013	11.1	10.7
	average	9.3	9.1
Gen Rec Return ($/ha)			
	2009	326.71	281.31
	2010	554.84	554.99
	2011	548.32	462.64
	2012	150.28	142.70
	2013	715.98	618.87
	average	459.23	412.10
Gen Rec Loss ($/ha)			
	2009	-2.01	-31.97
	2010	-137.44	-129.71
	2011	-92.33	-101.10
	2012	-0.13	-5.09
	2013	-235.90	-343.15
	average	-93.56	-122.20
N Test Rec (kg-N/ha)			
	2009	121	128
	2010	124	138
	2011	138	116
	2012	118	101
	2013	148	136
	average	130	124
N Test Yield (Mg/ha)			
	2009	9.0	9.1
	2010	9.2	10.1
	2011	9.9	9.8
	2012	6.9	6.8
	2013	11.5	11.4
	average	9.3	9.4
N Test Return ($/ha)			
	2009	314.66	299.36
	2010	514.62	632.58
	2011	554.23	468.15
	2012	147.32	133.40
	2013	767.66	725.93
	average	459.70	451.88
N Test Loss ($/ha)			
	2009	-14.06	-13.92
	2010	-177.65	-52.12
	2011	-86.41	-95.58
	2012	-3.09	-14.40
	2013	-184.22	-236.09
	average	-93.09	-82.42

Note Estimated net return is calculated as the value of the yield ($177/Mg, $4.50/bu) increase associated with applying the recommended fertilizer N rate in excess of the 30 kg-N/ha starter rate less the cost of the nitrogen fertilizer ($1.43/kg-N, $0.65/lb-N). Economic loss is an estimate of the reduction in profit associated with applying recommended rates instead of the maximum economic rate of N.