Project title: Long-term effect of nitrogen rates on corn – Year 7 (2015) Interim Report

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Executive Summary

This report summarizes results from year 6 & 7 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 2015 growing season was the seventh year that the various N rate treatments were imposed. Economic estimates presented in this summary are based on a Nitrogen:Corn price ratio of 8.1.

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 2014. Although statistically significant, N rate history effects in 2015 were relatively small with continuous application of N since 2009 associated with higher yields (averaging 0.3 Mg/ha)and grain N removal (averaging 3 kg-N/ha (P=0.08)) compared to where uniform N rates were applied the previous year. Nitrogen rate history did not affect corn development, yield and N uptake in earlier years as well suggesting that short-term history (6 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 2014 was not substantially affected by N application timing. Yield response to N was unusually linear in 2015 and calculated MERN exceeded 260 kg-N/ha for both application timings. Sidedress yields averaged 0.5 Mg/ha (P=0.07) higher when compared to when N was applied at planting in 2015. For the 6 years when yield response plateaued (2009-2014) N application timing did not substantially affect maximum economic yield which was always at least 98% of the non-N limited yields.

Sidedress application had rates of grain yield increase per unit of N applied between the starter and maximum economic rates of N that were 2.7 kg-grain/kg-N higher than when applied at planting in both 2014 and 2015. The average rate of increase was 38 kg-grain/kg-N in 2014 and   32 kg-grain/kg-N in 2015. The fertilizer N to grain conversion rates in 2014 and 2015 were at the high end of the range of conversion rates observed in earlier years (16 to 34 kg-grain/kg-n).

Applying 115 kg-N/ha over the starter rate increased average total above-ground corn N uptake by 79 kg-N/ha with an apparent fertilizer N recovery of 69% in 2014 and 57 kg-N/ha (fertilizer N recovery of 49%) in 2015. Fertilizer N recoveries to applying 115 kg-N/ha in 2014 and 2015 were within the range of recoveries observed in earlier years (41-72%). Similarly, applying 188 kg-N/ha over the starter rate increased average total above-ground N uptake by 111 kg-N/ha (fertilizer N recovery of 59%) in 2014 and 97 kg-N/ha (fertilizer N recovery of 51%) in 2015. Fertilizer N recoveries associated with applying 188 kg-N/ha in 2014 and 2015 were also within the range of recoveries observed in earlier years (27 to 64%).

General N recommendations under estimated fertilizer N requirements in 2014 by 71 kg-N/ha when applied at planting and 75 kg-N/ha when applied sidedress. Maximum economic N rates could not be determined in 2015 but general N recommendations underpredicted N requirements by at least 110 kg-N/ha. Ontario's general N recommendations at this site were based on a 11.3 Mg/ha yield goal for a silt-loam soil in a 2650 CHU area following grain corn.

The recalibrated soil N test utilizing an 11.3 proven yield goal correctly predicted that fertilizer N requirements at this trial exceeded 200 kg-N/ha in both 2014 and 2015 indicating the potential for this test to provide more accurate field and/or season specific N recommendations than those provided by General N recommendations.

For the last 3 years of this trial (2013-2015) the non-N limited yields exceeded 12 Mg/ha and fertilizer N requirements exceeded 200 kg-N/ha. Efficiency of fertilizer N use and recovery in the latter 3 years of this trial were also at the higher range of values observed over the 7 years of this trial.

Over the 7 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 7 years. Attempts to correlate fertilizer N requirements to weather events and in season corn N status using remote sensing are currently being investigated to determine if more accurate recommendation models can be developed that utilize corn N status and/or known and perhaps anticipated weather 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 2015 results represent the seventh 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) received the same fertilizer N rate for the seventh consecutive year in 2015.

2014 & 2015 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: DeKalb DKC 39-97 was planted on May 9, 2014 and May 6, 2015 in 0.76 m rows at 79,000 seeds/ha

Fertilizer:

- Broadcast phosphorous (0-46-0) was applied at 115 kg- P2O5/ha On November 13, 2013; 115 kg- P2O5/ha on November 11, 2014 and 120 kg- P2O5/ha on May 1, 2015.
- Broadcast potassium (0-0-60) was applied at 160 kg- K2O/ha on November 13, 2013; 140 kg-K2O/ha on May 8, 2014; 155 kg- K2O/ha on November 11, 2014 and 155 kg- K2O/ha on May 1, 2015.
- Fall broadcast phosphorous and potassium were incorporated using a moldboard plow. Spring broadcast phosphorous and potassium were incorporated using a single pass of a field cultivator.
- Starter in 2014 was 200 kg/ha of 15-15-15-2Zn that was applied in a band 5 cm beside, 5 cm below seeding depth. The nutrient rates were 30 kg/ha of N, P2O5 and K2O plus 4 kg-Zn/ha). In 2015 the starter was switched to 175 kg/ha of 17-17-17-2Zn. Starter band position and nutrient rates were equivalent in 2014 and 2015.
- Early application timing (planting) of fertilizer N was injected mid-row as UAN on May 23, 2014 and May 13, 2015 at treatment related rates of 0, 28, 57, 115, 188, and 230 kg-N/ha.
- The late application timing (sidedress) was June 27, 2014 and June 18, 2015 with N application methods and treatments that were the same as described for the early date

Site Fertility

Soil pH, phosphorous, potassium, and magnesium levels in the surface 15 cm for years 2008-2013 are presented in Table 1. In fall of 2014 only potassium and phosphorous levels were measured with separate samples taken on the continuous 30 kg-N/ha (starter N only) and 260 kg-N/ha plots. Slightly lower phosphorous (3 ppm) and potassium (9 ppm) soil tests were observed in the 260 kg-n/ha N rate which was probably due to higher yields and nutrient removal rates associated with the 260 kg-N/ha N rate. The soil test phosphorous and potassium levels in fall 2014 were rated as “moderately responsive”.

Soil mineral N concentrations on the May 8, 2015 sample date were affected by starter fertilizer N on some plots. Two plots were dropped where ammonium concentrations exceeded 10 ppm, but higher than expected nitrate concentrations were still observed for some plots and an obvious threshold nitrate concentration that indicated contamination could not be identified. Average and median nitrate concentrations were similar (within 0.5 ppm) for most spring sample dates since 2009 (Table 2). The 2 exceptions were May 7, 2010 and May 8, 2015, both of which had maximum nitrate concentrations that exceeded 30 ppm. Based on maximum values observed from 2009-2015, nitrate concentrations exceeding 20 ppm probably are the result of starter N contamination. Since the median and average nitrate concentrations are similar for most sample dates then for the 2 dates where starter fertilizer contamination is suspected then the median concentration probably is a reasonable estimate of the average uncontaminated soil nitrate concentrations for these 2 dates. As a consequence evaluation of the soil N test discussed later in this report will be based on median spring soil nitrate concentrations.

Soil nitrate concentrations in the surface 30cm for the planting (May 20, 2014 and May 8, 2015) and sidedress (June 26, 2014 & June 17, 2015) sample dates were not affected by the length of time (duration) that fertilizer N treatments had been imposed (data not shown). For the 2 2014 and June 2015 sample dates the nitrate concentration difference between long-term and short-term plots averaged less than 0.7 ppm. Similarly, for the 5 continuous (long-term) N rate treatments (30, 87 or 218 kg-N/ha) average nitrate concentrations did not differ by more than 1.7 ppm. This suggests that previous years’ N rate history had minimal residual (carry over) effect on spring nitrate soil N concentrations at this site in 2014 and 2015.

Site Median soil NO_3-N concentration in the surface 30cm for the planting sample dates were 5.9 ppm on May 20, 2014 and 8.3 ppm on May 8, 2015 (Table 2). On the sidedress sample dates the site median soil NO_3-N concentration in the surface 30cm were 7.6 ppm on June 26, 2014 and 7.0 ppm on June 17, 2015. Spring soil nitrate concentrations over years varied within a relatively narrow range (1.5 ppm at planting and 5.4 ppm at sidedress) suggesting that natural N supply did not substantially vary at this site over the first 7 years of this trial.

Timing and Previous Years’ N Rate Effect on Corn Development, Yield and N Uptake

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 in 2014 (Table 3. However in 2015 continuous application of the same N rates took 0.7 less days to silk (p=0.06), had 0.32 Mg/ha higher grain yield, had 0.56 Mg/ha higher total biomass and had 0.20 Mg/ha higher stover biomass (p=0.08) (Table 4).

Timing of N application on average did not affect corn development (days to 50% silking, harvest grain moisture) and final biomass (Grain, stover, and total above ground) in 2014 (Table 3. Applying N sidedress in 2014 did increase average harvest index by 0.7%. In 2015, applying N sidedress was associated with 0.3% lower harvest grain moisture, 0.49 higher grain yield (p=0.07), and 1.6% higher harvest index (p=0.08) (Table 4).

Prior to 2015, fertilizer N rate history and timing of application usually did not affect corn development yield and final biomass.

There was a tendency for lower N Rates to have later silking dates in 2014 and 2015 (Tables 3 and 4). Higher N rates (145, 218 and 260 kg-N/ha) also silked about 2 days earlier in 2009, 2010, 2011 and 2013 when compared to the 30 kg-N/ha (starter only) rate.

Higher N rates tended to have lower harvest grain moisture in 2014 and 2015 with grain moisture differences among N rates that did not exceed 1% (Tables 3 and 4). Higher fertilizer N rates were also associated with similar relative reductions in harvest moisture in previous years.

Harvest index, the percentage of total corn plant biomass which is grain, increased by 8.7% in 2014 and 5.5% in 2015 as N rate increased from 30 to 218 kg-N/ha. In 2015 increasing N rate from 218 to 260 kg-N/ha increased harvest index by 2% (Table 4). Similar N rate effects on harvest index were observed in earlier years as well.

Grain yield, stover biomass and total corn biomass responded to increasing fertilizer N rates up to the 218 kg-N/ha rates in 2014 (table 3) and 2015 (Table 4). Grain yields were increased by a factor of 2.2 to 2.3, total biomass by a factor of 2 and stover biomass by 50 to 70% when N rates were increased from 30 to 218 kg-N/ha. Applying 260 kg-N/ha always produced numerically higher grain yield, total biomass and stover biomass than where 218 kg-N/ha was applied in 2014 and 2015, but only the grain yield increase in 2015 was significant (P=0.05).

Above ground biomass in Tables 3 and 4 were estimated based on a calculation using the dry grain corn yield (0% moisture) and harvest index. The Stover yields in Tables 3 and 4 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, 2013, 2014 and 2015) 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.

Fertilizer N history or application timing did not affect grain N concentration, total N content, stover N concentration, stover N content or total N content in 2014 (Table 5).

In 2015, continuous application of the same N rates had grain N content that averaged 3 kg-N/ha (P=0.05) and total N uptake that averaged 5 kg-N/ha (P=0.05) higher than where a uniform rate was applied the previous year (Table 6). In 2015 applying N sidedress increased grain N content by 7 kg-N/ha and total N uptake by 9 kg-N/ha compared to where N was applied at planting.

Grain and Stover N concentration in 2014 and 2015 steadily increased, as fertilizer N rate increased from the starter rate (30 kg-N/ha) to 218 kg-N/ha (Tables 5 and 6). Applying 218 kg-N/ha increased grain N concentration by a factor of about 1.3 in 2014 and 1.2 in 2015 over where just the 30 kg-N/ha starter rate was applied. Similarly, applying 218 kg-N/ha increased stover N concentration by a factor of about 1.4 in 2014 and 1.2 in 2015 over where just the starter rate was applied. Applying 260 kg-N/ha did not significantly increase stover or grain N concentration in 2014. However, grain N concentration was increased by 0.05% in 2015 where 260 kg-N/ha was applied. Fertilizer N rate effects on stover and grain N concentrations in 2014 and 2015 were similar to those observed in 2010, 2011 and 2013 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 in 2014 (Table 5) and 2.5 in 2015 (Table 6) for the 218 kg-N/ha rate when compared to the starter only (30 kg-N/ha) rate. Grain N content, which represents N removal, increased by a factor of about 3.0 in 2014 and 2.6 in 2015 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 2.1 in both 2014 and 2015 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, 2011 and 2013; but in 2012 N contents did not significantly increase for rates above 145 kg-N/ha.

The highest grain and total N contents in 2014 occurred in the 260 kg-N/ha rate where grain N content was increased by 7 kg-N/ha (P=0.10) and total N content by 10 kg-N/ha (P=0.08) over where 218 kg-N/ha was applied continuously (Table 5). In 2015, applying 260 kg-N/ha increased grain N content by 8 kg-N/ha (P=0.05) over where 218 kg-N/ha was applied (Table 6).

Applying 115 kg-N/ha over the starter rate (145 kg-N/ha total) in 2014 increased total N content (Grain & Stover) by 79 kg-N/ha with an apparent fertilizer N recovery of 69% for the 115 kg-N/ha that was applied in addition to the starter N (Table 5). Similarly, in 2015 total N uptake was increased by 57 kg-N/ha with an apparent N recovery of 49% (Table 6). Apparent fertilizer N recovery at the 115 kg-N/ha rate (145 kg-N/ha total N rate) was within the range of values observed in the earlier 5 years)41 – 72%).

Applying 188 kg-N/ha over the starter rate (218 kg-N/ha total) in 2014 increased total N content by 111 kg-N/ha with an apparent fertilizer N recovery of 59% (Table 5). Similarly in 2015 total N uptake was increased by 97 kg-N/ha with an apparent fertilizer N recovery of 51% (Table 6). Fertilizer N recovery rates observed for the 218 kg-N/ha total rates in 2014 and 2015 were within the range of fertilizer N recoveries observed in the earlier 5 years (27 to 64%).

Late Season Soil N.

Soil mineral N content in the surface 30 cm in 2014 and 2015, measured shortly following black layering of corn (early October), was not affected by fertilizer N rate history or application timing (Table 7). Nitrogen rate history or application timing also usually did not affect fall residual soil mineral N content in earlier years of this trial.

Early October residual soil mineral N content was also not affected by applied N rates between 30 to 218 kg-N/ha in both 2014 and 2015 (Table 7). In 2014 increasing N rate from 218 to 260 increased residual mineral N content by 9 kg-N/ha. Differences in fall residual soil N among N rate treatments usually occur only when some rates are in excess of corn requirements. In 2014 yield response maximized at N rates that were less than 230 kg-N/ha (Fig. 1) and there was a slight increase in fall residual mineral N content for the 260 kg-N/ha rate (Table 7). In 2015 corn N requirements exceeded 230 kg-N/ha (Fig. 1) and as a consequence fall residual soil N differences among the various N rates were small. For earlier years of this trial only in 2012 were fall residual soil mineral N contents higher for the 218 and 260 kg-N/ha rates with fertilizer N requirements in 2012 that were about 140 kg-N/ha.

Grain Corn Yield and Economic Response to Fertilizer N

When this study was started the proven grain yield was assumed to be 10 Mg/ha (160 bu/ac). However, based on non-n limited yields observed over the 7 years of this study the proven average grain yield is probably closer to 11.3 Mg/ha (180 bu/ac). The Ontario Corn general N recommendations for this site following grain corn with a 11.3 Mg/ha expected yield and a Nitrogen:Corn price ratio of 8.1 are 153 kg-N/ha preplant and 128 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 2014 and 2015 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 the previous year or continuous application of the same rate over years).

Grain yield response to application timing, previous year’s N rate and their interactions with N rate were not significant in 2014 indicating that grain yield response to N rate was not affected by both application timing or previous year’s N rate (Fig. 1). Plateau yields occurred at similar fertilizer N rates for the four response curves which were within the range of the N rates applied ranging from 212 to 257 kg-N/ha. Estimated yields for the four response curves were similar at 0-N applied (Intercept) rangeing from 2.6 to 3.2 Mg/ha and also at maximum (plateau) yield ranging from 11.9 to 12.5 Mg/ha.

In contrast, application timing (P=0.07), previous year’s N history (P=0.01) and application timing by N rate interaction (P=0.03) were significant in 2015 indicating that grain yield response to N rate was affected by both application timing and previous year’s N rate (Fig. 1). Only the planting short-term response curve attained maximum (plateau) within the N rates applied with an estimated maximum occurring at 260 kg-N/ha and maximum yield of 11.6 Mg/ha. The other three response curves did not reach maximum response at a N rate less than 260 kg-N/ha and had an unusually linear yield response to applied N. Reasons for the linear responses observed in 2015 are not known. Overall, yields averaged about 0.5 Mg/ha higher where N was applied sidedress compared to at planting. Also, yields following where a uniform 145 kg-N/ha rate was applied the previous year (short-term) averaged about 0.2 Mg/ha lower than where N rates were continuously applied over the 7 years of this trial (long-term).

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. In both 2014 and 2015 continuous applications of less than adequate N rates did not produce substantially lower yields

(Fig. 1). Similar trends were observed in earlier years as well. The lack of consistent and significant yield reductions associated with continuous application of less than adequate fertilizer N rates at this trial in 2010 - 2015 suggest that shorter-term (1-7 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 substantially affect soil N supply in 2014 and 2015, even where lower fertilizer N rates were applied in earlier years, discussion of 2014 and 2015 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 rate history.

The average N rate that maximized yield in 2014 was 251 kg-N/ha when applied at planting and 225 kg-N/ha when applied sidedress (Table 8). Maximum (plateau) yield was not affected by timing of application in 2014 and is estimated at 12.3 Mg/ha. Maximum economic rate of N (MERN) was 21 kg-N/ha higher when N was applied at planting compared to sidedress with maximum economic yield (MEY) estimated at 12.3 Mg/ha (within 99% of the non-N limited (maximum) yield).

In 2015, non-N limited (maximum) N rate and MERN estimates exceeded 260 kg-N/ha; the highest N rate applied (Table 8). Applying the 260 kg-N/ha rate at planting had estimated yields that were 1.2 Mg/ha less than when applied sidedress. In earlier years, economic yield differences between application timings did not exceed 0.4 Mg/ha (Appendix 1).

Over the 7-year history of this trial timing of N application significantly affected mearn only in 3 years where sidedress MERN was 41 kg-N/ha (23%) less than when applied at planting in 2010, 27 kg-N/ha (13%) less than when applied at planting in 2011 and 21 kg-N/ha (9%) less than when applied at planting in 2014 (Appendix 1).

Applying the maximum economic rate of N increased corn yields in 2014, averaged over application timing, by 7.0 Mg/ha over where only starter N was applied (30 kg-N/ha) (Table 8). Similarly in 2015 applying 260 kg-N/ha (a proxy for MERN) increased yield by 7.3 Mg/ha when applied near planting and 7.9 Mg/ha when applied sidedress over the yield obtained with only the starter rate. The 2014 and 2015 yield increases were similar to 2013 and larger than those observed from 2009 to 2012 (Appendix 1.

In 2014 and 2015 the rate of grain yield increase per unit of applied fertilizer N between the starter rate (30 kg-N/ha) and MERN, was 2.7 kg-grain/kg-N higher when applied sidedress (Table 8). The 2014 rates of grain yield increase per unit of applied fertilizer N were the highest observed in the 7 year history of this trial (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, were $21/ha higher when applied at planting in 2014 and $108/ha higher when applied sidedress in 2015 (Table 8). The net returns observed in 2014 and 2015 were similar to those observed in 2013 and larger than those estimated for years 2009-2012 (Appendix 1).

General N Recommendations under estimated fertilizer N requirements in 2014 by 71 kg-N/ha for the planting recommendation and 75 kg-N/ha for the sidedress recommendation (Table 8). Applying the general recommended N rate in 2014 reduced planting applied N yields by 1.3 Mg/ha and for sidedress applied N by 1.6 Mg/ha. The associated losses in profits in 2014 were $134/ha when N was applied at planting and $182/ha when applied sidedress.

Similarly, General N Recommendations under estimated fertilizer N requirements in 2015 (Table 8). Yield and financial losses associated with following general recommendations in 2015 are based on yield estimates associated with applying 260 kg-N/ha; the highest N rate applied. Required fertilizer N was under estimated by 107 kg-N/ha for the planting recommendation and 132 kg-N/ha for the sidedress recommendation. Applying the general N recommended rate in 2015 reduced planting applied N yields by 2.4 Mg/ha and for sidedress applied N by 4.0 Mg/ha. The associated losses in profits in 2015 were $267/ha when N was applied at planting and $511/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 7 years; years when economic N rates were 71 to over 132 kg-N/ha greater than the general recommended N rate (Appendix 2.

In 2014 the Ontario Ministry of Agriculture, Food and Rural Affairs stopped supporting the preplant soil-N test and updated the PSNT test. The legacy versions of the N test will continue to be evaluated and discussed. Also, results from the new PSNT test will be presented.

The legacy versions of the Ontario soil NO_3-N test recommendations also underestimated corn N requirements in 2014 by 72 kg-N/ha for the planting recommendation and 51 kg-N/ha for the sidedress recommendation (Table 8). Following the preplant recommendations in 2014 reduced yield by 1.4 Mg/ha and profit by $137/ha. Similarly, following the sidedress recommendation in 2014 reduced yield by 0.9 Mg/ha and profit by $85/ha.

The legacy versions of the Ontario soil NO_3-N test recommendations also underestimated corn N requirements in 2015 by 138 kg-N/ha for the planting recommendation and 102 kg-N/ha for the sidedress recommendation (Table 8). In 2015, under recommendation was calculated as the difference between 260 kg-N/ha (the maximum rate applied) and the recommended rate. Following the preplant recommendations in 2015 reduced yield by 3.4 Mg/ha and profit by $405/ha. Similarly, following the sidedress recommendation in 2015 reduced yield by 2.9 Mg/ha and profit by $373/ha.

Ontario's legacy soil N test recommendations underestimated corn N requirements for each of the 7 years of this trial; especially in years with yield potentials that exceeded 10 Mg/ha (2010, 2011 , 2013, 2014 and 2015(Appendix 3)). For the 5 higher yielding years, soil N test recommendations were substantially less than actual N requirements (ranging between 39 to 138 kg-N/ha with an associated profit loss ranging between $45/ha to $405/ha (Appendix 3).

Consistent under prediction of corn fertilizer N requirements by the legacy versions of the soil nitrate-N test suggests that the trial site may have lower than average capacity to supply natural N and (or) the legacy versions of the soil N tests are 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 probably has a less than average capacity to supply natural N.

Evaluation of New PSNT and Delta-Yield Recommendations

In 2015 a recalibrated "new" PSNT recommendation model was introduced in Ontario. The new PSNT model also incorporates proven corn yield potential in the recommendation calculations.

The new PSNT recommendation model bases N recommendations on a relationship between yield response to N and agronomic efficiency when the non-N limited N rate is applied. The agronomic efficiency equation is a rectangular hyperbolic function:

AE=63*dY/(5400+dY) where

AE is the agronomic efficiency (kg-Grain /kg-N

dY is the grain yield response to a Non-N limited fertilizer N rate (delta yield).

The maximum agronomic efficiency is predicted to be 63 kg-Grain /kg-N with its inverse predicting a N requirement of 0.0159 kg-N/kg-grain. When corrected for 15.5% grain moisture and an assumed harvest index of 0.55% the N requirement per dry kg of biomass is 0.010 kg-N which is similar to the 1.0% N content associated with above ground corn dry biomass generally observed when economically optimum N rates are applied.

The 5400 kg/ha coefficient represents the delta yield response where agronomic efficiency is half of the maximum agronomic efficiency (63 kg-grain/kg-N). This value represents an efficiency parameter that changes based on the differences in grain production rates per unit of applied N among application methods or N sources; especially for lower delta yields.

The hyperbolic function was used to model changes in agronomic efficiency and delta yield since efficiency of N use can not exceed minimal biological requirements for N. Also it was observed that regressing maximum N rate on to delta yield (both of which were estimated from quadratic response models obtained from the Ontario corn N database) produced a linear relationship with an intercept that was greater than 0. Including higher order polynomials did not improve model fit. This is similar to linear relationships between MERN and delta yield reported by Lori and Scharf (Agron J., 2003, 95(4):994-999). These linear plots resemble linear transformations of hyperbolic Michaelis-Menten enzyme kinetic plots using the Hanes–Woolf transformation where the ratio of Independent/Dependant is plotted on to Independent (dY/a.e. on to dY = dY/(dY/maxN) = maxN on to dY). The assumption that linear relationships between N and associated delta yield represented linear transformation of a hyperbolic relationship between agronomic efficiency and delta yield supported the decision to use the hyperbolic function to model the agronomic efficiency delta yield relationship.

The new PSNT test predicts delta yield by using soil nitrate N concentrations to predict the 0-N yield and relies on producer experience to supply the non-N limited yield. Delta-yield is calculated as the difference between these 2 yield estimates. The delta-yield estimate is used to predict agronomic efficiency which in turn is used to provide a fertilizer N recommendation.

The PSNT soil nitrate N concentrations and PSNT recommendation estimates for the seven years of the IPNI trial are shown in Table 9. There are 2 scenarios for non-N limited yields, the 11.3 Mg/ha 7-year site average and the actual yearly observed yields. The latter serves as an example of potential recommendation accuracy if accurate yearly predictions of non-N limited yields are available.

The new PSNT model with an assumed non-N limited yield of 11.3 Mg/ha under predicted requirements by more than 45 kg-N/ha in 2013 and 2015 with financial losses that exceeded $50/ha (Table 9). Predicted N requirements were within 35 kg-N/ha for the other 5 years with financial losses that did not exceed $20/ha. Financial loss estimates for 2015 are uncertain since yield response to fertilizer N was unusually linear and calculated MERN was not within the range of N rates applied (Fig. 2). Average financial losses for the new PSNT recommendations were considerably less than for the legacy PSNT test. Averaged over years, financial losses were $40/ha for the new PSNT recommendations (Table 9) and $120/ha for the legacy PSNT recommendations (Appendix 3).

If accurate year specific yields could be predicted then estimated financial losses associated with following new PSNT recommendations did not exceed $6/ha for 6 of 7 years (Table 9). The exception was 2015, which as discussed earlier had an unusual yield response to applied N. Comparing average estimated financial losses from 2009 to 2014, using accurate year specific non-N limited yield estimates reduced financial losses from $16/ha to $3/ha; supporting the idea that use of proven historic yields may be sufficient to provide reasonable fertilizer N recommendations by the new PSNT test.

Another possible application of the above described delta-yield relationship is tu use the “learning plot” concept to provide estimates of 0 or low N and non-N limited yields for specific fields and/or management units and calculate delta-yield based fertilizer N recommendations. Over time average field and/or management unit N recommendations can be calculated. Table 10 contains the yearly fertilizer N recommendations based on delta-yield estimates calculated from the starter only (30 kg-N/ha) and 260 kg-N/ha (assumed non-N limited) yields. The recommended N values include the starter (30 kg-N/ha) rate. The largest financial losses were in 2015 and as discussed earlier there is uncertainty regarding interpretation of 2015 results. However, using actual measured yearly delta yields from 2009 to 2014 produced fertilizer N recommendations that were within 22 kg-N/ha of MERN and financial loss estimates that averaged only $3/ha.

The final column in Table 10 is the estimated financial loss associated with applying the seven year average delta-yield recommendation of 182 kg-N/ha. Average estimated financial loss from 2009 to 2014 was $22/ha; considerably less than the 2009 to 2014 average loss of $98/ha associated with following the sidedress general N recommendation (Appendix 2).

It should be acknowledged that the year specific and average loss comparison is not an independent evaluation since the same years were used to develop the average N recommendation. However, it is reasonable to assume that delta yield estimates from 2009 to 2014 are representative of the expected variation in yields for this site and that average recommended N if learning plots were conducted on this site prior to 2009 would have provided a similar average delta yield N recommendation. The results presented in table 10 does demonstrate the potential benefit of using historic delta-yield fertilizer N recommendations to provide better field or management unit specific fertilizer N recommendations when compared to General N Recommendations.

Synopsis

Grain yield response to sidedress applied N for years 2009 to 2015 are presented in Figure 2. 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 7 years. This is supported by a relatively small range (7.0 to 12.4 ppm) in PSNT soil nitrate concentrations (surface 30 cm) measured at this site over years (Table 11).

The highest PSNT nitrate concentration was observed in 2012 which was 1.5 times the 7 year average and was associated with the lowest total rainfall from April 1 to date of PSNT sampling which was half of the 7 year average. Otherwise there was little association between PSNT nitrate concentration and April to PSNT sample date rainfall amounts in the other 6 years. The relatively small PSNT soil N differences over years can not account for the relatively large differences in MERN observed over these 7 years (Fig. 2 and Table 11).

There was at least a 126 kg-N/ha variation in sidedress MERN over the 7 years of this trial (Table 11). 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 7 years of this site can be described by the following equation:

MERN= -14 + 18.6*Yield R^2=0.92.

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 7-year average for this site, yield potential was 119% of average and economic N requirement was 116% of average (Table 11). In contrast, 2012 April 1 to August 31 rainfall was 47% of average, yield potential was 62% of average and economic N requirement was 65% of average. The relationship between April 1 to August 31 rainfall totals can be described by the following equation:

Yield=3.6+0.017*rain R^2=0.72 where yield is Mg/ha and rain totals are in mm.

The first 7 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 2 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 11). 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 (2008-2014).

		pH		Phosphorous		Potassium		Magnesium	
Date	N Rate	Avg	Range	Avg	Range	Avg	Range	Avg	Range
	Kg-N/ha			- 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
30-Oct-2014	30			16	15-16	119	112-126		
	260			13	11-14	110	107-112		

Table 2. Summary of planting and sidedress soil NO_3-N concentrations in the surface 30 cm at Elora (2009-2015).

date	Count	Average	se	stddev	Median	Min	Max
	-- # --	---------- ppm ----------					
19-May-2009	20	8.2	0.51	2.28	7.8	6.9	17.6
24-Jun-2009	20	10.1	0.47	2.09	9.9	7.6	14.5
7-May-2010	40	9.7	1.01	6.37	8.0	5.9	38.0
14-Jun-2010	40	9.0	0.29	1.86	8.7	5.5	13.3
12-May-2011	40	6.9	0.12	0.76	6.9	5.6	8.5
14-Jun-2011	40	11.3	0.42	2.68	11.1	7.0	19.4
1-May-2012	40	8.6	0.20	1.26	8.4	5.9	11.2
8-Jun-2012	40	12.9	0.45	2.82	12.4	8.0	22.3
9-May-2013	56	6.2	0.16	1.16	5.9	3.9	9.9
24-Jun-2013	56	9.3	0.16	1.19	9.1	7.2	13.2
20-May-2014	40	5.8	0.17	1.08	5.9	3.8	8.7
26-Jun-2014	40	7.6	0.13	0.84	7.6	6.1	9.5
8-May-2015	38	11.1	1.24	7.63	8.3	4.4	35.1
17-Jun-2015	40	7.2	0.23	1.48	7.0	4.1	10.1

Table 3. Fertilizer nitrogen application history, timing and rate effects on days required to reach 50%

Group Treatment	50% Silking	Grain Moisture	Grain Yield	Harvest Index	Total Biomass[+]	Stover Biomass[++]
History	- Days -	- % -	-Mg/ha @ 15.5% -	- % -	Mg/ha @ 0% -	Mg/ha @ 0% -
Continuous	74.7	25.1	8.85	50.5	14.59	5.98
Uniform	74.5	25.2	8.73	50.8	14.33	5.86
Se	0.19	0.08	0.080	0.26	0.134	0.076
F (Pr>F)[+++]	0.72 (ns)	0.55 (ns)	1.00 (ns)	0.67 (ns)	1.85 (ns)	1.35 (ns)
Timing						
Planting	74.6	25.2	8.66	50.3	14.37	5.96
Sidedress	74.6	25.1	8.92	51.0	14.55	5.88
Se	0.19	0.08	0.122	0.26	0.178	0.076
F (Pr>F)[+++]	0.14 (ns)	0.99 (ns)	2.17 (ns)	3.88 (0.05)	0.51 (ns)	0.51 (ns)
N Rate			1.346737487		0.97920095	0.537233208
30 kg-N/ha	75.4	25.5	5.19	46.4	9.44	4.44
58 kg-N/ha	74.7	25.5	7.11	48.2	12.46	5.59
87 kg-N/ha	75.0	25.2	8.66	50.1	14.62	6.20
145 kg-N/ha	73.7	24.5	10.81	53.5	17.08	6.53
218 kg-N/ha	74.3	24.8	12.18	55.1	18.69	6.82
Se	0.30	0.13	0.127	0.42	0.212	0.120
Linear F (Pr>F)[++++]	9.85 (0.003)	30.4 (<0.001)	1825 (<0.001)	288 (<0.001)	1093 (<0.001)	191 (<0.001)
Quadratic F (Pr>F)[++++]	5.02 (0.03)	7.52 (0.008)	112 (<0.001)	12.4 (<0.001)	104 (<0.001)	47.1 (<0.001)
LOF F (Pr>F)[++++]	2.53 (0.09)	3.42 (0.04)	0.61 (ns)	0.50 (ns)	3.10 (0.05)	5.94 (0.004)
Continuous N Rate[+++++]						
218 kg-N/ha	74.4	24.5	12.30	55.2	18.85	6.84
260 kg-N/ha	73.6	24.9	12.53	55.0	19.25	7.03
Se	0.42	0.18	0.180	0.59	0.300	0.169
Pr>|t|[++++++]	ns	0.10	ns	ns	ns	ns

silking, harvest grain moisture, and final yields at Elora (2014).

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

++ 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.

+++ ANOVA F value and associated probability (Pr>F).. The symbol ns indicates that the F value was not sitnificant at P=0.10.

++++ F values and associated probabilities (Pr>F) for linear, quadratic and LOF (lack of fit) N rate orthogonal contrasts. The symbol ns indicates that F values are not significant at P=0.10.

+++++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the sixth year in 2014 averaged over Planting and sidedress application timing.

++++++ Paired T-test probability (Pr>|T|) evaluating response difference between the continuously applied 218 and 260 N rates. The symbol ns indicates differences not significant at P=0.10.

Table 4. Fertilizer nitrogen application history, timing and rate effects on days required to reach 50% silking, harvest grain moisture, and final yields at Elora (2015).

Group	50%	Grain	Grain	Harvest	Total	Stover
Treatment	Silking	Moisture	Yield	Index	Biomass[+]	Biomass[++]
History	- Days -	- % -	-Mg/ha @ 15.5% -	- % -	Mg/ha @ 0% -	Mg/ha @ 0% -
Continuous	80.5	22.6	8.59	52.6	13.69	5.32
Uniform	81.2	22.7	8.27	52.6	13.15	5.12
Se	0.24	0.10	0.091	0.28	0.160	0.083
F (Pr>F)[+++]	3.66 (0.06)	0.55 (ns)	6.39 (0.01)	0.00 (ns)	5.75 (0.02)	3.11 (0.08)
Timing						
Planting	81.0	22.8	8.19	51.8	13.25	5.27
Sidedress	80.7	22.5	8.68	53.4	13.59	5.18
Se	0.31	0.10	0.161	0.55	0.198	0.095
F (Pr>F)[+++]	0.61 (ns)	4.90 (0.03)	4.64 (0.07)	4.19 (0.08)	1.45 (ns)	0.45 (ns)
N Rate			1.207491556		0.987698185	0.692089917
30 kg-N/ha	81.6	22.9	5.50	50.7	9.18	3.80
58 kg-N/ha	81.3	23.0	6.60	50.4	11.08	4.67
87 kg-N/ha	81.3	22.7	7.91	51.4	13.02	5.32
145 kg-N/ha	80.1	22.3	10.01	54.3	15.58	5.88
218 kg-N/ha	79.9	22.3	12.14	56.2	18.25	6.43
Se	0.39	0.15	0.144	0.45	0.254	0.131
Linear F (Pr>F)[++++]	14.3 (<0.001)	18.3 (<0.001)	1370 (<0.001)	121 (<0.001)	788 (<0.001)	224 (<0.001)
Quadratic F (Pr>F)[++++]	0.17 (ns)	0.65 (ns)	8.64 (0.005)	0.42 (ns)	14.0 (<0.001)	19.6 (<0.001)
LOF F (Pr>F)[++++]	0.66 (ns)	1.31 (ns)	0.27 (ns)	2.89 (0.06)	0.44 (ns)	1.66 (ns)
Continuous N Rate[+++++]						
218 kg-N/ha	79.3	22.2	12.25	55.7	18.57	6.61
260 kg-N/ha	80.3	22.7	12.85	57.7	18.84	6.37
Se	0.55	0.21	0.203	0.63	0.359	0.185
Pr>|t|[++++++]	ns	0.08	0.04	0.04	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.

++ 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.

+++ ANOVA F value and associated probability (Pr>F).. The symbol ns indicates that the F value was not sitnificant at P=0.10.

++++ F values and associated probabilities (Pr>F) for linear, quadratic and LOF (lack of fit) N rate orthogonal contrasts. The symbol ns indicates that F values are not significant at P=0.10.

+++++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the seventh year in 2014 averaged over Planting and sidedress application timing.

++++++ Paired T-test probability (Pr>|T|) evaluating response difference between the continuously applied 218 and 260 N rates. The symbol ns indicates differences not significant at P=0.10.

Table 5. Fertilizer nitrogen application history, timing and rate effects on concentration and content of N in grain and Stover at Elora (2014).

Group	Stover[+] N		Grain N		Total N
Treatment	Concentration	Content	Concentration	Content	Content
History	- % -	- kg-N/ha -	- % -	- kg-N/ha -	- kg-N/ha -
Continuous	0.65	39	1.04	79	119
Uniform	0.64	38	1.03	78	117
Se	0.017	1.1	0.008	1.0	1.8
F (Pr>F)[++]	0.03 (ns)	0.50 (ns)	0.21 (ns)	0.64 (ns)	0.85 (ns)
Timing					
Planting	0.65	39	1.02	77	116
Sidedress	0.64	38	1.05	81	119
Se	0.025	1.7	0.009	1.4	3.1
F (Pr>F)[++]	0.04 (ns)	0.25 (ns)	3.95 (ns)	4.84 (ns)	0.51 (ns)
N Rate	1.380110497	2.111322691	1.293449198	3.031652806	2.681717103
30 kg-N/ha	0.57	25	0.94	41	66
58 kg-N/ha	0.61	34	0.94	57	91
87 kg-N/ha	0.60	37	0.98	72	109
145 kg-N/ha	0.69	45	1.10	101	145
218 kg-N/ha	0.78	53	1.21	124	178
Se	0.027	1.8	0.012	1.5	2.8
Linear F (Pr>F)[+++]	38.6 (<0.001)	135 (<0.001)	373 (<0.001)	1928 (<0.001)	983 (<0.001)
Quadratic F (Pr>F)[+++]	0.62 (ns)	2.68 (ns)	2.42 (ns)	21.5 (<0.001)	12.9 (<0.001)
LOF F (Pr>F)[+++]	0.54 (ns)	1.02 (ns)	3.01 (0.06)	0.54 (ns)	0.31 (ns)
Continuous N Rate[++++]					
218 kg-N/ha	0.83	57	1.21	126	183
260 kg-N/ha	0.85	59	1.26	133	193
Se	0.038	2.5	0.017	2.2	3.9
Pr>|t|[+++++]	ns	ns	0.04	0.01	0.08

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

++ ANOVA F value and associated probability (Pr>F).. The symbol ns indicates that the F value was not sitnificant at P=0.10.

+++ F values and associated probabilities (Pr>F) for linear, quadratic and LOF (lack of fit) N rate orthogonal contrasts. The symbol ns indicates that F values are not significant at P=0.10.

++++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the sixth year in 2014 averaged over Planting and sidedress application timing.

+++++ Paired T-test probability (Pr>|T|) evaluating response difference between the continuously applied 218 and 260 N rates. The symbol ns indicates differences not significant at P=0.10.

Table 6. Fertilizer nitrogen application history, timing and rate effects on concentration and content of N in grain and Stover at Elora (2015).

Group	Stover[+] N		Grain N		Total N
Treatment	Concentration	Content	Concentration	Content	Content
History	- % -	- kg-N/ha -	- % -	- kg-N/ha -	- kg-N/ha -
Continuous	0.51	28	1.05	78	106
Uniform	0.51	26	1.05	75	101
Se	0.014	0.8	0.009	1.3	1.7
F (Pr>F)[++]	0.02 (ns)	1.75 (ns)	0.00 (ns)	3.19 (0.08)	3.93 (0.05)
Timing					
Planting	0.49	26	1.04	73	99
Sidedress	0.53	28	1.06	80	108
Se	0.014	1.1	0.011	1.3	1.7
F (Pr>F)[++]	5.20 (0.03)	1.76 (ns)	1.31 (ns)	15.3 (<0.001)	14.4 (<0.001)
N Rate	1.235595391	2.065773942	1.190920398	2.646862681	2.480452023
30 kg-N/ha	0.49	19	1.01	47	65
58 kg-N/ha	0.44	20	0.99	55	76
87 kg-N/ha	0.47	25	1.02	68	93
145 kg-N/ha	0.56	33	1.06	89	122
218 kg-N/ha	0.60	39	1.20	123	162
Se	0.022	1.3	0.015	2.1	2.7
Linear F (Pr>F)[+++]	30.3 (<0.001)	163 (<0.001)	112 (<0.001)	874 (<0.001)	810 (<0.001)
Quadratic F (Pr>F)[+++]	1.45 (ns)	0.70 (ns)	14.6 (<0.001)	2.24 (ns)	0.54 (ns)
LOF F (Pr>F)[+++]	2.88 (0.06)	0.81 (ns)	0.78 (ns)	0.51 (ns)	0.52 (ns)
Continuous N Rate[++++]					
218 kg-N/ha	0.63	42	1.23	128	170
260 kg-N/ha	0.65	41	1.25	136	177
Se	0.031	1.9	0.021	2.9	3.9
Pr>|t|[+++++]	ns	ns	ns	0.05	ns

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

++ ANOVA F value and associated probability (Pr>F).. The symbol ns indicates that the F value was not sitnificant at P=0.10.

+++ F values and associated probabilities (Pr>F) for linear, quadratic and LOF (lack of fit) N rate orthogonal contrasts. The symbol ns indicates that F values are not significant at P=0.10.

++++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the seventh year in 2014 averaged over Planting and sidedress application timing.

+++++ Paired T-test probability (Pr>|T|) evaluating response difference between the continuously applied 218 and 260 N rates. The symbol ns indicates differences not significant at P=0.10.

Table 7. 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, 2014 and 2015).

Group	Mineral N+	
Treatment	2014	2015
History	- kg-N/ha -	
Continuous	36	33
Uniform	37	30
Se	1.4	2.7
F (Pr>F)++	0.13 (ns)	0.36 (ns)
Timing		
Planting	36	29
Sidedress	37	34
Se	1.4	3.2
F (Pr>F)++	0.23 (ns)	0.98 (ns)
N Rate		
30 kg-N/ha	36	36
58 kg-N/ha	35	29
87 kg-N/ha	36	33
145 kg-N/ha	35	29
218 kg-N/ha	40	32
Se	2.2	4.3
Linear F (Pr>F)+++	2.35 (ns)	0.25 (ns)
Quadratic F (Pr>F)+++	1.08 (ns)	0.74 (ns)
LOF F (Pr>F)+++	0.23 (ns)	0.52 (ns)
Continuous N Rate++++		
218 kg-N/ha	41	30
260 kg-N/ha	50	30
Se	3.1	6.1
Pr>|t|+++++	0.04	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.

++ ANOVA F value and associated probability (Pr>F).. The symbol ns indicates that the F value was not sitnificant at P=0.10.

+++ F values and associated probabilities (Pr>F) for linear, quadratic and LOF (lack of fit) N rate orthogonal contrasts. The symbol ns indicates that F values are not significant at P=0.10.

++++ Comparison of the 218 and 260 kg-N/ha N rates which were applied continuously for the seventh year in 2014 averaged over Planting and sidedress application timing.

+++++ Paired T-test probability (Pr>|T|) evaluating response difference between the continuously applied 218 and 260 N rates. The symbol ns indicates differences not significant at P=0.10.

Table 8. Summary of corn yield response equations for planting and sidedress fertilizer N applied at a long-term fertilizer N rate trial located at Elora (2014 and 2015). Summary includes estimates of net returns and losses associated with applying fertilizer N rates based on Ontario general recommendations and the legacy soil nitrate-N tests.

		2014		2015	
Parameter	Unit	Planting	Sidedress	Planting	Sidedress
Response Equations					
Intercept	kg/ha	2985	3004	3554	4292
Linear		74.8	82.4	54.2	47.3
Quadratic		-0.1490	-0.1827	-0.0777	-0.0445
Model C.V.	%	4.9	5.4	7.4	5.6
Maximum N	kg-N/ha	251	225	260[+]	260[+]
Plateau Yield	Mg/ha	12.4	12.3	12.4	13.6
Maximum Economic N Rate	kg-N/ha	224	203	260[+]	260[+]
Maximum Economic Yield	Mg/ha	12.3	12.2	12.4	13.6
Net Return[++]	$/ha	993	971	962	1071
N Use Efficiency[++]+	Kg-grain/kg-N	37.0	39.7	31.7	34.4
General N Recommendations					
Recommended N Rate	kg-N/ha	153	128	153	128
Estimated Yield	Mg/ha	10.9	10.6	10.0	9.6
Estimated Net Return[++]	$/ha	859	789	695	559
Estimated Loss[+++]	$/ha	-134	-182	-267	-511
Legacy Nitrate-N Test Recommendations[+++++]					
Recommended N Rate	kg-N/ha	152	152	122	158
Estimated Yield	Mg/ha	10.9	11.3	9.0	10.6
Estimated Net Return[++]	$/ha	856	886	557	698
Estimated Loss[+++]	$/ha	-137	-85	-405	-373

\+ Calculated maximum and economic N rates exceeded the highest N rate applied (260 kg-N/ha) in 2015. Yield and economic calculations assume a 260 kg-N/ha N rate.

++ 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.

+++ Nitrogen Use Efficiency is calculated as the economic yield increase over the starter yield (MEY-Starter yield) divided by the economic N rate over the starter rate (MERN-Starter rate or 30 kg-N/ha).

+++++ These versions of the soil nitrate-N test are no longer recommended for use in Ontario.

Table 9 Summary of new PSNT recommendations and estimated financial losses at a Nitrogen:Corn price ratio of 8.1 at the Elora IPNI trial (2009-2015). The non-N limited yield estimate was the 7-year trial average or the actual year specific yield.

Yield Year	Sidedress N Test	Estimated 0-N	Non-N Limited	Delta	Estimated A.E.	MERN	PSNT Rec.	Estimated [+] Loss
		----- Mg/ha --	---	kg-grain/kg-N	Kg-N/ha			
Average	- ppm -					kg-N/ha	$/ha	
2009	9.9	3.9	11.3	7.4	35.2	154	185	-19
2010	8.7	3.5	11.3	7.8	36.1	180	193	-5
2011	11.1	4.4	11.3	6.9	34.2	177	178	0
2012	12.4	4.9	11.3	6.4	33.1	134	170	-18
2013	9.1	3.6	11.3	7.7	35.9	240	191	-53
2014	7.6	3.0	11.3	8.3	36.9	203	200	0
2015	7.0	2.8	11.3	8.5	37.3	260	203	-186
Average	9.4	3.7	11.3	7.6	35.5	193	188	-40
Actual								
2009		3.7	9.4	5.7	31.4	154	159	0
2010		3.4	10.7	7.3	35.1	180	185	-1
2011		4.3	10.8	6.5	33.3	177	171	-1
2012		4.1	7.1	3.0	21.9	134	112	-6
2013		3.8	13.6	9.8	39.4	240	224	-6
2014		3.1	12.2	9.1	38.3	203	213	-3
2015		2.9	13.6	10.6	40.5	260	237	-70
Average		3.6	11.1	7.4	34.3	193	186	-12

\+ Estimated loss represents an estimate of the reduction in profit associated with applying PSNT recommended rates instead of the maximum economic rate of N (MERN) based on a corn price of 177/Mg ($4.50/bu) and nitrogen fertilizer cost of $1.43/kg-N ($0.65/lb-N)..

Table 10 Summary of delta yield N recommendations at a Nitrogen:Corn price ratio of 8.1 and associated estimated financial losses at the Elora IPNI trial (2009-2015).

	Yield				Yearly Delta		Average
Year	Starter	260 kg-N/ha	Delta	MERN	Recommendation	Loss+	Loss++
	---- Mg/ha ----			--- kg-N/ha ---		--- $/ha ---	
2009	6.5	9.3	2.8	154	139	-5	-16
2010	5.9	11.1	5.1	180	179	0	0
2011	6.3	11.2	5.0	177	176	0	-1
2012	5.5	7.7	2.2	134	127	-1	-32
2013	6.3	13.8	7.5	240	217	-11	-73
2014	5.2	12.4	7.3	203	213	-3	-15
2015	5.5	13.3	7.8	260	223	-118	-269
Average	5.9	11.3	5.4	193	182	-20	-58

\+ Year specific loss represents an estimate of the reduction in profit associated with applying delta yield recommended rates instead of the maximum economic rate of N (MERN) based on a corn price of 177/Mg ($4.50/bu) and nitrogen fertilizer cost of $1.43/kg-N ($0.65/lb-N).

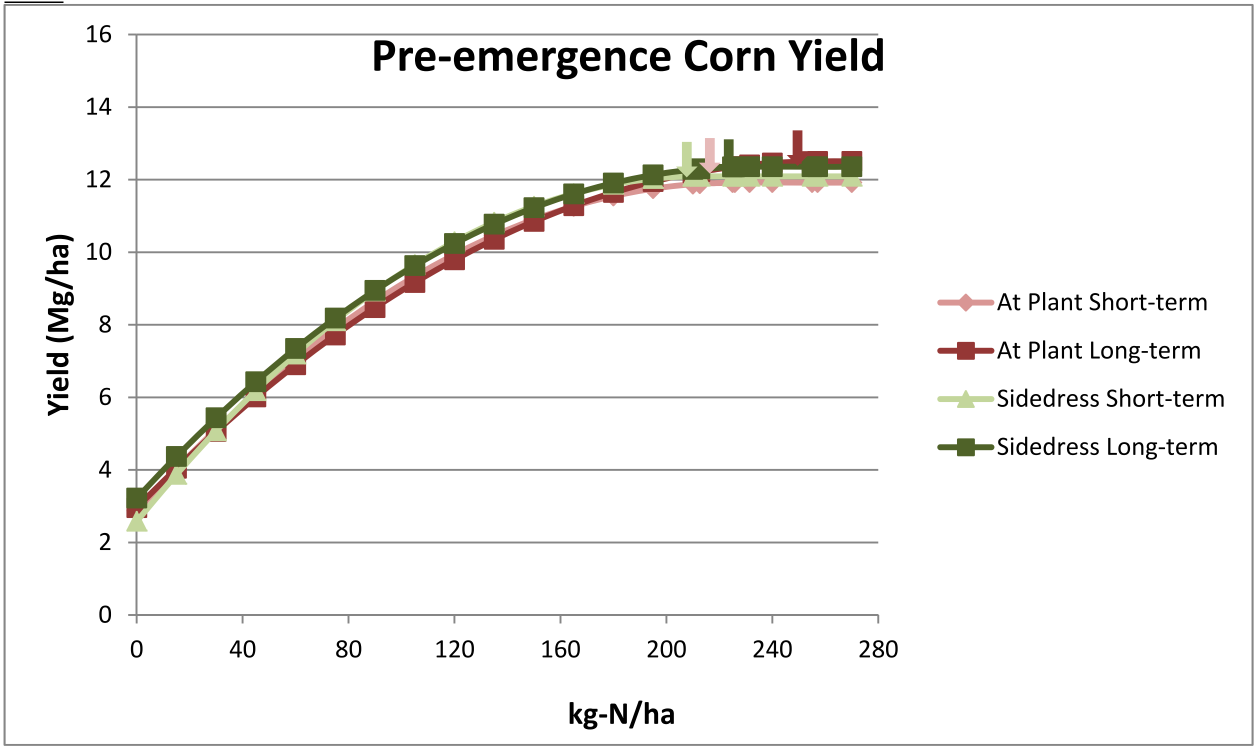
++ Average loss represents the estimated losses associated with applying the seven year average delta yield recommendation each year. Loss calculations are the same as the yearly loss calculations.

Table 11. 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 2009-2015).

	PSNT		Rain		Max. Economic	
Year	Date	Nitrate	Apr. 1 – PSNT Date	Apr. 1 – Aug. 31	N Rate	Yield
		ppm	Mm	Mm	kg-N/ha	Mg/ha
2009	24-Jun	9.9	222	427	154	9.4
2010	14-Jun	8.7	238	425	180	10.7
2011	14-Jun	11.1	267	492	177	10.8
2012	08-Jun	12.4	104	215	134	7.1
2013	24-Jun	9.1	336	595	240	13.6
2014	26-Jun	7.6	226	418	203	12.2
2015	17-Jun	7.0	240	478	260	13.6
Average		8.5	231	452	206	11.5

Figure 1. Grain corn yield response to fertilizer N rate history and timing of application at Elora in (2014 and 2015). The arrow associated with each response curve indicates MERN at a Nitrogen:Corn price ratio of 8.1. Response curves without an arrow had calculated MERN that exceeded 270 kg-N/ha.

2014



2015

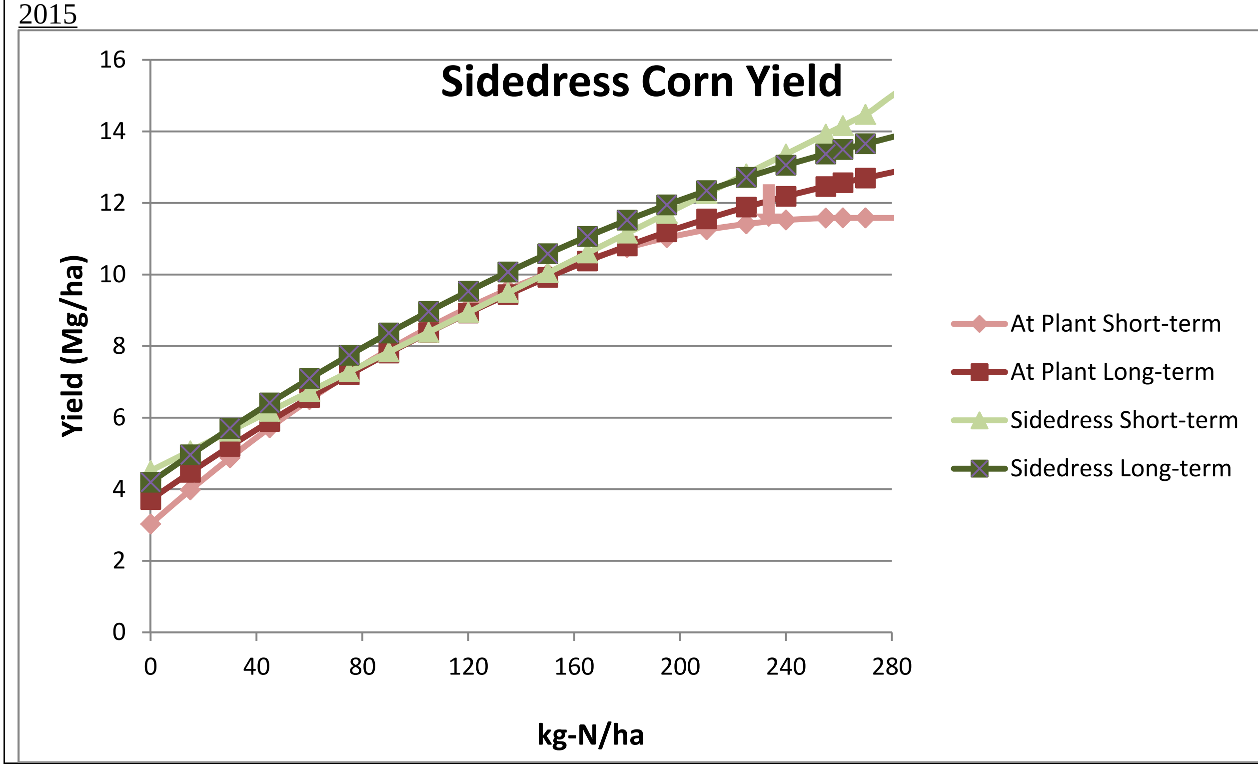
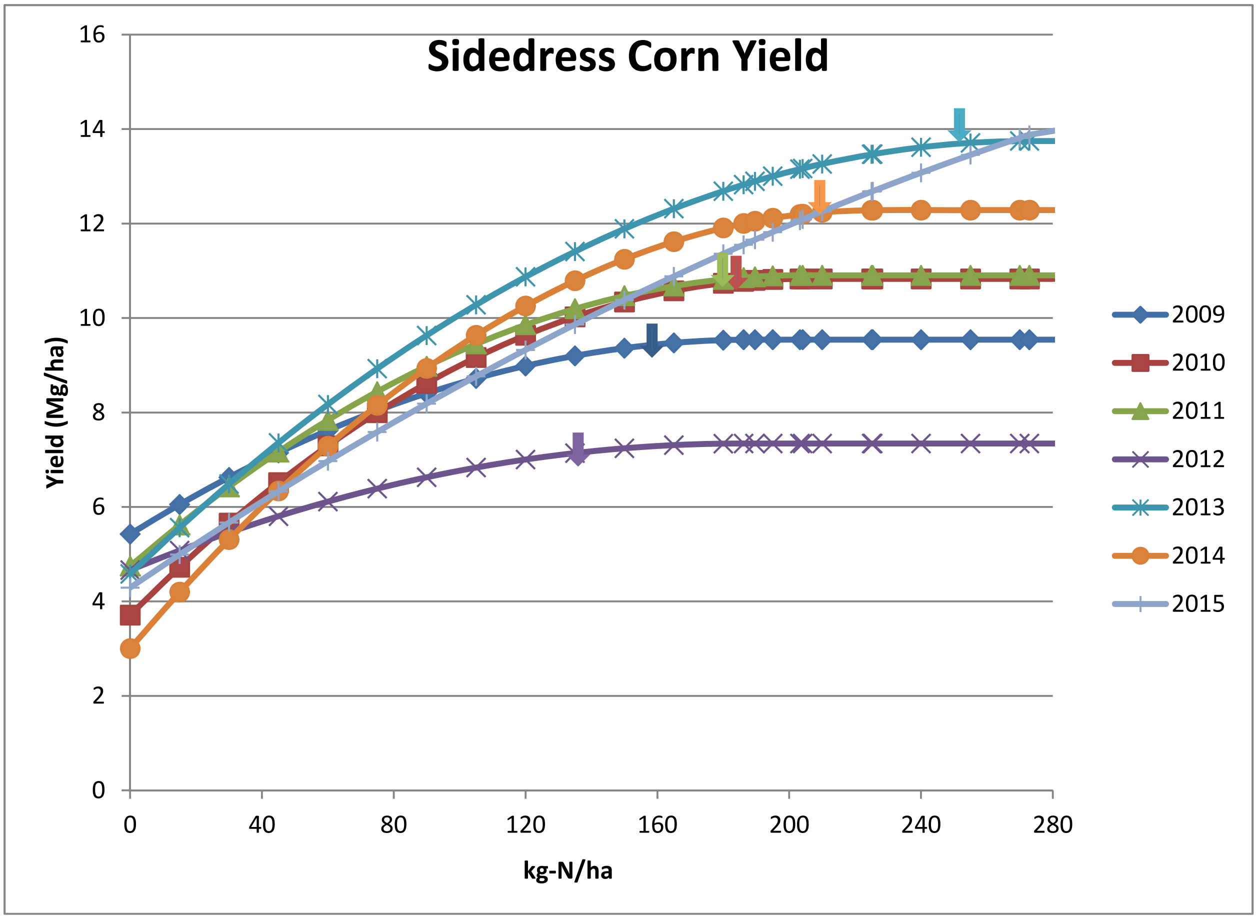


Figure 2. Grain corn yield response to rate of sidedress fertilizer N at Elora (2009-2015). The arrow associated with each response curve indicates MERN at a Nitrogen:Corn price ratio of 8.1. Response curves without an arrow had calculated MERN that exceeded 270 kg-N/ha.



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
	2014	224	203
	2015	260	260
	Average	203	193
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
	2014	12.3	12.2
	2015	12.4	13.6
	Average	10.9	11.1
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
	2014	7.2	6.9
	2015	7.3	7.9
	Average	5.2	5.1
Net Return ($/ha)			
	2009	328.72	313.28
	2010	692.28	684.70
	2011	640.65	563.73
	2012	150.41	147.80
	2013	951.87	962.02
	2014	993.23	971.27
	2015	962.18	1070.79
	Average	674.19	673.37
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
	2014	37.0	39.7
	2015	31.7	34.4
	Average	28.7	30.0

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 N recommendations and associated yield increases, net returns and potential losses at a Nitrogen:Corn price ratio of 8.1. The General N recommendation each year at planting was 153 kg-N/ha and at sidedress was 128 kg-N/ha.

Parameter		Planting	Sidedress
Gen Rec Yield (Mg/ha)			
	2009	9.3	9.1
	2010	9.9	9.9
	2011	10.3	10.1
	2012	7.2	7.1
	2013	11.6	11.2
	2014	10.9	10.6
	2015	10.0	9.6
	Average	9.9	9.6
Gen Rec Return ($/ha)			
	2009	327.08	299.51
	2010	604.48	603.61
	2011	590.59	502.17
	2012	144.64	147.36
	2013	786.52	689.48
	2014	859.43	789.23
	2015	694.86	559.49
	Average	572.52	512.98
Gen Rec Loss ($/ha)			
	2009	-1.64	-13.77
	2010	-87.79	-81.08
	2011	-50.06	-61.56
	2012	-5.77	-0.43
	2013	-165.36	-272.54
	2014	-133.80	-182.04
	2015	-267.32	-511.30
	Average	-101.68	-160.39

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.

Appendix 3. Yearly summary of planting and sidedress legacy versions of the Ontario soil N-test N recommendations and associated yield increases, net returns and potential losses at a Nitrogen:Corn price ratio of 8.1.

Parameter		Planting	Sidedress
Legacy N Test Rec (kg-N/ha)			
	2009	128	130
	2010	125	141
	2011	139	119
	2012	120	106
	2013	151	138
	2014	152	152
	2015	122	158
	Average	134	135
Legacy N Test Yield (Mg/ha)			
	2009	9.0	9.1
	2010	9.2	10.2
	2011	9.9	9.8
	2012	6.9	6.9
	2013	11.6	11.5
	2014	10.9	11.3
	2015	9.0	10.6
	Average	9.5	9.9
Legacy N Test Return ($/ha)			
	2009	321.86	301.28
	2010	517.01	639.26
	2011	556.05	476.25
	2012	148.12	137.49
	2013	780.65	735.55
	2014	855.96	886.46
	2015	557.49	698.06
	Average	533.88	553.48
Legacy N Test Loss ($/ha)			
	2009	-6.86	-12.00
	2010	-175.26	-45.44
	2011	-84.60	-87.49
	2012	-2.29	-10.30
	2013	-171.22	-226.47
	2014	-137.27	-84.82
	2015	-404.69	-372.73
	Average	-140.32	-119.89

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.