NITROGEN RESPONSE IN HIGH-YIELDING CORN SYSTEMS OF NEBRASKA

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ABSTRACT

Irrigated corn was grown at five different N levels in 34 environments in Nebraska to (1) evaluate the performance of the existing UNL N recommendation algorithm for corn at high yield levels and (2) add adjustments to the N recommendation to account for different application times and varying corn and nitrogen prices. At most sites, maximum corn yields were in the 210 to 275 bu/acre range. Average yield without N application was 166 bu/acre, but ranged from 90 to 247 bu/acre. Yield response to N application varied widely in corn following corn or corn following dry bean (CC), whereas response curves for corn following soybean (CS) were similar in shape and optimal N rates. At a corn (\$/bu) : N (\$/lb N) price ratio of 10:1, average economically optimal N rates (EONR) were 155 lb N/acre for CC (CV=39%) and 120 lb N/acre for CS (CV=23%). EONR declined to 112 lb N/acre for CC and 92 lb N/acre for CS when the corn : N price ratio decreased to 5:1. The current UNL N recommendation equation for corn was closest to the performance of the EONR at corn : N price ratios of about 8 to 10:1. Two additional coefficients were added to the UNL equation that allow producers to adjust the recommended N rate according to different timing of N application (e.g., fall, pre-plant, split) and to the actual corn : nitrogen price ratio. The new recommendation was implemented in a user-friendly spreadsheet software, which can be obtained at soilfertility.unl.edu.

RATIONALE AND OBJECTIVES

The University of Nebraska’s algorithm for estimating N fertilizer recommendations in corn predicts the amount of N needed as a function of crop N required for achieving a certain yield goal (expected yield), soil organic matter (SOM), nitrate content in the soil profile, and other N credits such as previous crop, manure and irrigation (Shapiro et al., 2003):

N-rate (lb/acre) = 35 + (1.2 EY) – (0.14 EY x SOM) – (8 NO_3-N)– other N credits

EY = expected yield (bu/acre), e.g., 5-year average yield + 5%

NO_3-N = root zone soil residual nitrate-N in 2-4 ft depth, depth-weighted average (ppm)

SOM = soil organic matter content in 0-8” depth (%)

The coefficients in this equation were derived from regression analysis of 81 site-years of N rate experiments conducted on irrigated and rainfed land during 1976 to 1982. On-farm demonstrations have generally shown good performance of this N algorithm, but there are also situations where it over- or under-estimates N needs for maximizing profit (Ferguson et al., 1991). It also remained uncertain whether the N recommendation would work well for yields that approach irrigated corn yield potential, which for most parts of Nebraska ranges from about 200 to 300 bu/acre (Dobermann et al., 2003; Dobermann and Shapiro, 2004). In the original N response trials, most sites were located in eastern Nebraska, the data set included 30 dryland sites with lower yields, and no yield response to N was observed for 40 of the 81 site-years due to high soil or irrigation water nitrate contents and various constraints to high yields. Yields averaged 153 bu/acre for irrigated corn and 102 bu/acre for dryland corn. Since then, corn hybrids have changed, yields have continued to rise at an average rate of 1.7 bu/acre per year, crop management practices have improved, and fertilizer-N use efficiency in corn has increased substantially (Dobermann and Cassman, 2002). It is likely that these trends have also led to lower residual soil nitrate levels than observed in the 1970s and 1980s. Likewise, the corn ($/bu) to nitrogen ($/lb N) price ratio has decreased from 15-20:1 in the 1980s to less than 10:1 in recent years, but this change is not accounted for in the existing N recommendations.

In 2002, a three year study was initiated to review current fertilizer recommendations for irrigated corn in Nebraska, focusing primarily on nitrogen (N), phosphorus (P) and potassium (K) recommendations. Specific objectives discussed here are to (1) quantify the yield response of corn to N at high yield levels, (2) evaluate the performance of the existing fertilizer recommendations for corn, (3) modify the UNL N algorithm to better account for timing of applications and prices, and (4) develop improved software tools for nutrient management.

MATERIAL AND METHODS

Nutrient response trials were conducted from 2002 to 2004 for a total of 34 site-years. In each calendar year, trials included 11-12 locations throughout different agroecological zones of Nebraska, including most major irrigated corn areas. Of the 34 site-years, 13 were on research stations and 21 in producers' fields. The data set included 11 no-till sites, 9 with ridge-till and 14 with conventional tillage (disk or chisel plow). At 16 sites corn was grown following corn, at 13 corn followed soybean, and at five sites in Western Nebraska corn followed dry bean. For the purpose of this analysis, corn following corn and corn following dry bean were combined into one category called continuous corn (CC), which is compared with corn-soybean rotation (CS).

Initial soil fertility characteristics varied widely among the sites (Table 1). About 40% of the sites had soil test P levels below the currently recommended critical levels, but only two sites had available soil K levels below 125 ppm K. Five nitrogen rates were tested at each site, with rates varying between CC and CS and also slightly between years. Nitrogen rates in CC were 0, 100 or 125, 150 or 175, 200 or 225, and 300 lb N/acre. In CS, rates were 0, 50 or 75, 100 or 125, 150 or 175, and 250 lb N/acre. All treatments received blanket doses of 41 lb P_2O_5/acre and 43 lb K_2O/acre. Individual plots were typically 20 ft wide and 50 ft long arranged in a randomized complete block design with four replications at each site. Fertilizer was broadcast either with small plot drop spreaders or by hand. Forty to sixty percent of N was applied pre-plant, with the remainder sidedressed at V6-V10. Fertilizer sources common to all sites were ammonium nitrate (34-0-0), triple superphosphate (0-46-0) and muriate of potash (0-0-60). No starter fertilizer was used. Final plant populations were typically in the 28,000 to 32,000 plants/acre range. All locations were irrigated. Other cultural practices (cultivation, herbicides and insecticides) were managed by the cooperator at each site. Hybrids used ranged in maturity from 2300 to 2860 GDD (base temperature of 50 degrees F) and were adapted to the areas grown. Yield was determined by hand-harvesting a subarea within each plot (2 rows × 20 ft length) at physiological maturity.

Grain yield (bu/acre) was plotted against nitrogen rate (lb N/acre) and two different response functions were fitted to each data set. For each model, the economically optimal N rate (EONR, lb N/acre) needed to achieve maximum net return from N application was calculated based on mathematical differentiation of the fitted equations for a range of different corn : N price ratios (R) going from 20 to 3:1. Corn price was held constant at $2/bu, whereas N price ranged from \$0.10 to \$0.67 per lb N. For each site year, the average EONR was calculated for each price ratio as the average of the two models fitted. The two response functions used were:

(1) Exponential rise to a maximum (modified Mitscherlich equation):

$$Y\text{ (bu/acre)} = a + b\,(1 - e^{-cN})$$

$$\text{EONR (lb N/acre)} = \frac{1}{-c}\ln\left(\frac{1/R}{bc}\right) \quad \text{for} \quad \frac{1}{-c}\ln\left(\frac{1/R}{bc}\right) > 0$$

$$= 0 \quad \text{for} \quad \frac{1}{-c}\ln\left(\frac{1/R}{bc}\right) \le 0$$

a = yield without N application
b = maximum yield increase from applying N (ΔY at max N rate)
c = curvature parameter
N = N rate (lb N/acre)
R = ratio corn price (\$/bu) : N price (\$/lb N)

(2) Spherical model (linear + nonlinear rise to a plateau):

$$Y\text{ (bu/acre)} = a + b\left\{\frac{3N}{2c} - \frac{1}{2}\left(\frac{N}{c}\right)^3\right\} \text{ for } 0 \le c$$

$$= a + b \quad \text{for} \quad 0 > c$$

$$\text{EONR(lb N/acre)} = \sqrt{\frac{1.5bc^2 - \frac{c^3}{R}}{1.5b}} \quad \text{for} \quad \left(1.5bc^2 - \frac{c^3}{R}\right) > 0$$

$$= 0 \quad \text{for} \quad \left(1.5bc^2 - \frac{c^3}{R}\right) \le 0$$

a = yield without N application
b = maximum yield increase from applying N (ΔY at max N rate)
c = N rate at which maximum yield occurred

Table 1. Initial soil properties, yields without N, P, or K fertilizer, and maximum corn yields achieved in the 34 site-years in Nebraska, 2002-2004.

	Average	Min.	Max.	
SOM, 0-8” (%)	2.3	0.7	3.4	
pH-water, 0-8”	6.5	4.8	8.1	
Bray-P, 0-8” (ppm)	24	5	84	13 <= 15 ppm
Olsen-P, 0-8” (ppm)	14	3	44	16 <= 10 ppm
Available K, 0-8” (ppm)	432	93	696	2 < 125 ppm
Soil nitrate-N, 0-4 ft (ppm)	4.4	0.8	8.9	10 >= 5 ppm
0-N yield (bu/acre)	166	90	247	
0P yield (bu/acre)	224	165	276	
0-K yield (bu/acre)	231	183	279	
Maximum yield (bu/acre)	233	182	275	14 > 240 bu

RESULTS AND DISCUSSION

Corn Yield Response to Nitrogen

The N response data collected represented conditions in which corn yields approached the climatic-genetic yield potential. Average maximum yield was 233 bu/acre. At most sites, maximum corn yields were in the 210 to 275 bu/acre range, including 14 site-years with yields greater than 240 bu/acre (Fig. 1, Table 1). Maximum yields of less than 210 bu/acre occurred for 7 of the 34 site-years and were caused by a range of management issues such as insect problems, acid pH in a sandy soil, insufficient irrigation, low plant population, cold damage at emergence, sulfur deficiency during early growth on a sandy soil, or slow maturing due to cold weather.

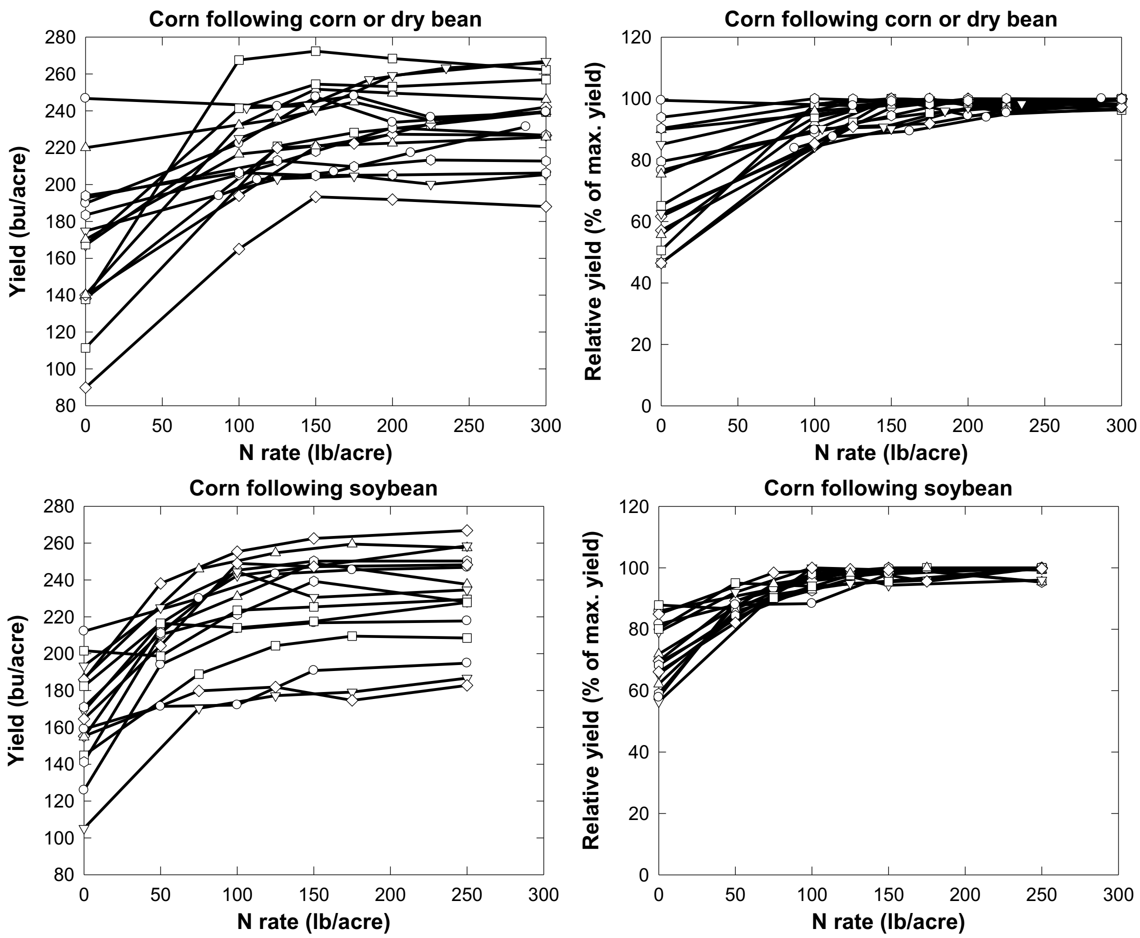
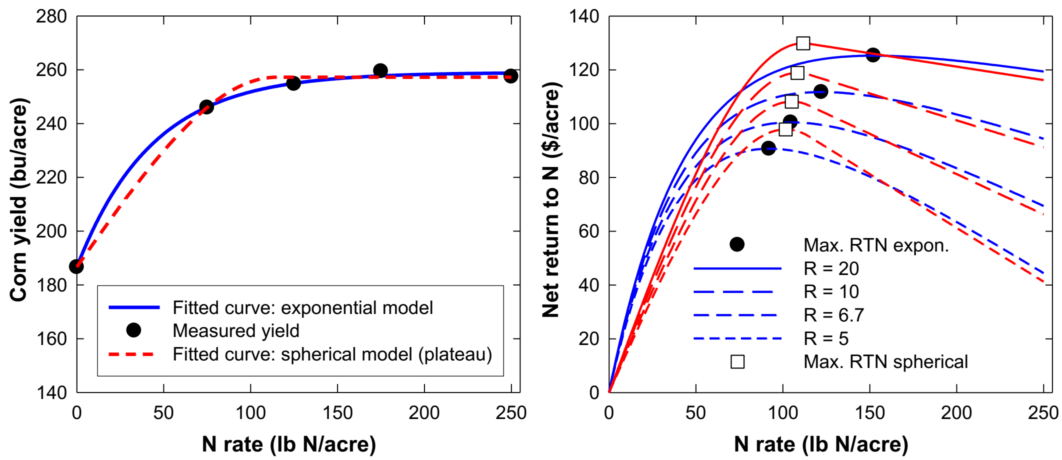


Figure 1. Variation in the yield response of irrigated corn to N application.

Yield response to N application varied widely in corn following corn or corn following dry bean (CC), whereas response curves for corn following soybean (CS) were generally similar in shape, despite differences in the 0-N and maximum yields (plateau) reached (Fig. 1). Overall, average yield without N application was 166 bu/acre, but it ranged from 90 to 247 bu/acre (Table 1). In CC, yield without N application ranged widely from 45 to 100% of the maximum yield measured (Fig. 1). In contrast, in CS, yield without N application was always within about 60 to 85% of the maximum yield, indicating greater uniformity of residual soil nitrate levels following soybean as well as more uniform response to N application in CS as compared to CC.

Economically Optimal Nitrogen Rate

Figure 2 shows an example of the two N response functions fitted to each data set. In general, both models fitted all data sets well, but they differ in shape and, therefore, in their sensitivity to price changes and the derived EONR. In this example, both models fitted the measured data very well, with R^2 values of 0.997 for the exponential model and 0.994 for the spherical model. However, because the exponential model is more gradual in shape, slowly approaching the maximum yield, it also results in a wider range of the EONR as the corn : N price ratio increases or decreases (Fig. 1). Since regression fit statistics alone made it difficult to justify choosing a single model as superior, we opted to always use both models and utilize the average EONR derived from both models in further statistical analysis and adjustment of N recommendations. This reduces potential errors associated with the choice of a particular model.



Corn/N ratio	Corn price $/bu	N price $/lb	EONR expon. lb N/ac	EONR spherical lb N/ac	EONR avg. lb N/ac
20	2.0	0.1	152	112	132
10	2.0	0.2	122	108	115
6.7	2.0	0.3	105	105	105
5	2.0	0.4	92	102	97

Figure 2. Yield response of corn following soybean at Clay Center, Nebraska, 2002, fit of the two response functions, and the EONR derived for different price ratios.

The relative value of corn has declined in recent years. During the 1975 to 1995 period, the corn ($/bu) : N ($/lb N) price ratio was in the 15 to 20:1 range. Since 1995, it has declined from 15:1 to about 7:1 in 2005 and even below that in recent months. Fertilizer recommendations are generally not very sensitive to price fluctuations within normal ranges, but the declining trend in the price ratio and the current low ratios of 5 or 6:1 warrant adjustments in recommended N rates to ensure profit maximization. The EONR generally declined with a decrease in the corn : N price ratio, particularly below ratios of about 8:1. Along with this the difference in EONR between CC and CS became smaller too (Fig. 3). At a price ratio of 10:1, average EONR was 155 lb N/acre for CC (CV=39%) and 120 lb N/acre for CS (CV=23%). EONR declined to 112 lb N/acre for CC and 92 lb N/acre for CS when the price ratio decreased to 5:1. The EONR varied less among sites in CS than in CC (see standard error bars in Fig. 3). These average EONR values are slightly below those reported for a large regional database of rainfed corn grown in other Corn Belt areas, which averaged 161 lb N/acre for CC and 140 lb N/acre for CS (Sawyer and Nafziger, 2005). Higher N use efficiency and hence lower EONR in our study was probably due to generally higher yield levels and split application of N (pre-plant + sidedress).

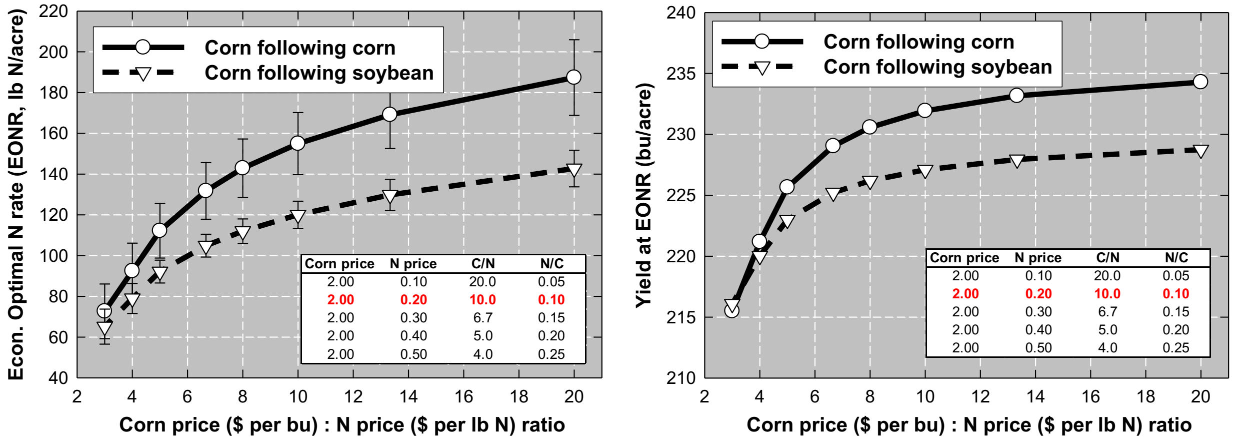


Figure 3. Influence of the corn : N price ratio on the economically optimal N rate (EONR) and irrigated corn yield obtained at the EONR (averages of 16 site-years for CC and CS each).

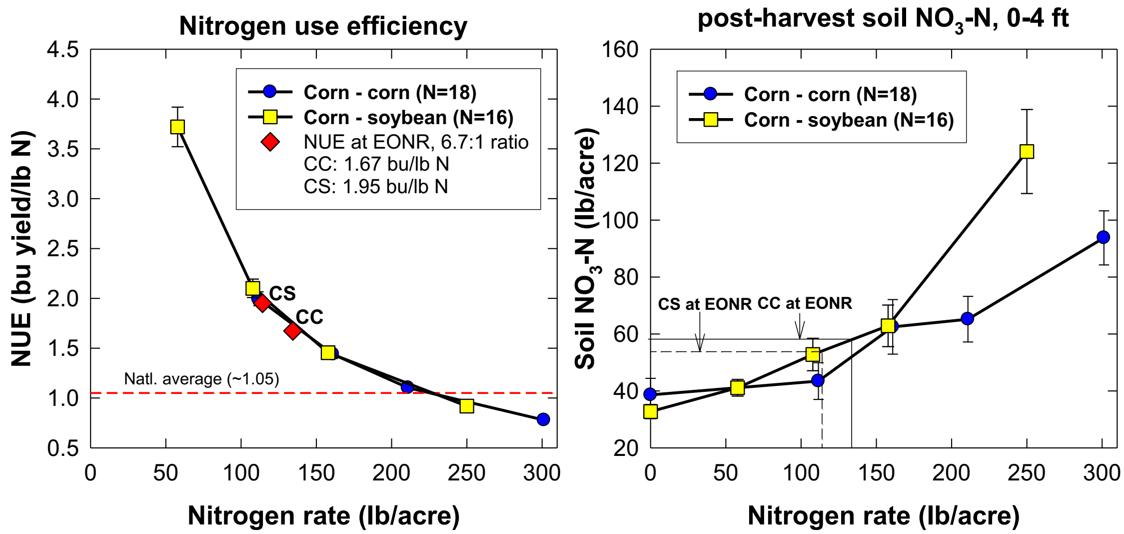


Figure 4. Nitrogen use efficiency (bu corn yield per lb N applied) and residual nitrate in the soil profile (0-4 ft depth) as affected by the amount of N applied to irrigated corn in Nebraska.

If N is managed at the site- and season-specific EONR, nitrogen use efficiency is high and residual soil nitrate levels remain low (Fig. 4). For irrigated corn in Nebraska, applying N at economically optimal rates for a 6.7:1 corn : N price ratio resulted in an average N use efficiency of 1.67 bu/lb N for CC or 1.95 bu/lb N for CS. This compares to an average N use efficiency in corn grown in the USA of about 1.05 bu corn per lb N applied (Dobermann and Cassman, 2002). Likewise, managing N at these optimal rates resulted in uniformly low post-season residual soil nitrate levels, which were generally in the 50 to 60 lb NO_3-N/acre range for a 4-ft deep soil profile (Fig. 4). In related research on managing high-yielding irrigated continuous corn and corn-soybean systems we have demonstrated that such high levels of N use efficiency can be maintained over longer periods and at very high yield levels (Walters et al., 2004). The requirement for this is that N recommendations are fine-tuned to site conditions and N is applied following Best Management Practices that focus on spring pre-plant application and sidedress application(s) at vegetative stages.

Performance of the UNL Nitrogen Algorithm

To evaluate the performance of the current UNL N recommendation equation in relation to the EONR, N rates, yields, and net return were calculated using the UNL N equation for each site. Site-specific input data for calculating the recommended N rate included (1) yield goal based on past yields and known site yield potential (Dobermann and Shapiro, 2004), (2) measured soil organic matter content (average of 40 samples, 0-8" deep), (3) measured residual soil nitrate in Spring (average of 20 soil cores, 0-4 ft deep), and (4) N credits for previous crop and N input from irrigation water. The calculated N rates were then plugged into the two N response curve fitted for each site, the predicted yields were averaged and used to calculate the net return from applying N for comparison with the EONR at different price levels.

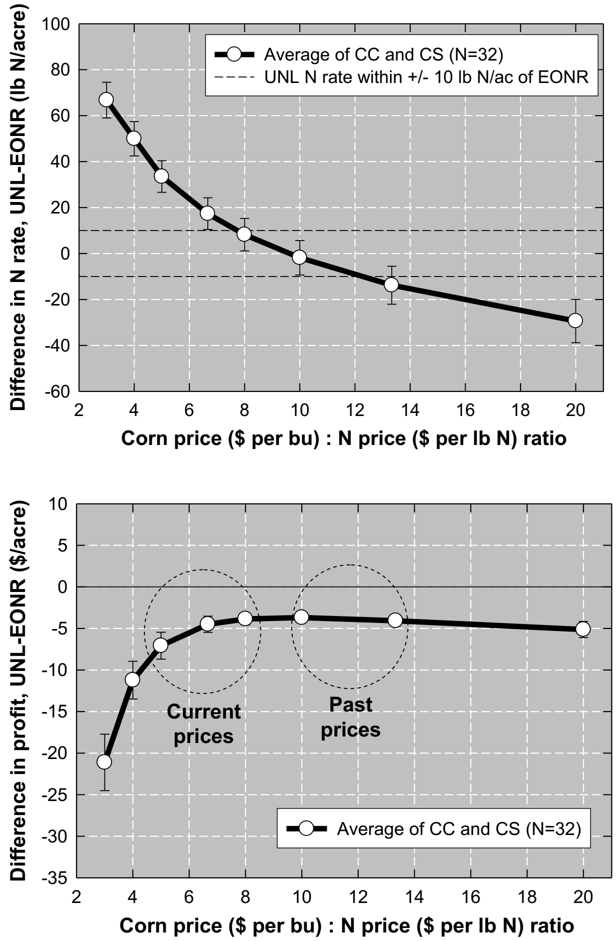


Figure 5. Performance of the original UNL N algorithm for corn in relation to the economically optimal N rate (EONR) fitted to each site-year. LEFT: Average difference between the N rate recommended by the UNL equation and the EONR; RIGHT: Average difference in profit between the N rate recommended by the UNL equation and the EONR.

The current UNL N algorithm performed well at price ratios that represented past conditions, but did not allow full profit maximization at low price ratios that have occurred in recent months. For example, at a corn : N price ratio of 10:1, the average difference between the UNL N rate and the EONR was only -2 lb N/acre, predicted UNL yield was within ±3 bu/acre at most sites, and the average profit with the UNL recommendation was 99.1% of the maximum profit (within 98.8 to 99.7% for 50% of all sites). On average, the recommended UNL N rate was within ± 10 lb N/acre of the EONR for corn : N price ratios of about 8 to 12:1, representing price scenarios that were typical for the late 1990s to early 2000s (Fig. 5). It exceeded the EONR by more than 10 lb/acre at low price ratios (expensive N) that represent current conditions. Likewise, the UNL N recommendation was closest to maximizing profit (maximum net return from applying N as estimated by the EONR) for price ratios of 8 to 10:1, but also stayed close to maximum profit at higher price ratios (Fig. 5). In contrast, large profit losses would occur when the unadjusted UNL recommendation was used at price ratios of less than 6:1.

These results suggest that, if it is correctly implemented (reasonable yield goal, good soil sampling and soil test results, full credits for previous crop, irrigation, manure), the current UNL N recommendation for corn results in profits that are close to the maximum profit for price scenarios in which corn is valued high relative to N. Adjustments of recommended N rates according to prices are of greatest importance in times when the price ratio is extremely low

Modification of the UNL Nitrogen Algorithm

As a first step towards revising the UNL N algorithm, we have added two new adjustment factors with which the recommended N rate is multiplied to (i) account for different time of N application and (ii) maximize profit at different corn : N price ratios:

N-rate (lb/acre) = [35 + (1.2 EY) – (0.14 EY x SOM) – (8 NO_3-N)– other N credits] × f_A × f_R

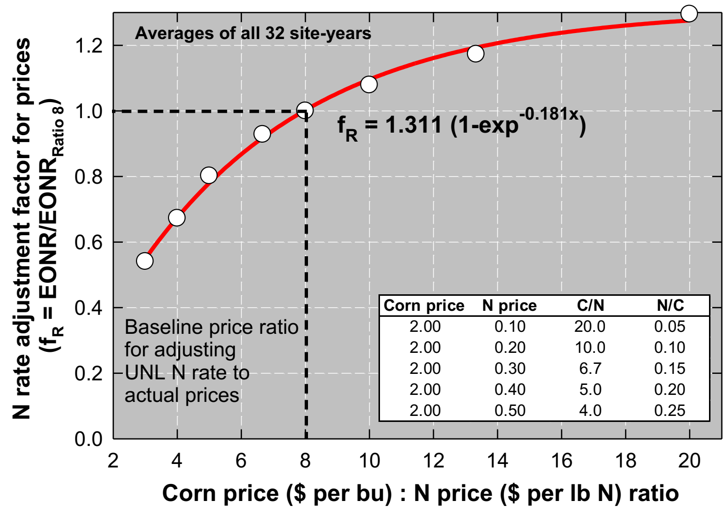
f_A = application timing adjustment factor

f_R = corn : nitrogen price ratio adjustment factor

The N response data (1976 to 1982) used to develop the coefficients in the original UNL N equation referred to experiments in which all N was applied in a single dose pre-plant or shortly after planting. Therefore, a small adjustment (f_A) of the recommended N rate is made to account for lower or higher N use efficiency depending on the time of application. If N is primarily applied through split application, N use efficiency is increased and the N amount can be decreased by about 5%. If N is primarily applied in fall, N use efficiency is lower and the N amount is increased by a 5% penalty. Mathematically, f_A is calculated as follows:

f_A = 0.95 IF sidedress + fertigation N is >=30% of total N applied (= mostly split N application)
f_A = 1.00 IF sidedress + fertigation N is < 30% of total N AND preplant N > fall N (=mostly preplant N)
f_A = 1.05 IF sidedress + fertigation N is < 30% of total N AND preplant N < fall N (=mostly fall N)

If the corn : N price ratio increases, more N should be applied to maximize profit; if the corn : N price ratio declines, less N should be applied to maximize profit (Fig. 3). By re-scaling EONR to the EONR for a baseline price ratio of 8:1, a price ratio adjustment factor (f_R) was derived for different levels of the corn : N price ratio. An exponential function was fitted to the relationship between f_R and price ratio, allowing to calculate f_R for any actual price ratio within a range of 3 to 20:1 (Fig. 6). A reference price ratio of 8:1 was chosen because it represented best the profit maximization performance of the current UNL equation (Fig. 5) and because it provides a relatively conservation adjustment of N rates, i.e., significant reductions in N rates are only recommended if the price ratio becomes very low (less than about 6:1).



Corn : N price	f_R
13	1.19
12	1.16
11	1.13
10	1.10
9	1.05
8	1.00
7	0.94
6	0.87
5	0.78

Figure 6. Derivation of the N rate adjustment factor to account for different corn : N price ratios (f_R) in the modified UNL N recommendations for corn. A corn : N price ratio of 8 : 1 was set as the baseline (f_R = 1.0) above or below which the N rate is increased or decreased, respectively.

Software Tools

Three new software tools have recently been released by the University of Nebraska:

- The **UNL Nitrogen Calculator for Corn**, which is an interactive spreadsheet for determining the most profitable rate of nitrogen fertilizer to apply and exploring different N management strategies. This software implements the modified N recommendation described above. Available at no cost at: soilfertility.unl.edu
- **Fertilizer Chooser**, a general software for translating a multi-nutrient recommendation into the correct amounts of different fertilizers needed and selecting an optimal combination of fertilizer nutrient sources based on quoted prices for fertilizer products and the cost of application. Available at no cost at: soilfertility.unl.edu
- **Hybrid-Maize**, a corn growth simulation model that allows to understand corn yield potential and explore how it can be maximized by changing crop management practices such as planting date, hybrid choice, plant population, or irrigation. Available for a small charge at: hybridmaize.unl.edu

CONCLUSIONS

In N response studies with high-yielding irrigated corn EONR was more variable for corn following corn or dry bean than for corn following soybean. The original UNL N algorithm performed well at yields that approached the genetic-climatic yield potential, but N rates must be adjusted to maximize profit in times of high N prices resulting in low corn : N price ratios. The variable yield and economic responses observed justify using a detailed N algorithm that includes yield goals, soil testing and accounting for other N credits. By using such a location-specific management approach yields and profits are maintained near maximum levels, N use efficiency is high, and residual soil nitrate levels are low. Accurate input data must be obtained for the UNL algorithm, including yield goal, SOM, NO_3-N in the in soil profile, and other N credits. Nitrogen rates calculated with the original UNL algorithm were most valid for price ratios of about 8 to 10:1. To account for different time of N application and to maximize profit when the actual price ratio is outside this range, we recommend multiplying the suggested N rate with two new correction factors. Ongoing research will evaluate different components of the UNL N algorithm and may lead to further changes.

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