A Historical Perspective on Nitrogen Fertilizer Rate Recommendations for Corn in Indiana (1953-2011)

EXPERT REVIEWED

James J. Camberato, Purdue Agronomy

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www.ag.purdue.edu/AGRY

Purdue Agronomy Soil Fertility
www.soilfertility.info

Purdue University

Nitrogen (N) fertilizer is one of the most costly and important inputs in corn production. Apply too little, and yields can fall; apply too much and a grower's investment can be lost to surface- and groundwater, or to the atmosphere. So, accurate N rate recommendations are important to the bottom line and environment.

For many years, N recommendations in the Midwest were based on achieving a specific corn yield goal (if you want so many bushels per acre, apply so much N). This began to change in 2006 when several universities in the Corn Belt adopted a substantially different N recommendation system. That system was developed from recent N trial results and took into account the relative costs of grain and N. Researchers from several universities detailed the new approach in *Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn* (Iowa State University Extension publication PM 2015, www.extension.iastate.edu/Publications/PM2015.pdf).

Purdue Extension adopted this approach to N recommendations in 2011 with *Nitrogen Management Guidelines for Indiana* (www.agry.purdue.edu/ext/corn/news/timeless/NitrogenMgmt.pdf) after conducting many N response trials that began in 2006. As growers consider adopting these new recommendations it is a good time to examine the history and rationale of the changes in Purdue's N recommendations since the 1950s.

Urging a Long-term Approach

In January 1953, the uncredited author of *Nitrogen Recommendations for Corn in Indiana* (Purdue Extension publication AY-50a, www.agry.purdue.edu/ext/soilfertility/historical/AY-50a1953.pdf) said that N application rates were most profitable when considered over a period of years. The publication was slightly revised in January 1959 (www.agry.purdue.edu/ext/soilfertility/historical/AY-50a1959.pdf).

Such considerations could account for variations in summer rainfall from one season to the next, the author said. The author also assumed that a bushel of corn would buy 10 pounds of N. In 1960, N from anhydrous ammonia was just less than 9¢ a pound and corn was $1 a bushel (the average Indiana yield was only 68 bushels per acre).

The publication's recommendations were based on soil color, soil moisture holding capacity, stand, growth, quality of the preceding legume, years after plowing down the legume, and manure application (Table 1). The highest N recommendation provided by this publication was 120 pounds of N per acre on light-colored soils after a grass sod or after three or more years of growing a legume. N rates decreased the more recent and better performing the legume, falling to 0 pounds of N per acre for the first year of corn after alfalfa or clover. The document did not mention soybean as a rotation crop for corn.

Table 1. Historical N recommendations from *Nitrogen Recommendations for Corn in Indiana* (Purdue Extension publication AY-50a), published in 1953 and revised in 1959.

Corn Following	Pounds of N Per Acre*		
	Light-colored Soils	Dark-colored Mineral Soils	Droughty Soils
1. Good legume (alfalfa, sweetclover, red clover)	0 to 40	0	0
2. Second year from good legume	60 to 80	40 to 60	20 to 40
3. Third or more years away from good legume	80 to 120	80 to 100	40 to 60
4. Poor legume†	40 to 80	40 to 60	0 to 20
5. Grass sod**	80 to 120	60 to 100	40 to 60

* For each load of manure applied reduce nitrogen 5 pounds per acre.
† Lespedeza or thin stand or poor growth of No. 1.
** Three or more years away from good legume.

Table 2. Historical N recommendations from 1962's *Fertilizing Farm Fields in Indiana* (Purdue Extension circular 474), by S.A. Barber and R.K. Stiver.

Amount of nitrogen (N) needed for 100-bushel corn. On soils where yields are limited by moisture and other factors, reduce these recommendations by 30 to 40 pounds per acre.

This corn crop:	Light-colored or Eroded Soils	Dark-colored Soils
• follows a good legume (alfalfa, sweetclover, ladino, or red clover)	30-60	0-40
• is second year from a good legume	80-100	60-80
• is three or more years from a good legume	100-140	80-100
• follows a poor legume (lespedeza or thin stand of a good legume)	80-100	60-80
• follows a grass sod	100-140	80-100

Recommendations for grain sorghum are the same as those for corn.

N recommendations were slightly higher for light-colored soils than those for dark-colored soils, presumably because the author recognized that darker soils inherently have higher N supplying capacities. The publication recommended even lower N rates for droughty soils, perhaps due to lower anticipated yields.

Same Recommendation Structure, More N

In 1962, S.A. Barber and R.K. Stiver's *Fertilizing Farm Fields in Indiana* (Purdue Extension circular 474, www.agry.purdue.edu/ext/soilfertility/historical/Circular474-1962.pdf), provided N recommendations that were similar in structure to those in AY-50a, but averaged about 20 pounds of N per acre higher (Table 2).

N rate recommendations needed for 100 bushels of corn per acre were as much as 140 pounds of N per acre on light-colored soils and 100 pounds of N per acre on dark-colored soils. A photo in this publication depicting the results of an N rate trial showed N rate treatments up to 200 pounds of N per acre and a maximum grain yield just shy of 150 bushels per acre. In contrast to the lofty yields attained in the research plot, the average Indiana corn yield in 1962 was only 82 bushels per acre. At this time, a bushel of corn bought 15 pounds of N, with N from anhydrous ammonia at 8¢ a pound and corn at $1.12 a bushel.

A photo caption in this publication depicting the results of an N rate trial reads, "Nitrogen stimulates corn yields greatly where corn is grown following corn."

Early Yield-Based Recommendations

The first recommendations specifically based on yield were published in 1968's *Corn Fertilization* (Purdue Extension publication AY-171, www.agry.purdue.edu/ext/soilfertility/historical/AY171-1968.pdf) by Marvin W. Phillips and Gary M. Lessman. The authors wrote that long-term continuous corn experiments on several Corn Belt soils found that these soils supplied about 40 pounds of N per acre per year.

Table 3. Historical N recommendations from 1968's *Corn Fertilization* (Purdue Extension publication AY-171), by Marvin W. Phillips and Gary M. Lessman.

Recommended nitrogen rates for corn grown on medium-textured soils.*

Previous Crop	Yield Levels (bu/A)				
	100-110	111-125	156-150	151-175	176-200
	Pounds Nitrogen per Acre				
Good legume (alfalfa, red clover, sweet clover)	40	70	100	120	150+
Average legume (legume-grass mixture, or poor stand)	60	100	140	170	200+
Continuous corn (desired yield obtained)	100	120	160	200	240+
Corn, soybeans, small grain, grass sod	120	140	170	220	260+

*Previous crop and desired yield level must be specified.

Table 4. Historical N recommendations from 1972's *Corn Fertilization* (Purdue Extension publication AY-171), by C.D. Spies.

Recommended nitrogen rates for corn grown on medium-textured soils.*

Previous Crop	Yield Levels (bu/A)				
	100-110	111-125	126-150	151-175	176-200
	Pounds N per Acre				
Good legume (alfalfa, red clover, sweet clover)	40	70	100	120	150
Average legume (legume-grass mixture or poor stand)	60	100	140	170	180
Continuous corn (desired yield obtained)	100	120	160	190	220
Corn, soybeans, small grain, grass sod	120	140	170	200	230

*Previous crop and desired yield level must be specified.

"Since corn requires 150 to 300 lb. N/acre to produce a yield of 120 to 200 bu./acre, most of the nitrogen has to be supplied as fertilizer unless a previous legume crop has built up the soil's nitrogen supply," they wrote.

Their N recommendations (Table 3) were based on the difference between crop N requirements for different yields and an estimate of N derived from soil and residue based on the previous crop. Previous crop scenarios affecting the recommendations were similar to those from 1953, although corn following soybeans was added. Surprisingly, the N rate recommended for corn after soybeans was 20 pounds per acre greater than the rate for continuous corn when the previous corn crop reached the desired yield target. Later recommendations would more accurately reduce the N fertilizer recommendation for corn after soybean compared to continuous corn.

The authors placed some emphasis on N fertilizer sources, timing, and placement even though N costs were relatively inexpensive at this time: just 5¢ per pound of N from anhydrous ammonia compared to $1.08 per bushel of corn. The 1968 average corn yield in Indiana was 88 bushels per acre, somewhat below the lowest category of recommendation: 100 bushels per acre. An estimated 112 pounds of N per acre was applied to corn in Indiana at this time.

Don't Apply More N Than Needed

In 1972, Clifford D. Spies revised *Corn Fertilization* (Purdue Extension publication AY-171, www.agry.purdue.edu/ext/soilfertility/historical/AY171-1972.pdf), and admonished readers, "Do not apply nitrogen in excess of what the corn crop can utilize."

In that spirit, the author made two significant changes. First, he reduced the N recommendations by 10 to 30 pounds per acre for yield goals of more than 150 bushels per acre. Second, he removed the + symbol for the rate recommendations for the highest yield category — in short, apply only the amount you'll need (Table 4).

N was still 5¢ per pound in 1972, so there was little compelling economic incentive to manage N more efficiently. A bushel of grain, which sold for $1.57, could buy 30 pounds of N. The average 1972 corn yield in Indiana was 104 bushels per acre, and an average acre of Indiana corn received 126 pounds of N per acre.

Table 5. Historical N recommendations from 1981's *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat & Alfalfa* (Purdue Extension publication AY-9-32-W), edited by M.L. Vitosh, J.W. Johnson, and D.B. Mengel.
Nitrogen recommendations for corn based on yield potential and previous crop.

Previous Crop	Corn Yield Potential (bu per acre)					
	80	100	120	140	160	180+
	Pounds N to apply per acre					
Corn and most other crops	80	110	140	160	190	220
Soybeans	50	80	110	130	160	190
Grass sod	40	70	100	120	150	180
Established forage legume* average stand (3 plants/sq ft)	0	10	40	60	90	120
Good stand (plants/sq ft)	0	0	0	20	50	80
Annual legume cover crop†	50	60	110	130	160	190

* Any legume established for more than one year.
† Previous crop and desired yield level must be specified.

Recognizing Nitrate's Impact

In 1981, Spies and David B. Mengel revised *Corn Fertilization in Indiana* (Purdue Extension publication AY-171, www.agry.purdue.edu/ext/soilfertility/historical/AY171-1981.pdf). That revision revealed a rising awareness of nitrate-N's adverse impact on water resources.

The N rates the authors recommended were nearly identical to the 1972 version and based on the idea that Corn Belt soils only provided 40 pounds of N per acre — enough to produce only 30-40 bushels of grain per acre. Spies and Mengel placed more emphasis on the comparative efficiencies among fall, spring, and sidedress N applications than earlier recommendations.

Fall-applied N was still considered appropriate, but the authors suggested that application rates for fall-applied N be 5-10 percent more than spring-applied N. They also recommended adding an inhibitor to fall-applied anhydrous ammonia to enable application 10-14 days earlier when soil temperatures were below 55°F. Spring preplant N application was considered suitable for all but the sandiest Indiana soils when conventionally tilled.

By this time, a bushel of corn paid for only 16 pounds of N, as anhydrous ammonia-N increased sharply to 15¢ per pound and corn sold for $2.50 a bushel. An average acre of corn in Indiana received 146 pounds of N per acre and the average yield was 108 bushels per acre.

The Last Yield-based N Recommendation

The last yield-based N recommendations for Indiana, Ohio, and Michigan were published in 1995 in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat & Alfalfa* (Purdue Extension publication AY-9-32-W, mdc.itap.purdue.edu/item.asp?Item_Number=AY-9-32-W). It was edited by M.L. Vitosh (Michigan State University), J.W. Johnson (Ohio State University), and D.B. Mengel (Purdue) (Table 5).

This publication made specific N recommendations for different N fertilizers, application placements, timings, soil types, and tillage systems. Many of the recommendations were illustrated with results from research trials as explanation and justification. Concerns for profitability, groundwater quality, and conservation of energy were cited as reasons for the detail.

The authors presented the biology and chemistry of N loss mechanisms as background for understanding the differences in N efficiency that resulted from differences in placement, timing, and form.

The authors placed considerable importance on urea hydrolysis and volatilization of ammonia from surface-applied urea-containing fertilizers. This emphasis likely arose because urea-containing fertilizers had recently become more prevalent and were expected to become the dominant N sources in the future. Also, contemporary measurements of ammonia volatilization found losses could be substantial and therefore greatly reduce corn yield.

Perhaps the most notable contribution of the tri-state publication to Indiana N rate recommendations was the use of grain yield potential and N credits to calculate an N rate recommendation. The equation was:

N recommendation (pounds per acre) =
-27 + [1.36 x yield potential (bushels per acre)] – N credit.

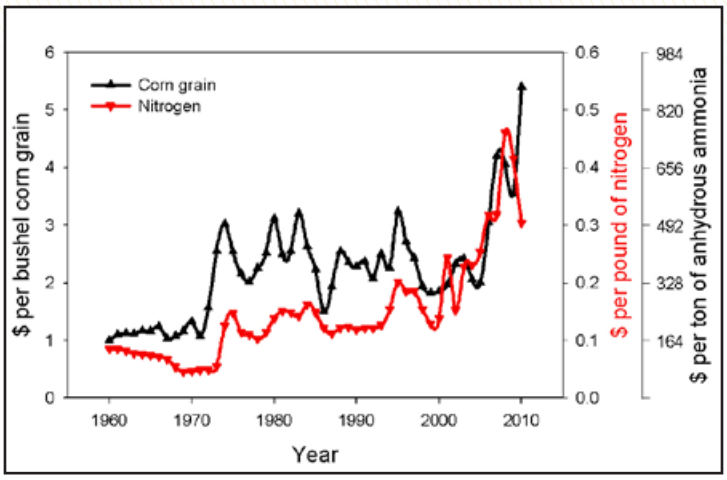

Figure 1. Average U.S. price of corn grain and N from anhydrous ammonia, 1960-2010. Sources: USDA-Economic Research Service and USDA-National Agricultural Statistics Service.

Photo provided by Edmondson Liberty Farms

Figure 2. A field-scale N rate experiment in a farmer's field typical of those used to build the database needed to improve N recommendations for Indiana corn growers. Three replications of five N rate treatments can be distinguished in the photograph.

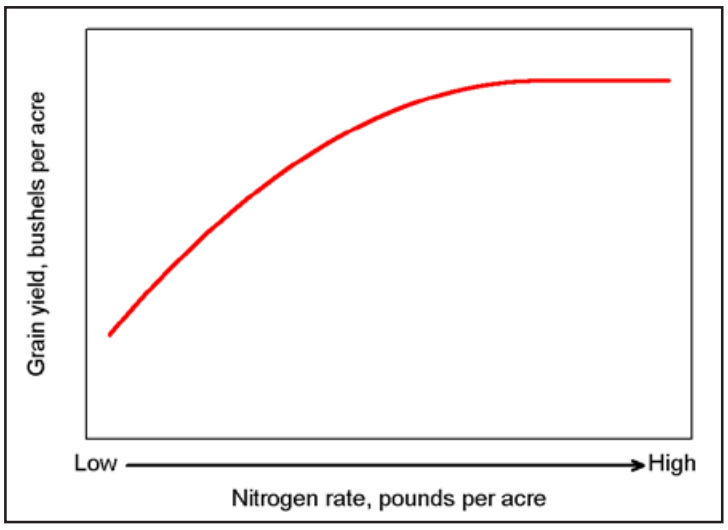

Figure 3. Illustration of a typical corn grain yield response to applied N fertilizer (a quadratic-plateau response function).

Credits of 30 pounds of N per acre for corn following soybeans, and 0 pounds of N per acre for corn after corn, were the most recognized and utilized credits. Considering the assumption that soils in continuous corn provide 40 pounds of N per acre, then soils in a corn-soybean rotation would provide 70 pounds of N per acre (considering the reduction in N recommendation based on the soybean N credit). Other credits were based on plowing down a perennial legume and were much like those used in the 1953 recommendations.

In 1995, a bushel of corn bought more than 15 pounds of N — anhydrous ammonia-N cost about 20¢ a pound and corn sold for about $3.25 a bushel. The average Indiana corn yield was 113 bushels per acre. An average acre of corn in Indiana received 132 pounds of N per acre.

The 21st Century

During the second half of the 20th century, N prices were relatively inexpensive compared to corn grain prices (Figure 1). However, since 2000 the relative cost of N has increased substantially. In addition, there is greater emphasis today on reducing the impact of N on water and air resources.

These factors prompted expanded research efforts to make more accurate N fertilizer recommendations and sparked greater interest in adopting new N recommendations.

To build the database necessary to develop new N rate recommendations for corn in Indiana, researchers conducted nearly 150 field-scale, replicated, multi-rate N fertilizer response trials from 2006 through 2011. The trials were conducted on Purdue research farms and on farmers' fields (Figure 2).

Figure 3 illustrates a common response pattern to increasing N fertilizer rate. Typically, the largest increase in yield per pound of applied N occurs at low N rates, but then diminishes at high N rates. At some point, grain yield reaches a plateau and does not increase despite additional N. Mathematically, this is termed a quadratic-plateau function.

The results of these multi-year N response trials revealed there was no relationship between the N rate needed to optimize grain yield and the grain yield (Figure 4). This outcome suggests that tying N recommendations to yield goal is not a valid approach to making N recommendations. Thus, the approach

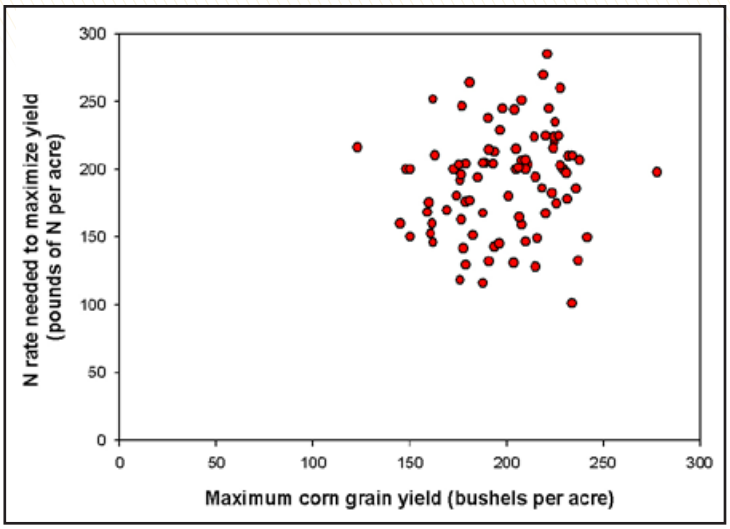

Figure 4. Maximum corn grain yield obtained in 86 N response experiments conducted from 2006 through 2010 in comparison to the N rate needed to achieve that grain yield. Increasing grain yields did not require increasing N rates.

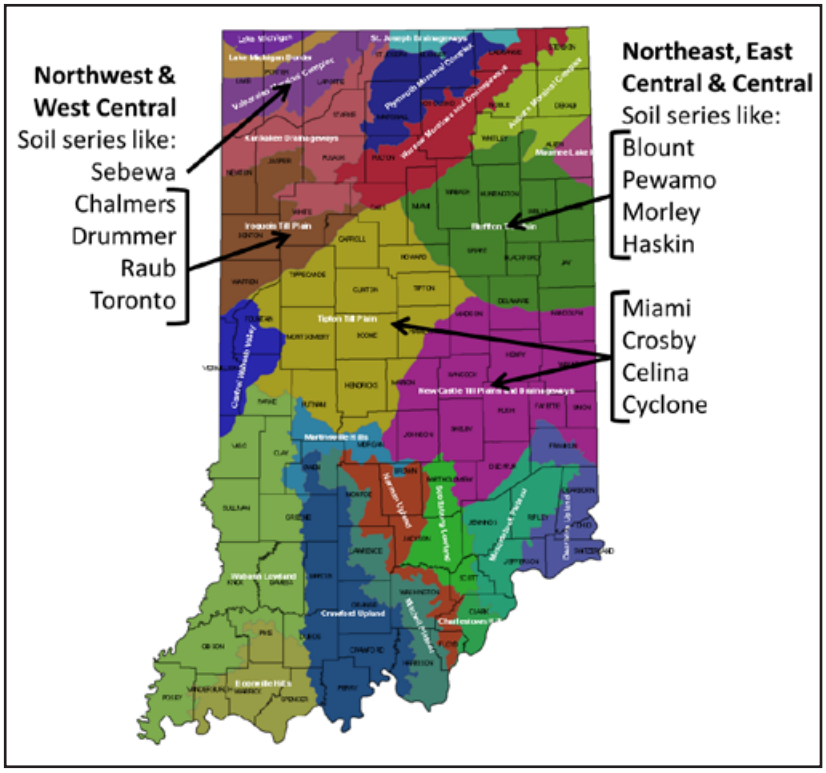

Figure 5. Indiana regions and soil types for which specific economic optimum N fertilizer rate recommendations are made based on the results of numerous field-scale N rate experiments.

outlined in 2006 in *Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn* was used to develop N recommendations that are specific to distinct regions and soil types of Indiana.

Following this approach, researchers statistically analyzed the results of each N response trial. From that analysis, they derived mathematical equations that accurately described corn grain yield response to N rate. Next, the researchers calculated the increase in grain yield for each pound of N added — from 0 to 240 pounds. Then, they calculated the net dollar return for each 1-pound increase in N rate using current N fertilizer and corn grain prices.

The net return was averaged across all trials for each region and soil type. The N rate that results in the highest net return to the grower is called *economic optimum N rate* (EONR). This term is equivalent to the term *maximum return to N* (MRTN) used in the 2006 publication.

The recommended rate to achieve EONR based on the N trial data varied by region and soil type. The high-organic matter, highly productive soils of west central and northwest Indiana had a lower EONR than the poorly drained soils of east central, northeast, and central Indiana (Figure 5). For corn grown after soybean and with efficient N fertilizer placement and timing the EONR was 163 pounds of N per acre for west central and northwest Indiana; while the EONR was 202 pounds of N per acre for the soils in east central, northeast, and central Indiana. Calculations were based on the 2000-2010 average price of corn grain ($2.99 per bushel) and cost of N fertilizer (28¢ per pound of N from anhydrous ammonia). The EONR for corn after corn was about 45 pounds of N per acre more than the EONR for corn after soybean. The average N application rate in Indiana between 2000 and 2006 was 148 pounds per acre, less than even the lowest N recommendation. During this time period the average Indiana corn yield was 150 bushels per acre.

Comparing the EONR to Previous Recommendations

Recent research has shown the yield-goal based N recommendations of the last 40 years are not useful for making N recommendations.

In other words the amount of N needed to maximize yield is not related to yield!

The EONR-based recommendation system described above provides accurate N recommendations for specific soils and regions of Indiana based on the results of numerous N rate response trials conducted over several years that maximize profit over the long term by accounting for the relative price of grain and N fertilizer

The main reason EONR-based recommendations are better than the yield-goal-based recommendations is they take into account the inherent differences in N provided by soils which can vary substantially — from more than 100 pounds of N per acre in the highly productive high-organic matter soils of west-central and northwest Indiana to less than 50 pounds of N per acre in the poorly drained soils of east-central, northeast, and central Indiana. In contrast, the yield-goal-based recommendations assumed all soils provided equal amounts of N – approximately 70 pounds of N per acre per year for corn grown in rotation with soybean. Also implicitly accounted for in the EONR-based recommendations are differences among soils in the percentage of fertilizer N applied that remains available to the crop (fertilizer N efficiency), which was not considered by the previous yield-goal-based N recommendations.

As a consequence, the EONR-based recommendations, compared to the yield-goal-based recommendations, recommend less N on productive soils in west-central and northwest Indiana — increasing farmer profit and decreasing potential N loss to the environment. On the other hand, N recommendations on poorly drained soils in east-central, northeast, and central Indiana are greater with the new recommendations than with the yield-goal based recommendations — improving profit but increasing potential N loss.

Surprisingly, from this standpoint the EONR-based recommendations are conceptually similar to those made in the 1950s and 1960s that were based on soil color in which dark-colored, higher organic matter, and more productive soils had lower N recommendations than light colored, lower organic matter, and less productive soils.

Another important difference between the EONR-based recommendations and the yield-goal-based recommendations is that the EONR-based recommendations account for the diminishing impact of increasing N rate on increasing grain yield — the quadratic-plateau response function. Utilization of this mathematical response function, which more accurately describes corn yield response to increased N rate rather than the inaccurate straight-line relationship of the yield-goal based recommendation, allows the calculation of EONR from N fertilizer and grain prices, which results in a recommendation that can be easily adjusted with changing economic conditions. Thus, the EONR-based recommendations increase with high grain relative to fertilizer prices and decrease with low grain relative to fertilizer prices.

N rate recommendations in Indiana have come full circle in 60 years to recommendations that take into account the N supplying capacity and N fertilizer efficiency characteristics of the varied soils on which corn is grown in Indiana. Future emphasis should be placed on assessing N response on more soils and periodically, if not continuously, the recommendations should be updated as the many farm practices that affect corn production and the use of N change over time.

Details about current N recommendations are provided in *Nitrogen Management Guidelines for Indiana*, www.agry.purdue.edu/ext/corn/news/timeless/NitrogenMgmt.pdf.

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