IN-SEASON NITROGEN RECOMMENDATIONS FOR CORN

G.E. Varvel, J.S. Schepers, W.W. Wilhelm, J.F. Shanahan, and D.D. Francis
USDA-ARS, Lincoln, Nebraska

Abstract

Making fertilizer N recommendations involves a great deal of guess work and uncertainty because much, essentially all, of the fertilizer N is applied before the crop is planted and the amount is based on estimated crop use from historical data. In addition, producers, consultants, and fertilizer dealers try to anticipate how much N might be lost because of untimely or excess precipitation or how much additional N might be required if the weather conditions are favorable. Sidedress and in-season N applications are approaches to reduce the risk of early-season N losses by delaying access of the fertilizer N source to loss mechanisms (leaching and denitrification). This study explored a technique for using the crop as a bio-indicator of soil N status and applying supplemental N on a variable rate basis using a locally derived algorithm. The objective of the study was to evaluate the approach for making in-season N applications and determine the wider-scale applicability of the algorithm.

Introduction

The high cost of N fertilizers and concerns over N losses to the environment are prompting producers to re-evaluate N management decisions in an attempt to increase NUE (nitrogen use efficiency) and profitability. A part of this challenge relates to how fertilizer N recommendations are made in general. Validation of the long-standing mass balance approach has been questioned by a group of Midwest scientists. These researchers have not been able to show a consistent relationship between yield goal, residual N levels, and recommended N application and corn yields. The result has been a blanket N recommendation for a given eco-region (dependant on climate and soil). Indirectly, yield levels are integrated into the N recommendation via historic records from the area, as are fertilizer N costs and grain value.

One shortcoming of this approach is that it does not encourage producers to incorporate knowledge of field spatial variability into management decisions. Spatial variability can affect nitrate leaching, denitrification, soil water holding capacity, fertility status in general, and yield. Over application of N fertilizer masks N deficiencies in areas prone to N losses and compensates for other yield retarding factors. Synchronizing N availability and crop uptake remains the leading challenge for creating more efficient N management strategies. Split applications via sidedress are widely recognized as a method for reducing early season N losses. High clearance sprayers have extended the window for sidedress applications. Concurrently, crop canopy sensors and imagery have made it possible to use the crop as a bio-indicator of N availability. These technologies have generated the need for N-recommendation algorithms that are based on crop vigor and color. The objective of this research was to develop an algorithm for irrigated corn in Central Nebraska and then to evaluate the applicability of it to other locations.

Approach

A concept for making in-season N recommendations was developed using over 10 years of N response data from the Nebraska Management System Evaluation Area (MSEA) project with sprinkler irrigated corn. Minolta SPAD[1] meter data were collected weekly from the V6 growth stage until shortly after silking and every other week until the R3 growth stage (Ritchie et al., 1986). This study included continuous corn and a corn/soybean rotation with four hybrids grown at five N rates with four replications.

SPAD meter readings were analyzed by sampling date each year. As noted in earlier publications (Varvel et al., 1997a, b), chlorophyll meter readings and grain yields responded similarly to N fertilizer applications and chlorophyll meter readings were an excellent indication of N sufficiency or deficiency in irrigated corn. Actual SPAD readings were normalized to adjust for variation not associated with N nutrition. SPAD readings from all treatments were divided by the maximum reading from all N rates within that cropping system, hybrid, and replication within each date and year to obtain a sufficiency index (SI), which is expressed as a decimal (Peterson et al., 1993). Chlorophyll meter data collection dates over the ten years of study were aligned based on thermal time [growing degree days, GDD, computed according to Method II of McMaster and Wilhelm (1997)] from planting for analysis.

Grain yield was determined with a plot combine by harvesting three interior rows for the entire length of each plot. Yield data were adjusted to 155 g kg^{-1} moisture. Grain yield data were also normalized by dividing each yield by the maximum yield from all fixed N fertilizer rate treatments within that cropping system, hybrid, and replication to obtain a relative grain yield – analogous to the computation above of SI for chlorophyll meter readings.

Results and Discussion

Corn grain yields from both the monoculture corn and soybean-corn system were collected and analyzed for this paper, but emphasis has been put on data from the monoculture corn system because it represented a wider range of deficiency conditions. Grain yields responded similarly in both cropping systems (Varvel and Wilhelm, 2003), but response to N fertilizer in monoculture corn was much greater in magnitude than in the soybean-corn system.

Corn grain yields in the monoculture corn system ranged responded significantly to the applied N fertilizer in each of the 10 years of the study (Fig. 1). It is apparent that although maximum grain yields varied from year to year (ranging from a low of 10.44 Mg ha^{-1} in 1995 to a high of 13.63 Mg ha^{-1} in 2004), in most years maximum yield occurred between the 150 and 200 kg N ha^{-1} rate (Fig. 1). Regression analyses performed on these data, combined over years, using a quadratic response model indicated the maximum yield occurred at 174 kg N ha^{-1} for this site. For each year individually, regression analysis indicated maximum grain yield occurred within 10 kg N ha^{-1} of the 174 kg N ha^{-1} in all years except 1995 (140 kg N ha^{-1}) and 2004 (200 kg N ha^{-1}). This result supports conclusions from research by Blackmer et al. (1997) in Iowa, Fox and

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[1] Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors, USDA-Agricultural Research Service, or the Agricultural Research Division of the University of Nebraska.

Piekielek (1995) in Pennsylvania, Kachanoski et al. (1996) in Ontario, Canada, Mulvaney et al. (2006) in Illinois, and Vanotti and Bundy (1994) in Wisconsin that contradict the so-called "proven yield" method for making N fertilizer recommendations for corn. The proven yield method has relied on a yield-based system that assumes a constant factor of 19.4-24.2 kg N Mg^{-1} of grain, multiplied by the expected yield goal to generate the basic N application recommendation (Mulvaney et al., 2006). Using this approach with actual maximum (optimum) yields from each individual year for the results from our multi-year study would have produced different N fertilizer recommendations calculated across years ranging from a low of 203 kg N ha^{-1} in 1995 to a high of 264 kg N ha^{-1} in 2004 (using the more conservative 19.4 kg N Mg^{-1} factor). Obviously if the greater factor, 24.2 kg N Mg^{-1} grain were used, the magnitude and range would be greater. Even if we used the average maximum yield over the 10-year period, 12.1 Mg ha^{-1}, 235 kg ha^{-1} of total N would have been recommended on an annual basis, all of which are much higher than the 174 kg N ha^{-1} indicated by solving for the maximum of the quadratic response function for the data in Fig. 1. Given these facts, it appears that factors other than, or in addition to, amount of available N determines fluctuations in maximum corn grain yields from year to year. Some of these factors are rainfall patterns, soil water conditions, thermal time accumulation patterns, total incoming and intercepted radiation, dates of planting, and weed, insect, and disease control.

Our approach to solving the dilemma of predicting the amount of N needed to maximize yield involved use of SPAD 502 chlorophyll meters (Peterson et al., 1993) for in-season monitoring of plant N status. Chlorophyll meter data had been shown to be highly correlated with in-season N status of corn Varvel et al. (1997a, b), but data throughout the years were collected on calendar date (i.e., every Wednesday) and not linked to specific developmental stage for the plant. Basing the analyses on calendar day, days after planting, or days after emergence proved unsuccessful. This obstacle had to be overcome before we could test whether a modeling approach that could predict if additional N was needed, and how much, additional N would be required for maximum yield would function successfully. Our solution was to use thermal time accumulation (growing degree days-GDD) based on Method II of McMaster and Wilhelm (1997). This approach allowed data to be combined and compared both within and across the ten years of the study.

Determination of N deficiencies at the earliest possible time in the growing season (earliest stage of crop development) will increase a producer's opportunity and potential ability to correct that deficiency. Chlorophyll meter data were consistently available at or near 450, 560, and 670 GDD (approximately V8, V10, and V12 growth stages, respectively; Ritchie et al., 1986) in all years. Analyses of data collected at these times from the monoculture corn system were used to determine how early in the season chlorophyll meter data could be used to predict future crop N need, how much N was needed, and if analyses based on data collected later in the season improved the accuracy of predicted N need.

As noted above, Varvel et al. (1997 a, b) demonstrated N fertilizer significantly increased both corn grain yield and chlorophyll meter readings in this study. Since the specific grain yield response to applied N varied from year to year (Fig. 1), yield data were normalized by dividing each yield by the maximum yield from all fixed N fertilizer rate treatments within that cropping system, hybrid, and replication to obtain a relative grain yield (Fig 2) – analogous to the computation of SI for chlorophyll meter readings. Linear correlations between relative grain yield and SI at the three times (450, 560, and 670 GDD) across the 10 years of the study were 0.73 or greater (Table 1) indicating the variables were highly related and that normalized yield and SI responded similarly to N fertilizer.

The task of describing the relationship between N rate and SI remained. Quadratic models for the three observation times (at 450, 560, and 670 GDD) had intercepts and linear and quadratic coefficients similar in magnitude (Table 2). However when compared using contrast statements in regression analyses, they were determined to be statistically different. This outcome is not surprising considering the large number of degrees of freedom in the analyses (N=800). All three equations reached a maximum SI at about 170 kg N ha^{-1}, similar to the 174 kg ha^{-1} N rate found from regression of N rate and maximum grain yield from data in Fig. 1. These results, and the relative similarity of the equations, indicated chlorophyll meter-based SI values throughout much of vegetative growth for corn were fairly stable. Based on this premise, we felt it was appropriate to combine data from all three thermal times into a single quadratic model to test its appropriateness for use across all three vegetative phases (Table 2). As would be expected, this model was very similar to the models from the individual thermal times, with the intercept and linear and quadratic coefficients intermediate to those describing the SI response at each individual thermal time (Table 2). Again, given the exceptionally large number of degrees of freedom available (N=2400), when this equation was compared to the three separate equations using an F test, it was found to be significantly different. In spite of statistical procedures, the combined quadratic model appeared similar to the individual equations obtained at the three thermal times and it seemed plausible that it could be used to represent the relationship between SI and N fertilizer rates throughout the vegetative growth period.

From a practical standpoint, this approach seemed worth considering. Also, the optimum N fertilizer rate of 179 kg N ha^{-1} for the overall model was again very close to those obtained for the individual thermal time models. Using this information, we determined the amount of N fertilizer that would be recommended from each of the individual thermal time equations and from the overall equation at selected SI values. This test seemed to be a practical way to determine how much variation would be obtained in the amount of N fertilizer recommended from the so-called "statistically different" equations. Using SI values of 0.90, 0.925, and 0.95, the calculated amount of N needed from the three thermal time equations ranged from 112 to 145 kg N ha^{-1}, 95 to 122 kg N ha^{-1}, and 72 to 94 kg N ha^{-1}, respectively. Using these same SI values, the calculated amounts of N needed from the overall equation were 125, 105, and 80 kg N ha^{-1}, respectively. Although the values are slightly different, given the amount of natural variation in field situations, the amounts of N fertilizer recommended using the overall equation are representative of the range of rates recommended from the individual equations. Practically, using one equation from approximately V8 through V12 growth stages to determine potential N fertilizer needs is much easier to implement.

Logically, a question arises as to whether this model is specific to monoculture corn. Because the relationship is built on in-season assessment of canopy N status, all sources and uses of N by the crop and other components of the N cycle are accounted for and N availability is "reported" by the plant. We believe the model is valid beyond its conditions of development, monoculture corn. Earlier research indicated corn following soybean at this location required less preplant fertilizer (65 kg N ha^{-1} yr^{-1} less) for maximum grain yields than in the monoculture corn system

(Varvel and Wilhelm, 2003). In addition, maximum grain yields were generally greater for the soybean-corn system than for the monoculture corn system (Varvel and Wilhelm, 2003). To test our supposition, SI data collected from the soybean-corn system for all three thermal times (2400 additional observations) was combined with the data from the monoculture corn system and analyzed as described above. The optimum N fertilizer rate for maximum SI (176 kg N ha^{-1}) was almost identical to that for the monoculture corn system, demonstrating our model's robustness and applicability in other cropping situations with varying amounts of available N early in the growing season. This analysis also demonstrated that even though the magnitude of N response was much less in the soybean-corn system, the response curves maximums were similar. Since the magnitude of response was less, it was also obvious that SI values in the soybean-corn system were much greater, indicating that less additional N fertilizer would need to be added for maximum grain yields. As we had postulated above, by monitoring the plant we were able to give credit for the additional N available to corn following soybean.

Conclusions

Our analyses indicate chlorophyll meters can be used to determine the amount of N needed for maximum yields. Several researchers have demonstrated that chlorophyll meters can be used during the growing season to determine whether corn is N deficient (Blackmer and Schepers, 1995; Peterson et al., 1993; Varvel et al., 1997a), but few, if any, have had success quantifying the amount of N fertilizer needed for a single in-season application. Our results indicate this is possible for monoculture corn and soybean-corn systems, at least in environments similar to the Shelton experiment. This procedure requires areas where sufficient N fertilizer (beyond yield-limiting rates) has been applied so that SI values can be determined; a condition not difficult to accomplish. Once an area of well-fertilized corn (non yield limiting) has been established, our model indicates that we can collect chlorophyll meter data anytime during vegetative growth between V8 and V12 from several areas of the field, which is then compared to data from the well-fertilized area to determine SI values. These values can then be put into the generalized model shown in Table 2 or graphically in Fig. 3 and solved for N rate. This N rate is the theoretical amount of preplant N fertilizer required to obtain that SI. This theoretical amount is subtracted from the optimum N rate (179 kg N ha^{-1}) to determine the amount of N fertilizer (Fig. 3) to be applied at or very near the time of chlorophyll meter data collection to achieve the maximum yield obtainable within the constraints of hybrid, location, and season.

The outlined methodology is a more proactive approach to uniform preplant N applications and should reduce N losses due to leaching or denitrification because the N is being applied during the period of highest demand by the corn plant. It also gives producers the option to site-specifically apply N fertilizer only to those areas where needed if they have equipment to variably apply N. Future plans include additional testing of the model on producer fields and other locations.

This general approach should be valid regardless of the instruments used to acquire data for SI. The only requirements are that the instrument readings respond to N rate and they are related to yield. These limitations are quite reasonable and should allow the approach to be used with the array of on-the-go sensors under development at this time. Wide-area use of modern sensors and this method of assessing the amount of N needed to maximize yield will reduce application of N in excess of crop need while maintaining high yield levels required for profitable grain production enterprises.

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Table 1. Linear correlation of relative corn grain yield with relative chlorophyll meter readings at different stages in an irrigated monoculture corn system for 1995 through 2004 at Shelton, NE.

Thermal time GDD‡	Linear correlation coefficients (r) †										
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1995-2004
- °C day -											
450	0.55	0.79	0.82	0.86	0.82	0.79	0.84	0.75	0.93	0.72	0.73
560	0.66	0.85	0.74	0.92	0.90	0.88	0.85	0.75	0.94	0.79	0.78
670	0.66	0.90	0.74	0.84	0.89	0.88	0.90	0.73	0.91	0.76	0.78

† - All correlations above were significant at the 0.001 probability levels.

‡ - Thermal time (growing degree days) by Method II (McMaster and Wilhelm, 1997).

Table 2. Quadratic response models from regression analyses of relative chlorophyll meter readings (SI) and N fertilizer rates at three thermal times (GDD) separate and combined for (1995-2004) monoculture corn data at Shelton, NE.

Thermal time GDD†	Quadratic model‡	N§	R^2¶
- °C day -			
450	$SI=0.8324 + 0.00160(N\ rate) - 0.00000417(N\ rate)^2$	800	0.64***
560	$SI=0.7982 + 0.00211(N\ rate) - 0.00000585(N\ rate)^2$	800	0.75***
670	$SI=0.7914 + 0.00230(N\ rate) - 0.00000680(N\ rate)^2$	800	0.73***
All	$SI=0.8073 + 0.00200(N\ rate) - 0.00000560(N\ rate)^2$	2400	0.70***

*** - Significant at the 0.001 probability level.

† - Thermal time (Growing degree days) by Method II (McMaster and Wilhelm, 1997).

‡ - N rate in kg ha^{-1}

§ - number of data points used in regression analyses

¶ - Regression correlation coefficient for the model.

Figure 1. Corn grain yield response to N fertilizer applications each year in an irrigated monoculture corn cropping system at Shelton, NE (1995-2004)

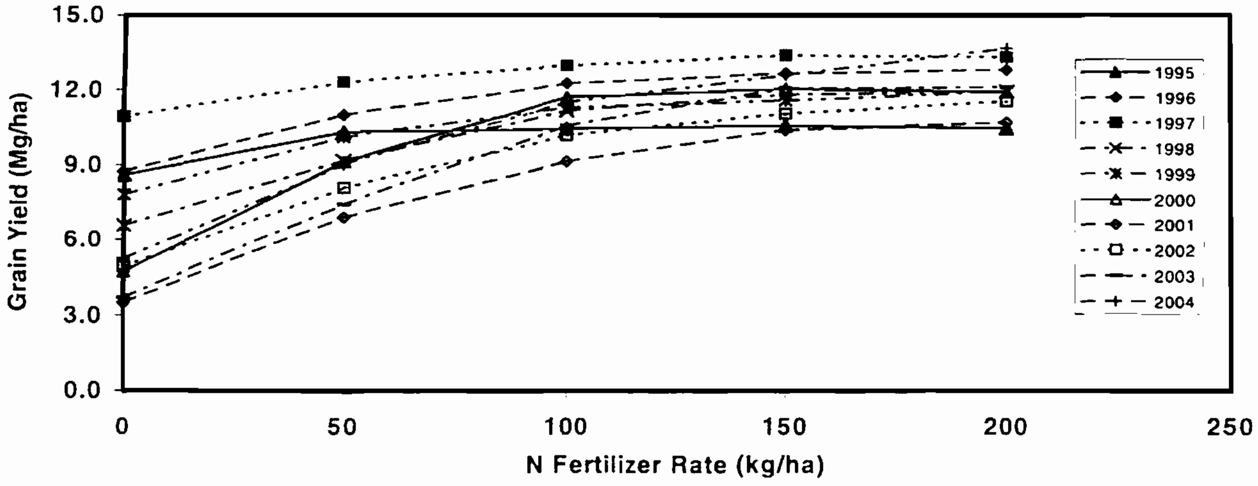


Figure 2. Relative corn grain yield response to N fertilizer applications each year in an irrigated monoculture corn cropping system at Shelton, NE (1995-2004).

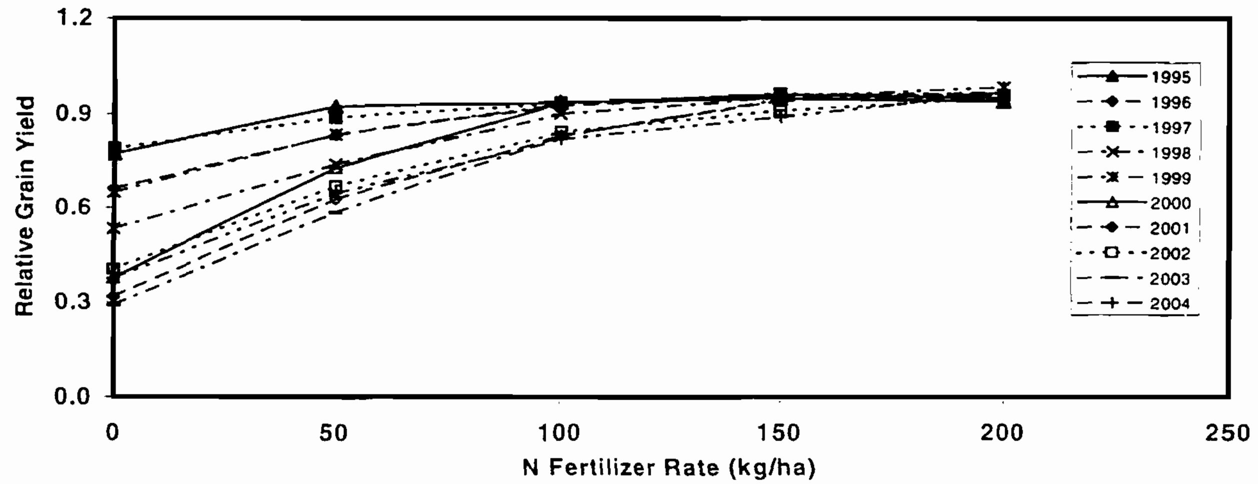
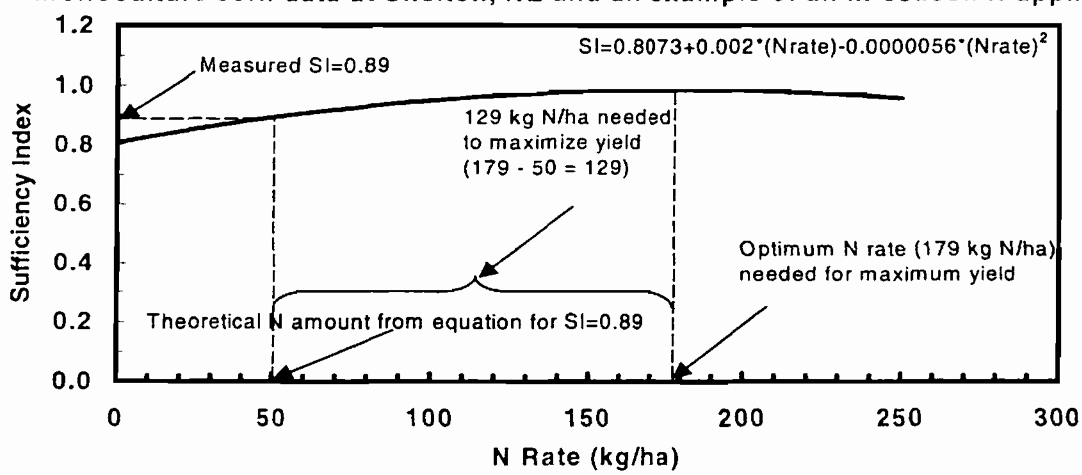


Figure 3. Quadratic response model from regression analyses of relative chlorophyll meter readings (SI) and N fertilizer rates at all growth stages combined for (1995-2004) monoculture corn data at Shelton, NE and an example of an in-season N application



PROCEEDINGS OF THE

THIRTY-SIXTH
NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 22

November 7-8, 2006
Holiday Inn Airport
Des Moines, IA

Program Chair:
Dale Leikam
Kansas State University
Manhattan, KS
(785) 532-6183
dleikam@ksu.edu

Published by:
Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org

Cover photo provided by Dr. Harold F. Reetz, Jr., Monticello, Illinois.