NEW HORIZONS IN SOIL SCIENCE

February 2005

Determining Optimum Nitrogen Application Rates for Corn

Larry Bundy, Todd Andraski, Carrie Laboski, and Scott Sturgul [1]

INTRODUCTION

Nitrogen (N) application rate is the most critical factor affecting the efficiency of N use by corn. It is imperative that N application rate recommendations accurately predict the amount of N needed to obtain profitable corn yields and minimize N losses to the environment. Applications of N greater than corn uptake increase the potential for nitrate losses to ground and surface water. On the other hand, N applied at rates lower than corn needs will result in lower economic returns to producers.

Expected yield or yield goal estimates have been a primary input for determining corn N fertilizer recommendations for most of the United States since the 1970s. However, research from Wisconsin, Minnesota, Iowa, and other Midwest states over the past three decades shows that economic optimum N rates (EONR) for corn are not related to yield.

More accurate N recommendations for corn have been developed using the results of N rate response experiments conducted on the major soils used for corn production in Wisconsin. This soil-specific approach is based on corn yield response and associated economic return to incremental rates of N. The collective data gathered from these experiments were the foundation for the corn N recommendations contained in the 1990 revision of the Wisconsin soil test recommendation program. Although soil-specific N recommendations have been in place in Wisconsin for some time, the concept of yield goal-based N recommendations continues to be used by some corn growers. Data collected since 1990 further support the theory that EONRs are not related to corn yield.

PROBLEMS WITH A YIELD GOAL-BASED APPROACH TO NITROGEN RECOMMENDATIONS

Since the 1970s, a yield goal approach has been used as the basis for corn N recommendations in most of the country. Typically, a factor of about 1.2 lb N/bushel of expected yield is used to calculate N application rates. There are numerous concerns with yield goal-based N recommendations. Some of the more important of these include:

- Selection of unrealistically high yield goals results in excessive N application rates which reduce economic return and increase N losses to the environment.
- Selection of yield goals that are too low results in N deficiency and lower than optimum yield and economic return.
- Lack of consensus on the appropriate techniques for determining a reasonable corn yield goal.
- Poor relationships between measured EONRs and yield goal-based N recommendations.

Numerous corn N response studies across the Midwest and Canada during the past 20 years show poor relationships between yield goal-based N recommendations and EONR (Table 1). Collectively, these studies suggest a basic conceptual problem in the

[1] Professor, Soil Science Researcher, Assistant Professor, and Nutrient Management Specialist, Department of Soil Science and Nutrient and Pest Management (NPM) Program, University of Wisconsin-Madison.

Table 1. Nitrogen rate response data showing weak relationships between corn yield-based N recommendations and economic optimum N rates (EONRs).

Location	Years	Number of Experiments	Yield vs. EONR Relationship* (r^2)
Wisconsin	1959 to 1989	117	0.02
Illinois, Minnesota, Missouri, Pennsylvania, Wisconsin	1982 to 1999	193	0.03
Ontario, Canada	1962 to 1992	300	<0.15
Pennsylvania	1982 to 1994	57	0.08
Wisconsin	1989 to 1999	101	<0.01
Iowa	1987 to 1999		
corn-corn		25	0.21
soybean-corn		25	0.06

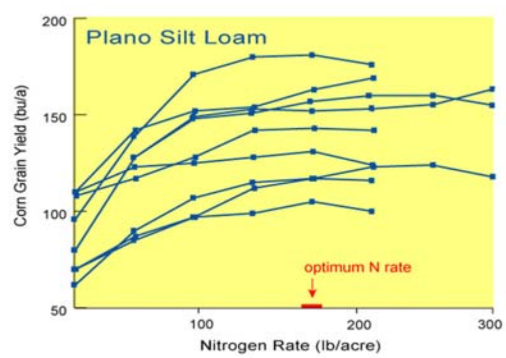
* r^2 values are for the relationship between yield goal-based N recommendations and measured EONR. The closer the r^2 value is to1.0, the stronger the relationship. The closer the r^2 value is to 0, the weaker the relationship.

application of yield-based approaches. If yield is a major factor in identifying optimum N rates for corn, a reasonable correlation between yield and EONR should exist. It does not.

WISCONSIN NITROGEN RECOMMENDATIONS FOR CORN

Wisconsin's N recommendations for corn are based on soil-specific characteristics that include: soil organic matter content, soil texture, and soil name (also known as soil series). These recommendations were developed from N response research conducted on a wide range of Wisconsin soils to determine the EONR. Yield goal estimates are not a parameter in determining optimum N fertilizer rates for corn. Figure 1 illustrates corn yield response to N over a range of application rates from numerous growing seasons on a Plano silt loam soil in southern Wisconsin. Similar data, with similar results, have been collected for other soils in numerous locations of the state. The optimum N rate is relatively the same in either low- or high-yielding years and typically occurs near the top of the yield response curve. Clearly, factors other than yield are more important in determining optimum N application rates.

Figure 1. Yield response to N in several Wisconsin experiments for corn following corn.

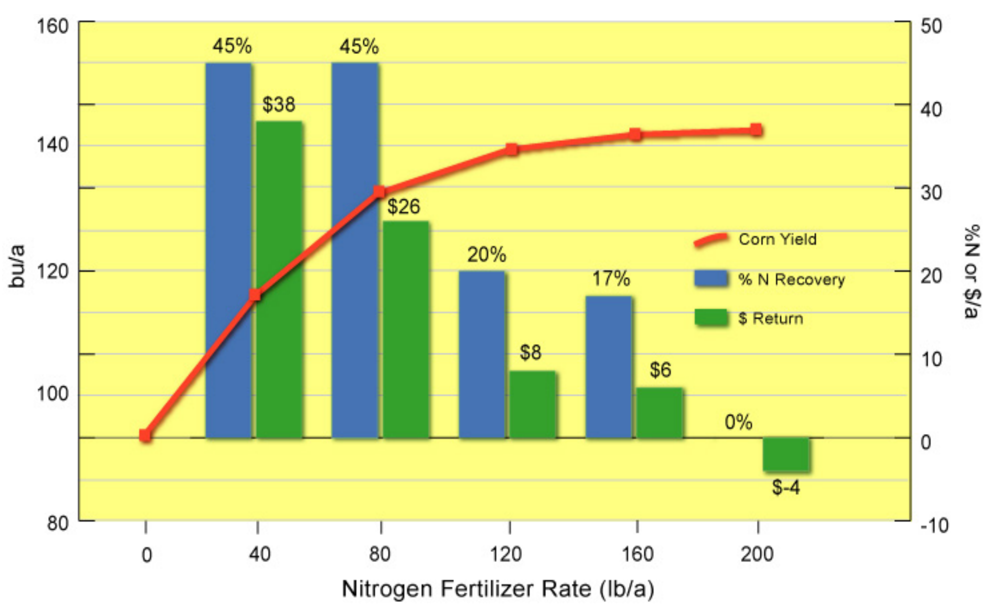


Another example of corn yield response to N, along with the economic return and crop recovery of incremental N, is illustrated in Figure 2. The largest yield responses to N occur with the first increments of applied N. At this stage of the N response curve, gains in economic return per pound of N are also the greatest. The size of these returns is lower as the N rate approaches the economic optimum. The EONR is reached when the cost of the last increment of additional N is equal to the value of the associated crop yield increase. For the soil illustrated in Figure 2, it is profitable to increase the N application rate to 160 lb/acre. Additions of N beyond 160 lb/acre do not produce a yield increase large enough to offset the cost of the additional N. The result is a negative economic return for N additions beyond the EONR of 160 lb N/acre. As noted in Figure 1, the EONR is not affected by annual variations in yield.

Similar to gains in economic return, crop recovery of N decreases and the potential for N losses to groundwater increases as N rates approach EONR and beyond. For example, crop recovery of applied N in corn grain decreased from 45% for the first 40 lb/acre of N to 17% for the final 40 lb increment at the 160 lb N/acre rate. Rates beyond the EONR pose increasingly greater risks for N losses to the environment as indicated by none of the final 40 lb N/acre at the 200 lb/acre rate being recovered by the corn grain.

As mentioned previously, soil-specific characteristics are the foundation of the University of Wisconsin N fertilizer recommendations for corn as illustrated in Table 2. Recommendations for N are divided into four categories based on soil texture. For medium- and fine-textured soils, N recommendations are based on soil organic matter content and soil yield potential. Every named soil in Wisconsin is assigned a yield potential ranking of very high, high, medium or low. This ranking is based on individual soil characteristics, such as drainage, rooting depth, and water holding capacity, as well as the length of the growing season. Consistent with the results of N response experiments conducted across Wisconsin, soils with very high or high yield potentials receive a higher N recommendation than those with a medium or low yield potential ranking. Sandy soils (sands and loamy sands) are given separate N recommendations which are dependant upon organic matter content and irrigation. Lower

Figure 2. Relationships between corn grain yield, economic return*, and recovery of applied N.



* Corn:N price ratio of 13.3:1.

Table 2. Nitrogen recommendations for corn.

Soil Organic Matter	Medium & Fine Textured Soils Yield Potential [1]		Sandy Soils	
	Low/Medium[2]	High/Very High	Non-irrigated	Irrigated
-- % --	lb N/acre [3]			
< 2	150	180	120	200
2 – 9.9	120	160	110	160
10 – 20	90	120	100	120
> 20	80	80	80	80

[1] To determine a soil's yield potential, see UWEX publication *Soil Test Recommendations for Field, Vegetable and Fruit Crops* (A2809) or contact your agronomist or county agent.
[2] Irrigated non-sandy soils with a medium/low yield potential should use the very high/high recommendation.
[3] If more than 50% residue cover from a previous corn crop remains on the surface, increase N by 30 lb/acre.

recommendations for non-irrigated sandy soils reflect the lower optimum rates seen in N response studies conducted on these soils.

The N recommendations for corn in Table 2 should be considered the maximum amount of N needed for economically optimum yields. These recommendations should be reduced for year-specific N contributions from sources such as manure and legume crops. Information for determining the amount of N supplied by manure and legumes can be found in the publications *Credit What You Spread* (A3580), *Using Legumes as a Nitrogen Source* (A3517), and *Nutrient Management Fast Facts*. All of these publications and additional information can be found at the http://ipcm.wisc.edu/ website.

Corn growers are often hesitant to adjust N rates to account for manure and legume N because of perceived risks that yield and profit will be reduced due to inadequate N. A recent Wisconsin study shows just the opposite to be true. Yield and economic return were collected from 50 corn N response experiments during 1989 to 1999. The economic gain from lowering N fertilizer application rates to corn following a legume crop and/or manure application(s) ranged from $9 to $17/acre with an average gain of $13/acre. Adjusting N rates to account for available N credits from manure and/or legumes most often results in higher economic returns.

Conducting soil tests specifically for soil nitrate-N allows producers to fine-tune their N applications even

The economic optimum N rate for corn depends on:

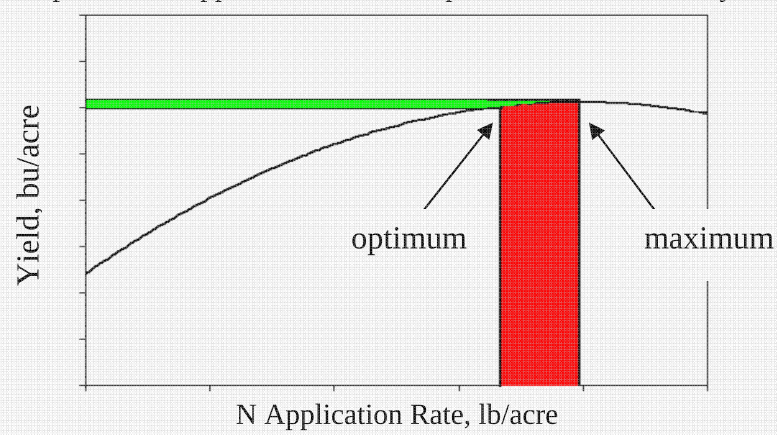
- **Soil-specific characteristics**
  - soil organic matter content
  - soil texture
  - soil yield potential
  - irrigation (sands only)
- **Year-specific adjustments**
  - prior organic N inputs (N credits)
    - manure
    - previous legumes
    - other organic materials (e.g., sludge, whey)
  - soil nitrate levels (carry-over N)
  - tillage/residue adjustments

further by accounting for the unique soil- and year-specific characteristics of their corn fields. In Wisconsin, two soil nitrate tests are available to corn growers: a preplant and a presidedress soil nitrate test. The preplant test measures residual, or carry-over, N from the previous growing season. The presidedress test measures the amount of N supplied by previous legume crops and/or manure applications, as well as a portion of any residual N. The presidedress test is also a useful tool for confirming N credits. Full details on the use of each test for various Wisconsin cropping systems can be found in the publication *Soil Nitrate Tests for Wisconsin Cropping Systems* (A3624).

Maximum Corn Yield versus Economic Optimum Yield

There can be substantial differences in the amount of N needed for maximum corn yield compared to the economic optimum yield. Numerous corn N response experiments have investigated this issue and typical results are shown in Figure 3. Comparisons of maximum corn yield to corn yield at economic optimum levels of N show very little yield gain by increasing N rates to allow for maximum yield. As shown in Figure 2, the economic consequences of fertilizing to maximum yield are usually negative. Environmentally, the reduced crop recovery of N at rates in excess of optimum results in a greater potential for N loss.

Figure 3. Corn yield response to N applied at economic optimum and maximum yield rates.

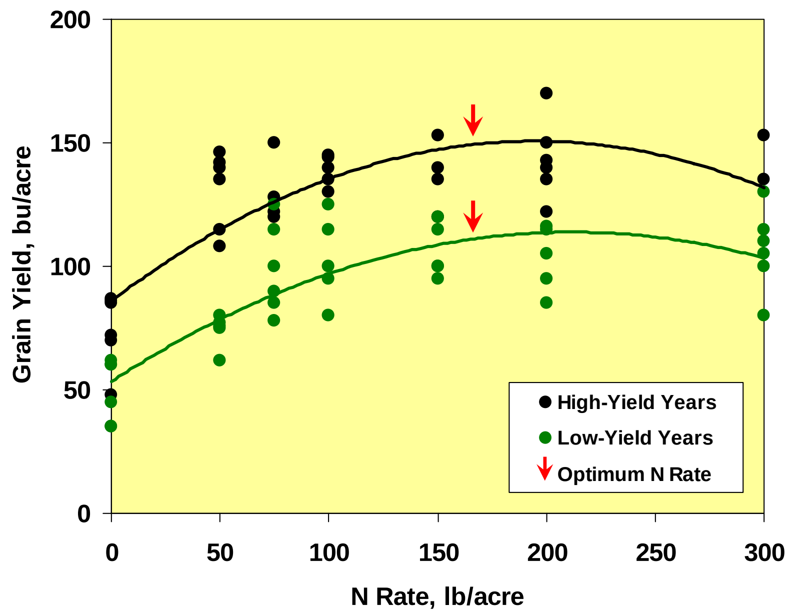


RESEARCH SUPORTING SOIL-SPECIFIC NITROGEN RECOMMENDATIONS

Research base for the Wisconsin N recommendation approach:

A study located near Lancaster, Wisconsin evaluated the relationship between corn yield and N application rates over a period of 24 years (1967-1990). Data collected from these experiments were separated into two groups - high and low yielding - based on the maximum yield attained in each growing season. The EONRs for each group and year were calculated and compared. Figure 4 shows that the optimum N application rate for these years was around 160 lb N/acre in both the high- and low-yielding groupings. Regardless of the yield obtained in an individual year, the optimum N rate was nearly the same. Even with maximum corn grain yields ranging from 70 to 170 bu/acre, there was no correlation between optimum N rates and corn grain yields. This study's findings were consistent with results from other soils and locations, both within and outside of Wisconsin, indicating that the optimum N rate for a given soil does not vary relative to corn yield.

Figure 4. Optimum N rates for corn following corn in high- and low-yielding years (1967-90), Lancaster, WI.

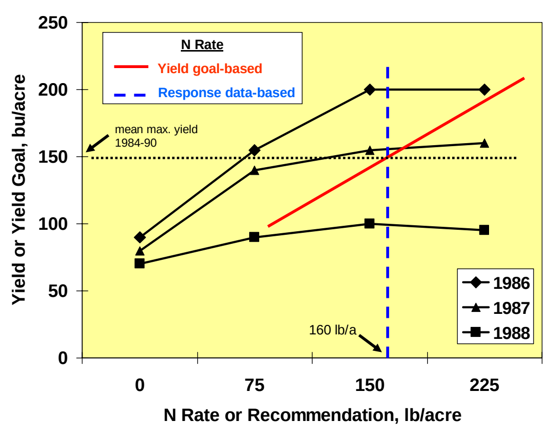


Economic optimum N rates calculated at a corn:N price ratio of 13.3:1.

An obvious question to ask based on the study's results is: Why is the optimum N rate for corn the same in high- and low-yield years? The answer is that the crop is apparently recovering greater amounts of N from the soil during high-yielding years than low. Good growing conditions enhance the release of N from soil organic matter (a process called mineralization) and improve the efficiency of N use, resulting in higher recovery of available N by the crop. As a result, there is a relatively constant, rather than increasing, requirement for the amount of N needed for optimal corn yield. Researchers in other corn belt states have also reported relatively constant EONRs across low- and high-yielding years.

The fact that the EONR for corn is relatively constant is further illustrated by data from 3 years of a long-term continuous corn experiment on a Plano silt loam soil at Arlington, Wisconsin (Fig. 5). These years had very contrasting growing conditions. Although the range in yield among the 3 years was more than 100 bu/acre, the EONR in each year was about 160 lb N/acre. Recovery of fertilizer-N by corn was high under favorable growing conditions in 1986, but recovery was low under the poor growing conditions caused by soil moisture stress in 1988.

Figure 5. Comparison of corn yield response to N recommendations based on yield goal and soil-specific N response approaches, Arlington, WI.



Expanding the economic optimum N rate concept to other Wisconsin soils:
Data from 117 corn N application rate experiments conducted over 30 years on the major soil regions for corn production in Wisconsin were used to compare yield and profitability impacts of N recommendations based on soil-specific response (i.e. University of Wisconsin recommendations) and yield goal methods. The EONRs were calculated from yield responses to applied N at various N to corn price ratios. Analysis of this database revealed that optimum N rates for corn on these soils did not vary greatly with yield (as shown in Fig. 1, 4, and 5). Comparing the two N recommendation systems (Fig. 5) shows that yield goal-based recommendations do not follow the typical corn yield response to N curve. A yield-goal based approach to corn N rates could lead to serious errors in the identification of the optimum N rate, particularly if very high or very low yield goals are selected.

While conducting separate corn N response studies on all of Wisconsin's 700+ soils is not feasible, this study shows that the grouping of soils with similar N response characteristics is valid - - provided N response research has been conducted for the major corn production soils in the state. This has been accomplished in Wisconsin and is reflected in the N recommendations for corn (Table 1).

More recent Wisconsin data:
Data collected over the past 11 years further support the concept of using soil-specific characteristics to identify the EONR for corn. Figure 6 illustrates the lack of a relationship between corn yield and EONRs from experiments conducted in a variety of cropping systems on 77 soils across the state from 1992 to 2003. As indicated by the low r^2 value of 0.01, there is no relationship between corn yield and EONR. The recent data show that the assumptions used in the University of Wisconsin N recommendation program for corn are still sound.

Figure 6. Relationship between economic optimum N rate (EONR) and corn yield from 77 sites in Wisconsin, 1992-2003.

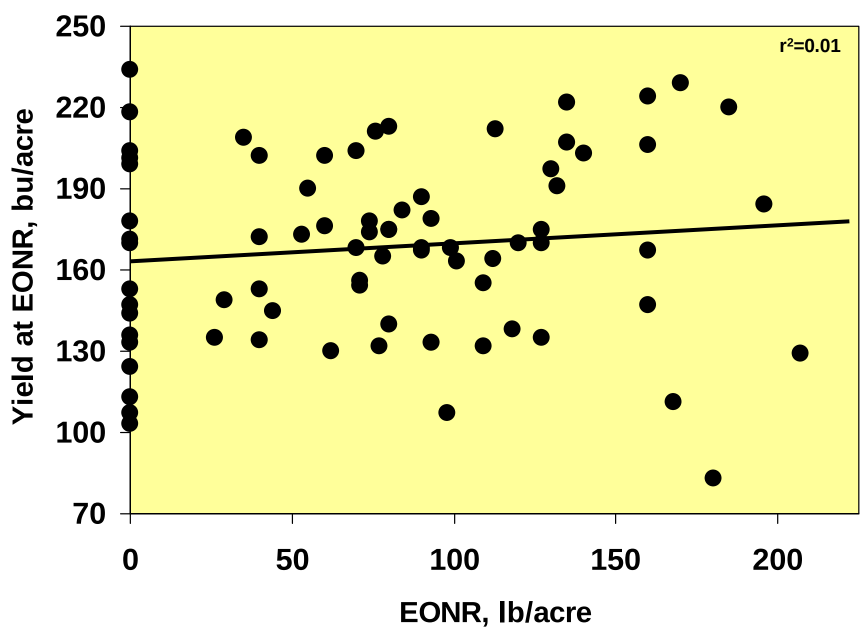
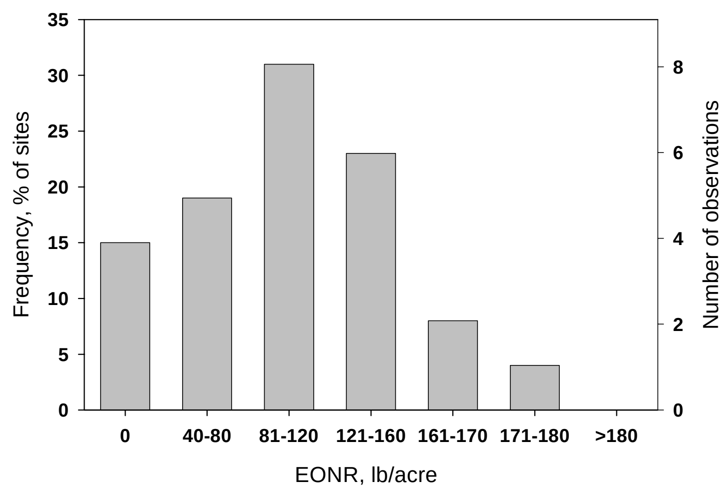


Figure 7 illustrates the distribution of EONRs from 26 corn N response experiments over a 13-year period. When compared against the recommended rate of 160 lb N/acre for corn on these southern Wisconsin silt loam soils, the EONR for 88% of the fields (23 of 26) was at or below 160 lb N/acre. Of the three sites that required slightly more than 160 lb N/acre, two of the EONRs were within 10 lbs of the University of Wisconsin recommended N rate and the third was within 20 lbs. The majority of the sites (65%) had an EONR well below (40 lbs N or more) the recommended N rate.

Figure 7. Distribution of economic optimum N rates (EONRs) for corn following corn on southern Wisconsin silt loam soils over 26 site-years, 1991-2003.



Corn:N price ratio of 10:1.

ASSOCIATED QUESTIONS & ANSWERS

1) Do corn and fertilizer price fluctuations impact optimum N application rates?

The goal of N recommendations based on corn yield response is to provide the N rate that produces the greatest economic return. Using typical corn and N fertilizer prices during the 1980's and 1990's, Wisconsin researchers found that moderate changes in corn prices or N fertilizer costs do not cause major changes in EONRs. Corn to N price relationships (i.e. corn:N price ratios) in the range of 10:1 or greater had little impact on EONRs (Table 3). At these price ratios, greatest return from N applied to the four soils shown in Table 3 was at rates recommended by the University of Wisconsin. The reason for little if any change in EONR recommendations for corn with historically typical variations in N or corn prices is due to the broad plateau near the top of the corn-N response curve where the EONR occurs (as illustrated in Fig. 1 to 5). Because of the relative flatness in this region of the curve, shifts in corn or N prices at corn:N price ratios higher than 10:1 do not have major effects on EONRs.

However, due to recent substantial increases in the cost of N fertilizers, EONRs for corn **are** now being affected by the corn:N price ratio. This is also illustrated for the four soils in Table 3 at corn:N price ratios of 8:1 or less (i.e. cost of N of $0.25/lb or greater at a corn price of $2.00/bu). The net effect of more expensive N is a lowering of the EONR from traditional values to levels below current University of Wisconsin recommendations. It should be noted that

Table 3. Net return from fertilizer N at recommended, higher, and lower N rates for corn production at various corn:N price ratios on several Wisconsin soils.

Soil	N Rate	Yield Increase from Fertilizer N	Net Economic Return from Fertilizer[1] Corn:N Price Ratio ($/bu / $/lb) 13.3:1 ($2.00/0.15)	10.0:1 ($2.00/0.20)	8.0:1 ($2.00/0.25)	6.7:1 ($2.00/0.30)	5.7:1 ($2.00/0.35)
	- lb/acre -	- bu/acre -	$/acre				
Plano	130	50.1	75.60	69.10	62.60	56.10	49.60
	160[2]	54.4	79.80	71.80	63.80	55.80	47.80
	190	56.1	78.60	69.10	59.60	50.10	40.60
Withee	90	24.3	30.10	25.60	21.10	16.60	12.10
	120[2]	27.5	32.00	26.00	20.00	14.00	8.00
	150	28.2	28.90	21.40	13.90	6.40	-1.10
Meridian	90	21.7	24.90	20.40	15.90	11.40	6.90
	120[2]	25.2	27.40	21.40	15.40	9.40	3.40
	150	26.7	25.90	18.40	10.90	3.40	-4.10
Plainfield	170	101.8	173.10	164.60	156.10	147.60	139.10
	200[2]	106.9	178.80	168.80	158.80	148.80	138.80
	230	108.1	176.70	165.20	153.70	142.20	130.70

[1] Calculated as: value of yield increase from N – cost of N – cost of N application (assumed $5/acre).
[2] Recommended (base) N rate prior to taking legume/manure N credits.
(Yellow highlight) Indicates maximum profit and economic optimum N rate (EONR).

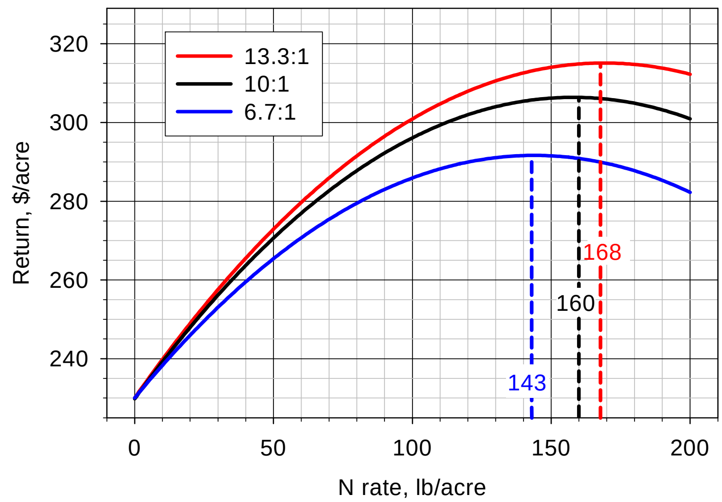
although EONRs occur at rates lower than current recommendations at corn:N price ratios less than 8:1, the difference in economic return between EONRs and recommended rates is usually small. Larger differences in economic return relative to the EONR occur at N rates higher than current recommendations. For example, on a Withee soil at a 6.7:1 price ratio, applying 150 lb N/acre (30 lb greater than the current recommendation) results in a $7.60/acre loss in profit compared to the recommended N rate, and a $10.20/acre loss in profit compared to the EONR of 90 lb N/acre at this corn:N price ratio.

The impact of corn:N price ratios on the EONR for corn on southern Wisconsin silt loam soils is shown in Figure 8. Similar to the N response curves illustrated in this paper, the curve in Figure 8 has a broad plateau. Thus, EONRs for corn are relatively stable at corn:N ratios higher than 10:1. At corn:N ratios below 10:1, EONRs for corn drop significantly.

An illustration of the relationship between N rate and total economic return at three of the corn:N price ratios shown in Table 3 is shown in Figure 9 for southern Wisconsin silt loam soils. Note how both EONRs and economic return are reduced at lower corn:N price ratios. As N gets more expensive (at a constant corn price), the N fertilizer rate needed to optimize economic return decreases as does overall economic return.

Figure 8. Relationship between corn:N price ratios and economic optimum N rate (EONR) for corn on southern Wisconsin silt loam soils (1991-2003).

Figure 9. Relationship between N rate and total return at three corn:N price ratios for southern Wisconsin soils.

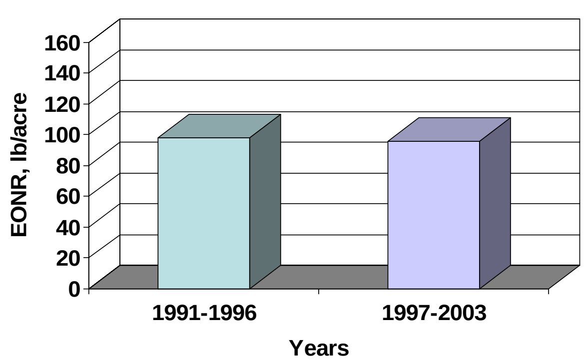


2) Is it true that new corn hybrids have an increased need for N?

Data have never been collected to prove or disprove the question. The truth is that the research needed to investigate this claim could not be conducted and evaluated before the hybrid in question was obsolete. However, some inference to this issue can be drawn from the 30 years of data discussed in this publication. Over the course of these corn-N response experiments, a wide variety of corn hybrids were used. Economic optimum N application rates did not vary significantly as a function of hybrid and time. Data illustrating this point over 13 growing seasons from several sites across Wisconsin are shown in Figure 10. These observations suggest that changing corn hybrids has little, if any, impact on optimum N application rates.

Additional information indicating that EONRs for corn have not changed significantly over time is found in Table 4. Over the time periods of 1963 to 1990 and 1991 to 2003, EONR data were collected from 340 (42 site-years) and 133 (21 site-years) experiments, respectively, on southern Wisconsin silt loam soils. Comparing the results from these two time periods shows substantially higher corn yields at all rates of applied N in the more recent data set. However, at traditional corn:N price ratios between 10:1 and 16.7:1, there is little if any change in EONRs between the two time periods. At the unfavorable corn:N price ratios of 6.7:1 and 5.7:1, EONRs in both time periods are less than current N recommendations, but the EONRs are higher in the 1991-2003 period. These higher EONR values are due to the higher yields and more dramatic response to applied N in the more recent data. Essentially, the higher yields allow the cost of N to be spread over more bushels resulting in a higher EONR at ratios of 6.7:1 or less.

Figure 10. Economic optimum N rate (EONR) for corn following corn in two time periods over 13 years from several sites across Wisconsin.



Corn:N price ratio of 10:1.

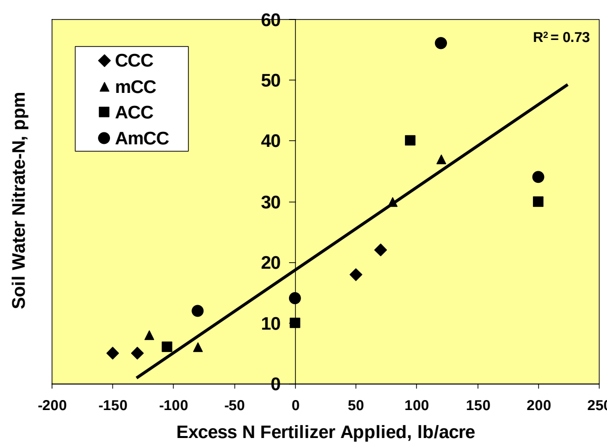
Table 4. Comparison of economic optimum N rate (EONR) and corn yield over two time periods.

Time Period	Corn:N price ratio 16.7:1	13.3:1	10:1	6.7:1	5.7:1
- - years - -	*- - - - EONR, lb N/acre - - - -*				
	- - - - Yield, bu/acre - - - -				
1963-1990	176 154	166 153	151 152	121 148	106 146
1991-2003	173 170	168 170	160 169	143 167	134 166

3) Extra N fertilizer is cheap insurance in a corn production system relative to other expenses. Due to the mobile nature of N, isn't it wise to insure against shortages by applying extra?
This mindset ignores the water quality consequences of applying excess N. Applications of N beyond crop needs are unwise from both an environmental and economic perspective. The economic consequences of over-applying N have been discussed previously in this publication. Additionally, reoccurring increases in energy costs are driving up the price, as well as reducing the overall supply, of fertilizer N.

Environmentally, applications of N greater than corn requirements increase the potential for N, in the nitrate-N form, to leach to groundwater. Leaching is the movement of substances by water infiltration through soil to groundwater. Nitrate-N is the most common groundwater contaminant found in Wisconsin and N use in crop production is often the main contributor to elevated nitrate levels. In corn production systems, N application rate is the single most important factor affecting the efficiency of N use and the extent of nitrate loss to groundwater. A Wisconsin study of the effects of various N fertilizer rates on nitrate-N leaching from several crop rotations, found a direct relationship between nitrate-N loss by leaching and the amount of N applied in excess of crop needs (Fig. 11). Soil water nitrate-N concentration increased steadily as the amount of excess N increased, which strongly indicates a direct link between excessive N applications and the potential for nitrate-N loss to groundwater.

Figure 11. Relationship between amount of excess N applied and soil water nitrate content for several cropping rotations (C=corn, A=alfalfa, m=manure).



SUMMARY

The identification of N fertilizer rates for corn that maximize economic return while reducing the potential for N loss to the environment should be the goal of any fertilizer recommendation program. Wisconsin research results from over 30 years clearly show that economically optimum N fertilizer rates for corn are not correlated with actual crop yield or crop yield expectations (i.e. yield goals). Optimum N rates are best identified using soil-specific information with further adjustments for year-specific situations, such as previous manure applications, legume crops, or residual soil nitrate. Although the N response research data used to develop corn N recommendations remains the same, the recent trend toward significantly higher N prices has had the effect of lowering economic optimum N rates for corn.