HOW CAN WE IMPROVE NITROGEN USE EFFICIENCY?

Larry G. Bundy[1]

Introduction

With escalating nitrogen (N) fertilizer costs and continuing concerns about environmental impacts of N losses from cropland, there is substantial interest in improving the efficiency of nitrogen use by crops. In the Midwest, this interest is focused on corn since that crop receives most of the fertilizer N and most of the non-fertilizer N inputs from manures and previous legume crops. Nitrogen use efficiency (NUE) refers to the proportion of available or applied N that is taken up by the crop. Alternatively, NUE can also be expressed in terms of yield produced per unit of applied N (e.g., bu/lb N). The interest in improving NUE employs the rationale that enhanced NUE could allow less N to be applied without reducing yield, and if less N is used more efficiently, then losses of excess N to the environment should be lowered.

Current Trends in Nitrogen Use Efficiency

The good news is that NUE in the United States has increased since about 1980, and evidence from Wisconsin studies suggests that this increase in NUE is also occurring in this state. Cassman et al. (2002) reported that corn grain yields produced in the USA increased linearly between 1965 and 2000. However, N fertilizer use has leveled off since about 1980 resulting in a linear increase in NUE since that time. A similar observation can be made using data from a long-term (1958 to present) continuous corn N rate experiment at the Arlington Agricultural Research Station (Motavalli et al., 1992; Vanotti et al., 1997). In this experiment, three N rates as anhydrous ammonia have been applied each year, and the rates used since 1984 were 0, 125, and 250 lb N/acre. Yields from the experiment (1958 to 2004) are illustrated in Figure 1 and show that while yields in the control plot (no N) remained relatively constant, yields in the fertilized plots increased linearly throughout the experiment. When NUE is expressed on a bu grain/lb of N basis (Figure 2) for the 1980 through 2004 period, a linear trend toward increasing NUE over time is apparent. This trend is quite similar to that observed for the same time period by Cassman et al. (2002). Although the clear trend is toward increasing NUE for the entire period, substantial variation in NUE among years is apparent. This year-to-year variation in NUE is one of the major problems in developing N recommendation guidelines for corn because no method currently exists for predicting NUE in advance for individual years.

Why is NUE increasing over time? A major source of this improvement is likely due to enhanced crop productivity achieved through genetic modification of corn hybrids. Improvements in cultural practices have accompanied the genetic improvements such as use of higher plant populations with hybrids designed to tolerate increased plant densities and adoption of more effective pest management techniques. To some extent, improved N management practices have probably contributed to enhanced NUE over time by allowing selection of more appropriate N rates and implementation of best management practices (BMPs) to minimize losses of applied N. Efforts to improve NUE could include activities in each of the following three areas: 1) Improving the determination of optimum N rates; 2) Adjusting optimum N rates for non-fertilizer N contributions including those from manures and previous legume crops; soil N mineralization, and residual soil nitrate; and 3) Managing N to avoid losses using appropriate placement and timing methods.

[1] Professor, Dept. of Soil Science, Univ. of Wisconsin-Madison.

Selecting Optimum N Rates

Selection of the optimum rate of N to apply in various production conditions is usually the most important factor for improving agronomic NUE and for lowering the potential for N loss to the environment. The importance of selecting the optimum N rate for specific production situations can be seen by considering the shape of the typical corn N response curve and the relationships between maximum yield and the economic optimum yield. The typical N response curve shows that the first increments of added N are the most efficient at increasing yield while N applied as yields approach maximum values is used much less efficiently. To increase yields from the point of optimum economic return to the maximum level requires a significant amount of applied N resulting in very little yield increase and low NUE.

The influence of accurate selection of the optimum N rate on the potential for loss of applied N to the environment can be seen in Figure 3 which shows the relationship between excess N applied (the amount greater than the economic optimum rate) and soil water nitrate concentration below the root zone in a corn N rate experiment. This relationship shows that the soil water nitrate increases dramatically when the rate of N applied exceeds the economic optimum.

Several approaches are in use for selecting optimum N rates for corn production. Many states base corn N recommendations on a yield goal or expected yield approach where the anticipated yield is multiplied by a factor (typically 1.2 lb N/bu) and the result is adjusted for non-fertilizer N sources to arrive at the N application rate. This approach has received criticism because of the poor relationship between yield-based N recommendations and observed economic optimum N rates. This is a particular concern at current high corn yield levels where observed crop N needs are frequently much less than would be predicted using a yield goal approach. Some states including Wisconsin have departed from yield-based N recommendations and instead use a soil-specific approach (Wisconsin) or an approach based on cropping system (Iowa). Recently, a regional effort in the North Central region has resulted in an improved process for making N rate recommendations (Sawyer and Nafziger, 2005). This process, known as the maximum return to N (MRTN) approach, has clear advantages over yield-based strategies and is likely to be employed for making N rate guidelines throughout the North Central region. The MRTN method is based on an economic interpretation of N response data from numerous corn N rate response experiments conducted on soils and in cropping systems relevant for making N rate recommendations in individual states or in multi-state regions with similar soils and cropping patterns (Laboski and Bundy, 2005). This approach can easily account for shifts in corn:N price ratios that must be considered under current economic conditions, and seems promising for avoiding excess N use associated with yield-based N rate guidelines.

Adjustments for Non-fertilizer N Sources

When an optimum N rate is selected for a specific production situation, this rate must be adjusted for non-fertilizer N sources that will contribute to the available N supply. These sources include N from previous forage legume crops, manure applications, N from previous soybean crops, and soil N contributions from residual nitrate and mineralized organic N. It is well established that first-year corn following alfalfa on medium- and fine-textured soils usually needs little or no additional N to achieve optimum yields. Similarly, manure applications can supply part or all of the N needs of corn, depending on the available N content of the manure and the application rate. Historically, corn N needs following soybean have been adjusted using an N crediting approach (usually 40 lb N/acre). However, it is generally accepted that the influence of soybean on the N requirement of a subsequent crop is due to a rotation effect rather than a direct contribution of symbiotically-fixed N as is the case with forage legumes. In the MRTN approach for N rate guidelines (discussed previously), the effect of a previous soybean crop on optimum N rates for corn is handled as a cropping system effect rather than a N credit.

Accounting for soil N contributions is probably the most difficult adjustment to accomplish, due to the transitory nature of nitrate in soils and the lack of a reliable method for assessing N contributions from organic N mineralization. Existing tools such as the preplant soil nitrate test can be used to account for residual or carryover nitrate, and the pre-sidedress test can help assess the N contributions from organic N mineralization. A continuing need is a reliable diagnostic test to predict the amount of available N that will be released from soil organic N mineralization. This need is emphasized by recent findings that 50 to 70% of the corn yield obtained in the North Central region is due to N provided by the soil alone (without added N) (Sawyer, 2006). These substantial soil N contributions have an important effect on the use efficiency of added fertilizer N, indicating that NUE could be substantially improved if a reliable procedure for assessing soil N mineralization was available.

Managing N to Avoid Losses

After determining an optimum N rate through a sound selection process and making appropriate adjustments for non-fertilizer N sources, the N applied must then be managed to avoid losses that could occur prior to plant N uptake. Obviously, direct losses of the applied N will have a negative effect on NUE. The management practices most likely to influence NUE are those related to placement and timing of the fertilizer N application. Fertilizer N placement is critical where urea or urea-containing fertilizers such as urea-ammonium nitrate solutions are used as the fertilizer source. Since surface applications of urea are subject to N loss through ammonia volatilization, and the importance of urea as an N source is increasing rapidly, controlling ammonia volatilization losses are a major factor in improving NUE. Although large losses of urea-N through ammonia volatilization under field conditions are rare, the 20 to 30% (of applied N) losses that can occur are of obvious concern for NUE enhancement. Practices for controlling ammonia volatilization from urea include incorporating or injecting urea-containing fertilizers into the soil, using a soil urease inhibitor with fertilizer urea, or using non-urea fertilizer sources for surface N applications.

Timing of N applications can have important effects on NUE depending on soil characteristics and climate, the N loss mechanisms that are likely to occur, and the timing of N demand by the crop. Ideally, N would be applied just before the period of crop N use, thus providing adequate N to the crop and avoiding N losses that could occur with other times of N application. In practice, other times of N application can be used with equal effectiveness and NUE. Typically, N timing options for corn include fall, preplant, and sidedress or split applications. Fall applications are subject to higher risks of N loss than other timing options, and require use of BMP's to obtain acceptable performance and NUE. In all cases, fall applications should be limited to well-drained, medium- and fine-textured soils, applications should be delayed until soil temperatures remain below 50^{o}F, and N should be applied as anhydrous ammonia containing a nitrification inhibitor. Even when appropriate BMPs are employed, fall applications are usually10 to 15% less effective than the same amount of N applied in the spring. With current N prices and the lower average effectiveness, fall applications are becoming more difficult to justify. The relative performance of fall and spring N timings and their impacts on tile drainage water nitrate-N concentrations is illustrated in Table 1. These results indicate that yields with fall applied N were about 15 bu/acre less than with the same rate of spring applied N even when a nitrification inhibitor (N-Serve) was used with the fall applied N and when the rate of fall N was increased. Economic returns were also much higher with the spring N timing. Although tile drainage nitrate-N was not determined in the spring N treatment, it is clear that nitrate concentrations in drainage water increased as the rate of fall-applied N increased.

Preplant N applications are as effective as other timing options on most medium- and fine-textured soils with moderate or better drainage. Sidedress or split applications are essential for obtaining acceptable NUE on coarse-textured sandy soils and on some poorly drained soils. A comparison of preplant and split sidedress N applications for corn on a sandy irrigated soil at Hancock, WI is shown in Table 2. These results show that yields and plant recovery of applied N (NUE) were higher for the sidedress application than for preplant N at all rates. Yields were maximized at lower N rates with the sidedress timing, and a yield of 194 bu/acre was obtained with 100 lb/acre less N in the sidedress treatment with about 30% more of the applied N being recovered. Applying N just before anticipated N uptake avoids N losses by leaching on the sandy soils and by denitrification on the poorly drained soils, resulting in substantial improvements in NUE. In some situations, use of a nitrification inhibitor with ammonium forms of N or use of slow-release N fertilizers such as polymer-coated urea may also be effective in controlling these losses.

Summary and Conclusions

Improvements in NUE in corn production in the USA since 1980 should be exploited to take advantage of the genetic improvements in crop productivity and improved management practices. This could include use of plant densities to optimize productivity and implementation of improved cultural practices. Additional opportunities for improving NUE include improving the N rate selection process by using N rate guidelines based on N response data and economic considerations such as those offered by the emerging MRTN approach. Further improvements in NUE are possible through complete accounting for non-fertilizer N contributions to the available N supply including legume and manure N as well as the soil N contribution. Accounting for non-fertilizer N is essential for avoiding losses of excess N to the environment. Development of techniques for improved assessment of the soil N contribution to the plant available N supply is a key research need for NUE improvement. Finally, managing applied N to avoid losses through use of appropriate placement and timing practices is critical for improving NUE. These practices include control of ammonia volatilization losses from urea, use of sidedress or delayed N application times on coarse-textured soils, and minimizing the use of fall N applications.

References

Andraski, T.W., L.G. Bundy, and K.R. Brye. 2000. Crop management and corn nitrogen rate effects on nitrate leaching. J. Environ. Qual. 29:1095-1103.

Andraski, T.W., and L.G. Bundy. 2002. Using the PSNT and organic N crediting to improve corn nitrogen recommendations. Agron. J. 94:1411-1418.

Bundy, L.G., and T.W. Andraski. 1995. Soil yield potential effects on performance of soil nitrate tests. J. Prod. Agric. 8:561-568.

Cassman, K.G., A. Dobermann, and D.T. Walters. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31:132-140.

Laboski, C., and L. Bundy. 2005. New nitrogen rate guidelines for corn in Wisconsin using a regional approach. New Horizons in Soil Science no. 3-05. Dept. of Soil Science, Univ. of Wisconsin. 9 p.

Motavalli, P.P., L. G. Bundy, T. W. Andraski, and A. E. Peterson. 1992. Residual effects of long-term nitrogen fertilization on nitrogen availability to corn. J. Prod. Agric. 5:363-368.

Sawyer, J. (ed). 2006. Concepts and rationale for regional N rate guidelines for corn. Iowa State Univ. Extension, Regional Pub. Iowa State Univ., Ames, IA. (In press).

Sawyer, J.E., and E.D. Nafziger. 2005. Regional approach to making nitrogen fertilizer rate decisions for corn. p. 16-24. In Proc. North Central Ext. Industry Soil Fertil. Conf., Des Moines, IA. 16-17-Nov., 2005. Potash and Phosphate Inst., Brookings, SD.

Vanotti, M.B., L.G. Bundy, and A.E. Peterson. 1997. Nitrogen fertilizer and legume-cereal rotation effects on soil productivity and organic matter dynamics in Wisconsin. p. 105-119. In E.A. Paul et al. (ed.) Soil organic matter in temperate agroecosystems: Long-term experiments in North America. CRC Press, Inc., Boca Raton, FL.

Table 1. Nitrogen timing, rate, and N-Serve effects on yield, return and nitrate loss in tile drainage for a soybean-corn rotation in Minnesota (3-year average).

N treatment				Economic	Tile
Rate	Time	N-Serve	Yield	return	nitrate-N
lb/acre			bu/acre	$/acre	ppm
0	--	--	106	--	ND
120	Fall	Yes	160	66	18
160	Fall	Yes	169	74	23
120	Spring	No	175	100	ND

ND = not determined. Randall (2005), see Sawyer (2006).

Table 2. Nitrogen rate and timing effects on corn yield and N recovery, Hancock WI, 2003-2004.

N rate	Yield (bu/acre)		N recovery (%)	
(lb/acre)	Preplant	Sidedress*	Preplant	Sidedress*
0	96	96	--	--
50	122	142	47	84
100	145	175	45	79
150	164	194	42	73
200	180	202	40	66
250	193	202	37	57
Average	161	183	42	72

* Split sidedress N applied at 4 and 7 wk after planting.

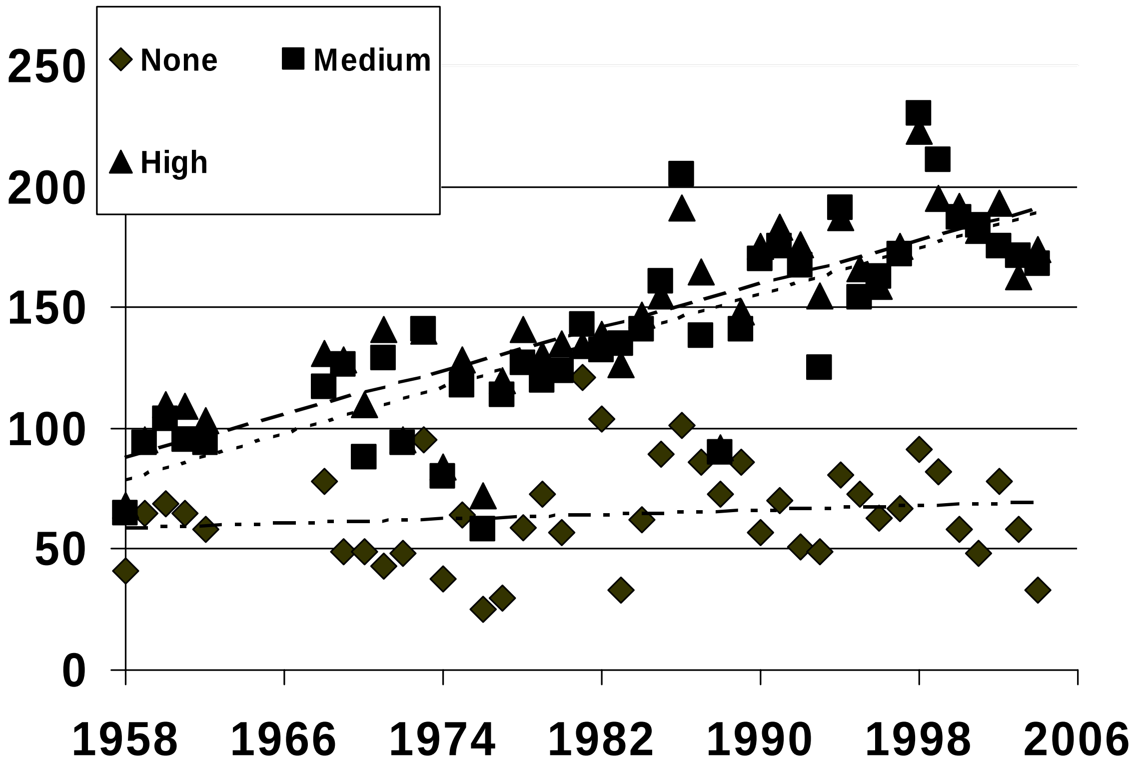

Figure 1. Continuous corn yields with three long-term N fertilizer rates at Arlington, WI, 1958-2004. Current N rates are None, Medium, 125 lb N/acre, and High, 250 lb N/acre.

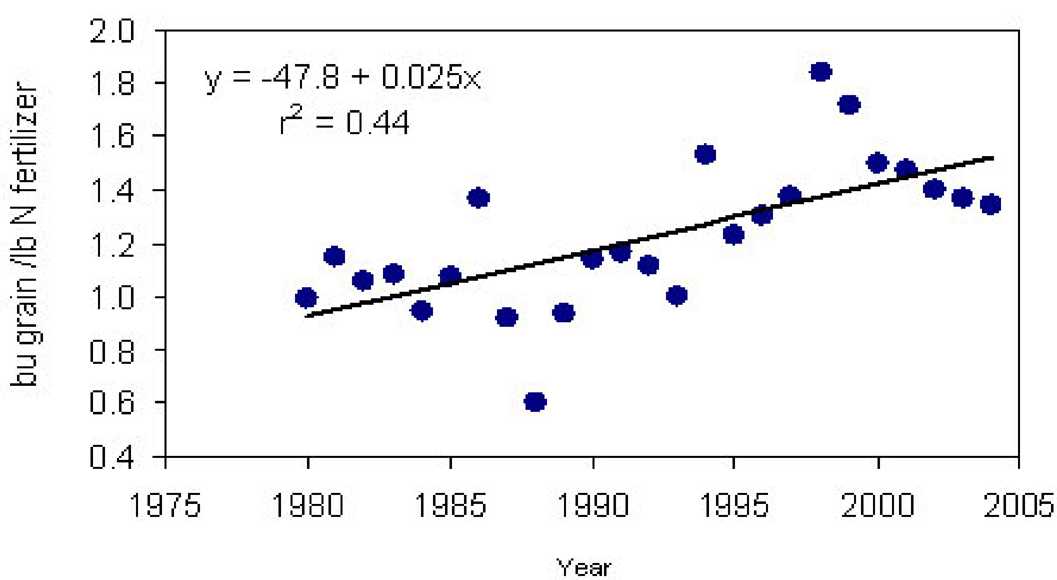

Figure 2. Nitrogen-use efficiency in long-term continuous corn, Arlington, WI, 1980-2004.

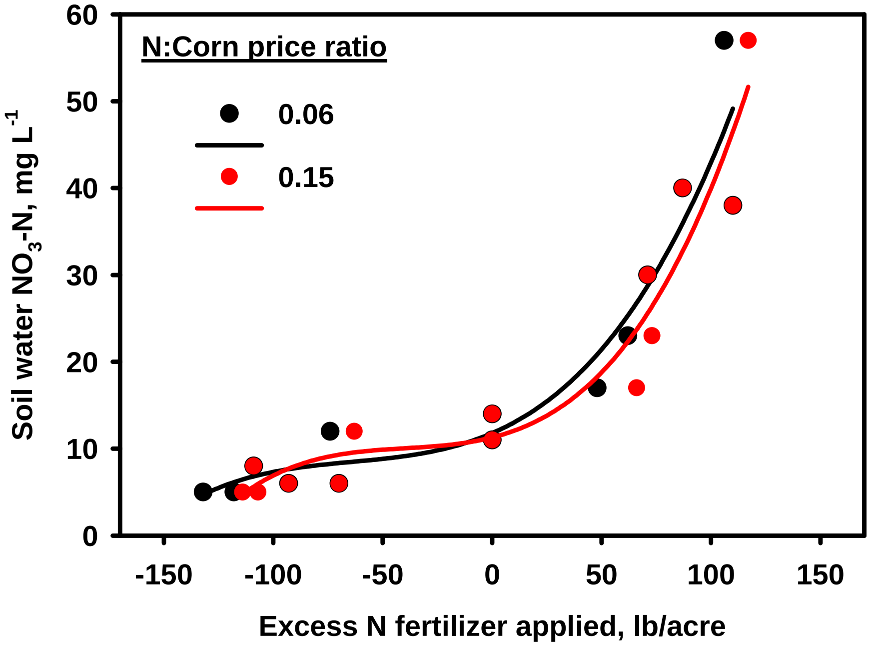

Figure 3. Relationship between the amount of excess N fertilizer applied to corn (at two N:corn price ratios) and average soil water NO_3-N concentrations at Arlington, WI (Andraski et al. 2000).