UPDATING GENERAL FERTILIZER NITROGEN RECOMMENDATIONS FOR CORN IN ONTARIO

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Abstract

Corn yield response data from field trials conducted over the past 40 years which evaluated yield response to fertilizer nitrogen (FN) in Ontario were compiled and reanalyzed in order to update general FN recommendations for corn in Ontario. The primary objectives of the reanalysis were to 1) determine the impact of the quadratic plateau model on FN recommendations and 2) develop a set of general recommendations that are free of adjustments based on geographical regions. The new proposed recommendations are based on fitting the quadratic plateau response model because, especially for sites with low FN requirements, the quadratic plateau model explained greater variability in yield response to FN than did the traditional "normal" quadratic model. For the dataset as a whole, fitting the quadratic plateau model reduced predicted economic fertilizer N rates by 20 kg-N/ha (13%) compared to those derived from the quadratic response model. Inclusion of Ap horizon soil texture and heat unit rating into the new proposed general recommendation model explained the geographical (or regional) differences that exist in the current general recommendations. The proposed general recommendations predict FN requirements based on 1) average historic yield, 2) previous year crop, 3) Ap horizon soil texture, 4) long-term heat unit rating, 5) timing of fertilizer N application and 6) the ratio of fertilizer N cost to the value of grain corn.

Introduction

General fertility recommendations, in order to be effective, have to be based on easily definable parameters that are not perceived to be arbitrary in nature. Recommendations that are either complicated and (or) perceived to be arbitrary, will not gain widespread acceptance.

Current general FN recommendations for corn in Ontario are based on the division of the province into three geographical regions, within which FN recommendations are based on different FN rate adjustments attributed to average historic yield, previous crop and timing of FN application (OMAF Staff, 2002). These recommendations became especially controversial when initial drafts of nutrient management legislation suggested that significant differences in allowable FN application rates would be imposed based on county boundaries. For example, current general recommendations for corn grown following soybeans with an expected yield of 9 Mg/ha suggest that allowable FN rates differ by as much as 80 kg-N/ha among regions. Although subsequent drafts of nutrient management legislation have provided mechanisms that minimize regional differences in allowable FN rates; Ontario is still left with a set of general FN recommendations that are ignored by many corn producers because of a perception that they are arbitrary, derived principally from university research stations and cannot be defended as representing actual on-farm requirements.

The accuracy of general FN recommendations can also be affected by the choice of yield response model utilized to interpret yield response data. Over the past few years, the quadratic plateau response model has been promoted as providing lower, and perhaps more representative, estimates of actual FN requirements when compared to the traditional "normal" quadratic response model (Bullock and Bullock, 1994; Cerrato and Blackmer, 1990).

The primary objectives of this study were to 1) reanalyze historic data using both the quadratic plateau and "normal" quadratic models in order to determine which more consistently provided better estimates of FN requirements and 2) utilize the results of the reanalysis of historic data to develop a new set of general FN recommendations for corn which are less complicated and free of geographical (or regional) considerations.

Approach

Available corn yield response data to application of FN from historic, as well as currently on going, field trials conducted in Ontario were collected and reanalyzed in order to ensure that all data was subjected to the same response fitting routines. Since one of the primary objectives was to fit different response models, only historic research projects that documented actual yield responses to FN application could be utilized. Also, the yield data must have originated from a replicated trial. Attempts were made to also collect the cropping history (at least the previous year), primary tillage system, timing and method of FN application, form of FN applied, Ap horizon soil texture, long-term heat unit rating, and location of trial. The long-term heat unit rating is based on the Ontario Crop Heat Unit rating system (Brown and Bootsma, 1993).

Acceptable yield response data must have included at least four rates of FN with the lowest rate being 0 (not including FN which may have been part of a starter fertilizer which was applied to all treatments) and the highest rate must have exceeded current recommended rates (OMAF Staff, 2002). For many field trials, a starter fertilizer that contained N was uniformly applied across the whole experimental area (including the check treatment), but the rate of N rarely exceeded 30 kg-N/ha. The starter and treatment rates of N were added together, and these combined (total) rate values were utilized to develop the yield response curves. If the lowest total FN rate applied exceeded 40 kg-N/ha (including the starter N), then the yield response was not included in the development of general recommendations.

Yield data was fitted to linear and "normal" quadratic response models using the GLM procedure of SAS ver 8.2 (SAS Institute, Cary NC). Yield data was fitted to the quadratic plateau model using the NLIN procedure of SAS.

The development of the proposed general recommendations was based upon deriving the Maximum Economic Rate of Nitrogen (MERN) for curvilinear responses from the quadratic plateau model for a situation where the value of FN is five times higher than the value of corn (on a mass basis). Allowable MERN values ranged from 0 to the highest FN rate applied plus the average FN interval. If calculated MERN exceeded the highest FN rate plus the average FN rate interval, then MERN was set to equal the maximum FN rate plus the average FN interval. For linear responses (i.e. identified by a fitted quadratic response which does not attain a maximum FN value), MERN was set to equal the highest FN rate applied provided that the rate of yield increase exceeded 5 kg for every kg of FN applied. Otherwise MERN was set to the lowest FN rate applied. Maximum Economic Yield (MEY) was calculated by substituting the MERN value into the appropriate response model.

Subsets of the dataset were tested where comparisons of tillage utilized to establish corn, previous crop, form of FN and timing of FN application were evaluated within the same experimental site in order to determine if these parameters should be used in development of general recommendations. It was eventually determined that form of FN did not contribute significantly to FN requirements and tillage utilized to establish corn had significant effects only following red clover cover crop established following small grains. Within these sites, multiple MERN and MEY estimates attributed to evaluation of multiple forms of FN and tillage (except following red clover cover crop) were averaged to a single pair of values. The tillage effect following red clover cover crop was incorporated into the proposed general recommendations by creating two distinct previous crop adjustments following red clover cover crops based on if corn was planted with, or without, tillage.

The effect of MEY, previous crop management, timing of N application, long-term heat unit rating and Ap Horizon soil texture on MERN was determined by conducting an analysis of variance using the mixed procedure of SAS. Site-year was considered a random effect. MEY was considered to provide an estimate of expected yield. Previous crop adjustments (credits) were indexed relative to grain corn and were derived by subtracting the various MERN estimates for the previous crops from the estimate for grain corn. The previous crop MERN estimates were calculated based on MEY and long-term Crop Heat Units set to the database average, the soil was a silt loam and FN was applied pre-plant.

Ap soil texture effects were developed by first dividing soils into two groups based on their apparent ammonium fixing capability. Certain soil series from Eastern Ontario have been identified as having a relatively "high" ammonium fixing ability because of relatively high vermiculitic clay contents (Drury and Beauchamp, 1991; Drury et al., 1989). These soils with "high" ammonium fixing ability were shown to also release greater quantities of fixed N as free ammonium concentrations were depleted. Initial analysis of the data did indicate that soils of Eastern Ontario had lower apparent FN requirements when compared to the rest of the province. This may, in part, be attributed to these soils inherent ability to fix greater amounts of recently applied ammonium and then release this fixed N when corn demand is high. The Ap soil texture for soils of Eastern Ontario were mostly either clay loam or sandy loam, so soil adjustments specific to Eastern Ontario were developed based on two soil categories called sandy or clay textured.

For soils considered to have "normal" fixing ability, adjustments based on Ap horizon texture were developed by including the actual sand and clay content into the regression analysis. For sites where only the soil texture name was known, average clay and sand percentages were assigned based on texture name averages for Ontario obtained from the National Soil Database (http://sis.agr.gc.ca/cansis/procedures/texture.html).

The Ap horizon soil adjustment is indexed relative to a silt loam textured soil of "normal" fixing capability and was calculated in a manner similar to how previous crop adjustments were derived.

In order to characterize the sidedress credit, as a proportion of the preplant rate, a regression analysis was conducted where the size of reduction in sidedress N requirement (Preplant MERN subtract Sidedress MERN) was regressed on actual observed preplant MERN. The regression model utilized also accounted for differences in yield associated with the various preplant and sidedress MERN (Preplant MEY subtract Sidedress MEY) and the sidedress credit was constrained to equal 0 when the preplant application rate is 0).

The recommended FN adjustment based on changes in the value of FN relative to corn was derived by calculating the MERN for various price ratios using the first derivative of the quadratic plateau response equations. The price ratio represents the value of FN relative to the value of corn (i.e. FN Value/Corn Value) on a mass basis. The change in MERN for a 1-unit change in price ratio was calculated for each quadratic plateau yield response and then they were averaged to obtain the price ratio adjustment value.

Summary

Choice of Yield Response Model

Development of the proposed general recommendations was based on 890 yield response datasets. At a number of sites, multiple MERN and MEY estimates were attributed to evaluations of multiple forms of FN and tillage utilized to establish corn. It was determined that form of FN and tillage (except following red clover cover crops established following small grains) did not significantly affect FN requirements. So, MERN and MEY were averaged within these sites. Similarly, at sites where multiple hybrid response was evaluated, MERN and MEY were also averaged. After averaging, the proposed general recommendations are based on 599 MERN and MEY values; over 80% of which were obtained from experiments conducted on actual production farm fields.

The quadratic plateau model was utilized to identify MERN and MEY for yield responses characterized as curvilinear because, on average, the quadratic plateau model explained greater variability then did the "normal" quadratic model. This was especially true when the quadratic plateau model predicted the maximum FN response rate to be less than half of the highest FN rate applied (n=168), where the amount of variability explained by the quadratic plateau model was 7% higher and average MERN (Nitrogen:Corn Price Ratio (PR)=5) was reduced by 40 kg-N/ha. Averaged over all curvilinear responses, MERN according to the quadratic plateau model was 20 kg-N/ha less than those predicted by the "normal" quadratic model.

Development of Timing of FN Application Adjustments

Sidedress application of FN was usually associated with lower MERN than when applied preplant, with a tendency for application timing effects to increase as Ap horizon sand content decreases. By grouping soils into 3 categories, based on their sand content, the majority of the texture effect on MERN response to application timing was explained. The 3 sand categories are described as 1) High, which includes the sand and loamy sand soils (sand content >70%); 2) Intermediate, which includes the sandy loam, sandy clay and sandy clay loam soils (sand contents of 45-70%) and 3) Low, which includes all soils which do not have sand in their texture name (Sand content <45%). Within these soil groupings, average MEY was not affected by application timing.

A regression analysis indicated that the sidedress credit (preplant-sidedress MERN), expressed as a proportion of preplant MERN, was -0.07 (se=0.115, P=0.5523) for High sand soils; 0.12 (se=0.063; P=0.0511) for Intermediate sand soils, and 0.20 (se=0.051; P=0.0002) for Low sand soils. Therefore, the recommended sidedress rates, expressed as a proportion of preplant recommendations, are suggested to be 1.0 on High sand soils, 0.9 on Intermediate sand soils and 0.8 on Low sand soils.

Development of Expected Yield, Previous Crop, Soil Texture and Heat Unit Adjustments

The regression model utilized to develop the proposed General Recommendations explained 32.6% of the observed variability in MERN. At a nitrogen: corn price ratio of 5, the average MERN was 123 kg-N/ha and MEY was 8.24 Mg/ha.

Maximum Economic Yield explained 9.8 percent of the total variability in observed MERN. Fitting a non-linear response did not explain additional variability. When the various other parameters (previous crop, soil texture, long-term heat unit rating and application timing) are entered into the regression model, MERN is predicted to increase by 0.0136 kg-N/kg-Grain Corn/ha (se=0.00158).

As expected, MERN was affected by previous year crop. After accounting for MEY, previous year crop explained an additional 12.7% of total variability in MERN. Some of the more significant crop adjustments (indexed relative to following grain corn) are: 30 kg-N/ha reduction in requirements following soybeans and 82 kg-N/ha reduction in requirements following a red clover plow down crop which was interseeded into small grains (refer to Table 1 for all proposed crop adjustments).

MERN values were also influenced by location in the province and soil texture. The primary factors used to characterize the size of regional and soil texture adjustments were 1) long-term Crop Heat Unit (CHU) rating, 2) soil texture of the Ap horizon and 3) soils with relatively high N fixing capabilities in Eastern Ontario. Soil texture and long-term CHU rating (combined) explained 9.0% of the total variability in MERN, after accounting for yield and previous crop effects.

MERN values tended to be higher in regions with higher long-term CHU ratings. The MERN adjustment is 0.041 kg-N/CHU/ha (se=0.0147).

For soils with "normal" N fixing capacity a relationship between observed MERN and the clay and sand content was developed as follows:

$$SAdj=(1.15*Clay)+(0.62*Sand)-(0.0126*Clay*Sand)-24.9$$

where
SAdj is soil adjustment relative to silt loam (kg-N/ha)
Clay is clay (%)
Sand is sand (%)

In general, MERN requirements are the lowest for silt loam soils and tend to increase as either the clay or sand content increases (Table 1). Relative to silt loam soils, MERN recommendations are increased by a little over 30 kg-N/ha for both sandy and clay soils. The soil adjustments by texture name were derived by using the appropriate Ap horizon clay and sand content averages for Ontario obtained from the National Soil Database.

The dataset for the "high" N fixing soils of Eastern Ontario was mostly limited to soils of either a sandy loam or clay loam texture. When indexed relative to silt loam soils of "normal" fixing capacity, MERN recommendations are reduced by 19 kg-N/ha on clay textured soils (Table 1). The MERN recommendations for sandy textured soils with "high" N fixing capacity are essentially the same as the silt loam soils with "normal" N fixing capacity.

Table 1. Previous crop and soil texture adjustments for the proposed general FN recommendations. A negative value indicates that the FN requirement is reduced.

Previous Crop		Soil Texture	
	Kg-N/ha	Normal N Fixing	Kg-N/ha
Grain Corn	0	Silt loam	0
Silage Corn	-14	Loam	12
Soybeans & Edible Beans	-30	Silty Clay loam	16
Small Grains	-12	Clay loam	20
Small Grain, Underseeded Clover tilled	-82	Silty Clay	29
Small Grain, Underseeded Clover No-till	-67	Clay	33
Established Forage (Over 2/3 Legume)	-110	Sandy Clay loam	23
Established Forage (1/3 to 2/3 Legume)	-55	Sandy loam	18
Forage Grass (Less 1/3 Legume)	0	Loamy Sand	26
		Sand	32
		High N Fixing	
		Clay textured	-19
		Sandy textured	-1

Fertilizer Nitrogen and Grain Corn Price Adjustments

The relative value of FN relative to value of grain corn does have minor effects on MERN recommendations. Analysis of the Quadratic plateau response curves suggested that MERN decreases by 7 kg-N/ha for a 1-unit increase in nitrogen:corn price ratio.

Maximum Economic Rate of Nitrogen Prediction Equation

The base prediction equation for the proposed general recommendations is:

MERN=(SDAdj(0.0136(EY)+0.041(CHU)+CROPAdj+SOILAdj+7(5-PR)-88.7)

Where

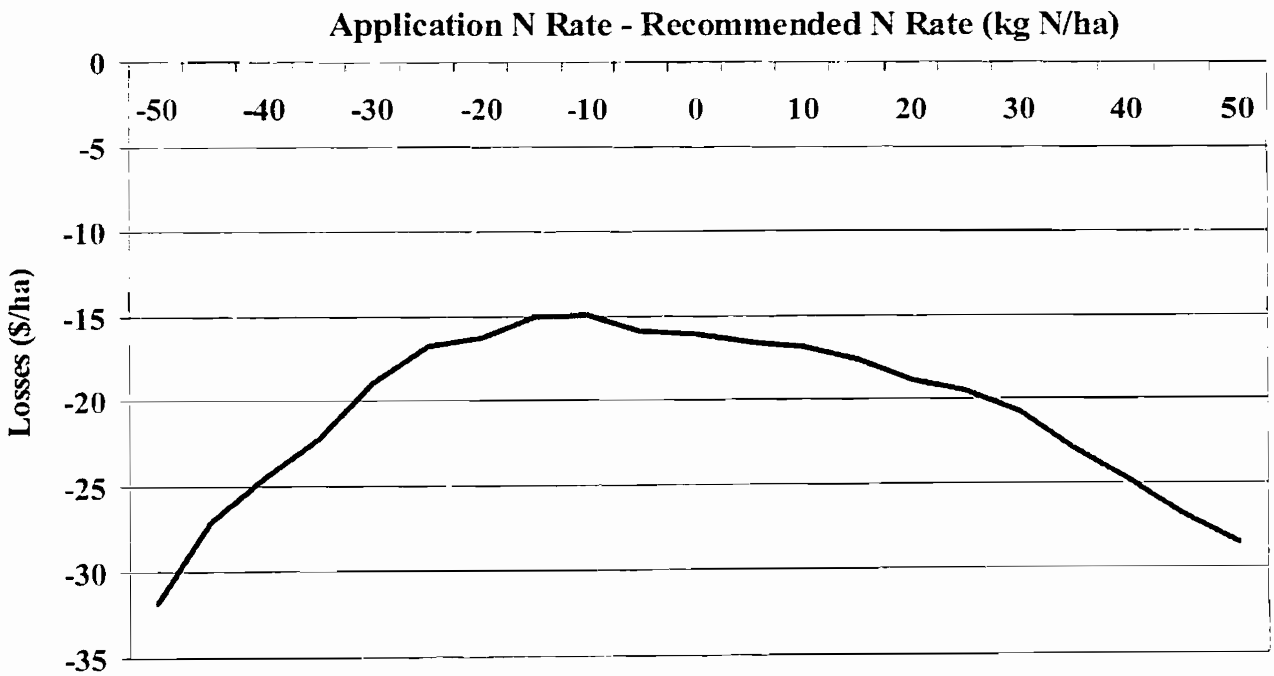
MERN is the predicted N requirement (kg-N/ha)
SDAdj is the soil texture specific sidedress adjustment ratio
EY is expected yield (Kg/ha)
CHU is the long-term Ontario Crop Heat Unit Rating
CROPAdj is the previous crop credits (indexed relative to grain corn)
SOILAdj is the soil texture adjustments (indexed relative to silt loam)
PR is the nitrogen:corn price ratio

Model Accuracy and Profitability

Testing of model predicted FN requirements, against those actually required (i.e. MERN), indicated that average deviations for the various previous crops, timing of FN application and soil texture categories did not differ from 0. Also, the deviations within each of the three regions utilized by the current recommendations do not significantly differ from 0; suggesting that the soil and long-term heat unit adjustments in the proposed general recommendations are appropriate substitutes for the regional adjustments present in the current recommendations.

A financial analysis, based on a corn price of $117.90/Mg ($3.00/bu) and a FN cost of $0.59/kg-N ($0.27/lb-N) indicated that for most previous crop, soil type and timing of FN application categories that the average loss associated with following the proposed recommendations was less than $30.00/ha ($12.00/ac) and the median loss was usually less than $25.00/ha ($10.00/ac) (data not shown). Financial loss calculations are based on calculating, for each response curve, the difference between estimated profit for the general recommended rate and the FN rate associated with maximum profit (MERN). Also, when the dataset was considered as a whole, application of FN rates other than those recommended did not improve profitability. Figure 1 shows the median losses associated with applying FN rates both higher and lower than those recommended. This graph illustrates that median losses were not lowered by adopting a practice of applying FN in excess of recommendations (i.e. an "insurance" N rate).

Figure 1. Median financial losses associated with fertilizer nitrogen application at rates surrounding the general recommended rate. 418 site/year comparisons for corn following corn, soybeans or winter wheat.



At recommended FN rates, the median financial loss for the dataset as a whole was about $16.00/ha ($6.4/ac). This suggests that for half of the observations more accurate FN predictions would not increase profitability by more than $16.00/ha ($6.40/ac). It should be noted that 10% of the observations have financial losses associated with following the proposed general recommendations which exceed $54.30/ha ($22.00/ac), with over-recommendation of FN accounting for 25% of these occurrences. Also, occurrences of relatively large financial losses due to under recommended FN were disproportionately high for clay textured soils.

The financial analysis implies that improvement in profitability through more accurate FN recommendation systems, than those provided by the proposed general recommendations, may occur only if additional costs (soil sampling, N tests, site specific management, etc.) are minimal. In Ontario, the clay textured soils were associated with a disproportionately high occurrence of relatively large financial loss, suggesting that for these soils further refinement of the proposed general recommendations may be necessary and(or) higher cost FN recommendation strategies may be warranted.

Reanalysis of the data with an assumed relative FN cost which was doubled (i.e. nitrogen:corn price ratio of 10) resulted in estimates of adjustments for expected yield, previous crop, soil texture and timing of FN application which remained essentially the same as those derived using a Nitrogen:Corn price ratio of 5. This suggests that the FN recommendations proposed by the model are stable across the range of FN costs and corn prices likely in the foreseeable future.

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