The MRTN approach to making nitrogen rate recommendations: Background and implementation

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Photo by Paul McDivitt/University of Minnesota Extension.

Based on a seminal paper published by Stanford in 1973, many land grant universities adopted N rate guidelines that used expected yield times a factor (such as 1.2 lb N/bu), with adjustments for previous crop, to formulate N rate recommendations for corn. However, discrepancies between yield-based N rate recommendations and recent N response data led to the development of an empirical approach, using N response data to generate optimum N rates. The idea of combining crop N response data, dubbed the Maximum Return to Nitrogen (MRTN) approach, was initiated in the mid-2000s and is today used in seven Corn Belt states.

Abbreviations

CNRC	corn N rate calculator
EONR	economic optimum N rate
MRTN	Maximum Return to Nitrogen
PSNT	presidedress nitrate test
RTN	return to nitrogen

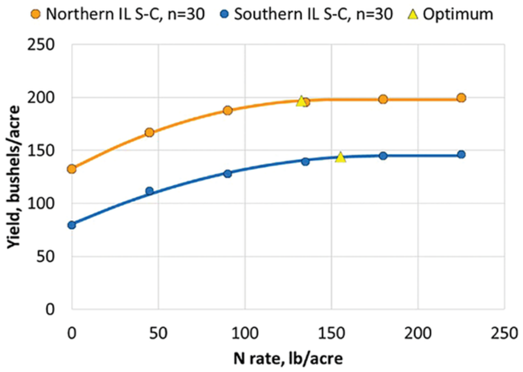

Figure 1, *Nitrogen responses of corn following soybean across 30 trials in northern Illinois and 30 trials in southern Illinois, 1999–2008.*

Based on a seminal paper published by Stanford (**1973**), many land grant universities adopted N rate guidelines that used expected yield times a factor (such as 1.2 lb N/bu), with adjustments for previous crop, to formulate N rate recommendations for corn. Although determining "expected" yield was not a precise process, this was a simple, logical (higher yields needed more N) system that provided a single N rate for each field. This system was favored by producers, especially those farming productive soils with higher organic matter: such fields both produced high yields and supplied substantial amounts of N from mineralization of soil organic matter. That this did not work very well across regions became clear with results such as those shown in Figure **1**. In this 10-year study, corn following soybean across three sites with productive prairie soils in central and northern Illinois produced 197 bu/ac with only 133 lb of N/ac while trials across three sites in southern Illinois produced 144 bu/ac using 155 lb of N. Taking actual yield as "expected" yield would have meant using some 65 lb too much N in prairie soils and some 20 lb N/ac less than the amount of N needed in southern Illinois soils.

Another piece of evidence that indicated the need for a new approach to replace yield-based N rate recommendations was the lack of correlation between economic optimum N rate (EONR) and yield at the EONR across large sets of N rate trials (Figure **2**). While predicted yields used to set yield-based N rates are not the same thing as actual yields observed in these trials, this lack of correlation shows that more N comes from mineralization of soil organic matter, and proportionately less from fertilizer, when yields—and the amount of N needed by the crop—are high. This in part stems from the fact that higher-organic-matter soils, with more mineralizable N and often with higher water-holding capacity, also tend to produce higher yields. Weather and soil conditions that favor high yields also tend to be favorable for N mineralization. Yield-based N rate recommendations failed to account fully for the influence of the soil on both the N supply and N demand (yield) of the corn crop.

Maximum Return to Nitrogen

The discrepancies between yield-based N rate recommendations and recent N response data led to discussions among land grant scientists aimed at finding a way to recommend N rates based on recent data. Given the difficulty in predicting yields and N responses in individual fields, and the lack of correlation between yield and N rate required to reach that yield, we decided on an empirical approach, using N response data to generate optimum N rates. The idea of combining crop N response data, dubbed the Maximum Return to Nitrogen (MRTN) approach, was initiated in the mid-2000s and is today used in seven Corn Belt states.

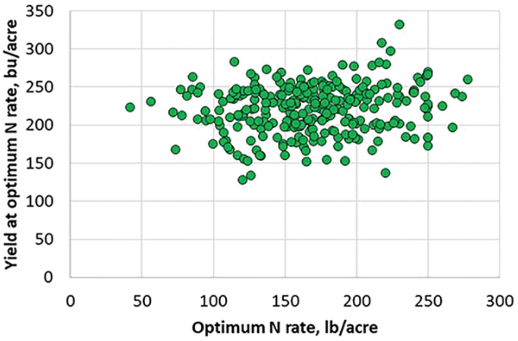

Figure 2, *Relationship between economic optimum N rate (EONR) and yield at the EONR across 284 trials in central Illinois, corn following soybean. The N to corn price ratio used is 0.1: the dollar value of 10 lb of N equals that of 1 bu of corn.*

The MRTN method is straightforward: yield data from N rate response trials are fitted to a model; then a “return to N” (RTN) response is generated across N rates for each trial by multiplying the predicted yield increase (the yield without N is subtracted) by the price of corn and subtracting the N cost (N rate times the price of N.) The average RTN across trials within a specific state or region of a state is calculated in 1 lb N/ac increments. The apex of the resulting curve identifies the N rate predicted to produce the MRTN. The corn N rate calculator (CNRC) at **http://cnrc.agron.iastate.edu/** allows the user to input N and corn prices to find MRTN values for corn following corn and corn following soybean in each participating state. Some states have more than one region, and some have MRTN calculations separated by soil type. The website contains links to more information about the approach.

State: Illinois
Region: Central
Number of sites: 284
Rotation: Corn Following Soybean

N Price ($/lb N):	$0.50	$0.75	$1.00	$1.25
Corn Price ($/bu):	$5.00	$5.00	$5.00	$5.00
Price Ratio:	0.10	0.15	0.20	0.25
MRTN Rate (lb N/acre):	181	165	152	141
Profitable N Rate Range (lb N/acre):	169 - 194	154 - 175	142 - 162	131 - 150
Net Return to N at MRTN Rate ($/acre):	$445.47	$402.30	$362.69	$326.08
Percent of Maximum Yield at MRTN Rate:	99%	98%	97%	96%
Anhydrous Ammonia (82% N) at MRTN Rate (lb product/acre):	221	201	185	172
Anhydrous Ammonia (82% N) Cost at MRTN Rate ($/acre):	$90.50	$123.75	$152.00	$176.25

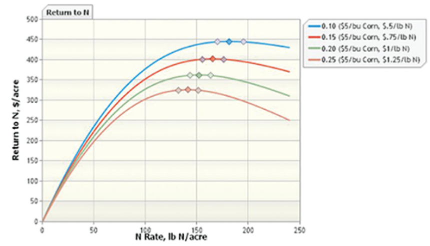

Figure 3, *Output from the N rate calculator for central Illinois, corn following soybean, comparing MRTN values with corn at $5.00/bu and N cost ranging from $0.50 to $1.25 per pound of N.*

The CNRC includes an option to compare N responses and MRTN calculations for up to four different N cost-to-corn-price ratios. Figure **3** shows a sample output from central Illinois, corn following soybeans, with 284 trials in the database. Here, the corn price is set at $5.00/bu, and N prices range from $0.50 to $1.25 per pound of N (the N cost in spring 2022 is expected to be around $1.00 per pound of N). It is the ratio of N to corn price that determines the MRTN: N at $0.50/lb and corn at $5.00/bu would produce the same MRTN value as N at $0.40/lb and corn at $4.00/bu. Nitrogen costs can be entered as dollars per pound or as price (dollars per ton) of one of several N fertilizer materials: here the price per pound was entered, and the cost per ton of fertilizer was automatically calculated. The MRTN N rate decreased as N cost rose, from 181 lb N/ac when N cost $0.50/lb to 141 lb N/ac when N cost $1.25/lb. Although lowering the N rate by 40 lb/ac when N prices go up seems counterintuitive, keeping the N rate at 181 lb N/acre with the higher N price would cost $1.25 × 40 lb = $50 more per acre while the value of yield (6.7 bu/ac, a number from the database not provided by the CNRC) retained by keeping the N rate high is only $33/ac; the net effect would be a loss of $17/ac.

Flexibility for Choosing Rates Based on Risk

Because the RTN response was relatively flat around its maximum, the CNRC calculates a range of N rates within which the RTN is expected to be within $1.00/ac (the default value) of the RTN at the MRTN. This provides some flexibility for choosing rates depending on a user's approach to risk even though the risk introduced by moving from the MRTN rate to either end of the range is not very great. Other calculated values include net return to N at the MRTN N rate; this (RTN) value is affected by N and corn prices, so it changes when both N price and corn price change even if the MRTN (based on the price ratio) stays the same. The percent of maximum yield is included to provide confidence that high yield can be expected even though the MRTN rate is lower than the rate needed to maximize yield. The amount of fertilizer product needed and its cost per acre are also calculated.

Nitrogen responses vary greatly among fields, soils, and growing seasons, resulting in wide variation among the individual RTN curves that are averaged to produce the single curve used to calculate the MRTN. Among the 284 trials in the database for corn following soybean in central Illinois, economic optimum N response (EONR) values, using an N:corn price ratio of 0.1 (e.g., $0.50/lb of N and $5.00/bu of corn), range from 42 to 276 lb/ac (Figure 2). The average EONR of 168 lb N/ac is 13 lb/ac less than the MRTN at the same price ratio. This difference reflects the fact that the relatively small number of trials with a low yield at zero N and high yield at the EONR (this difference is called "delta yield", or dY) have very high RTN values and so move the MRTN upwards more than trials with more modest N responses, even if both have similar yields at higher N rates. That makes this a conservative measure, with the MRTN N rate a bit higher than the average optimum N rate across trials. We do not exclude any trials from the database unless there's reason to doubt the accuracy of the data although unusually severe wind, water, or pest damage may rule out using data, particularly if such damage is considered unlikely to recur in the future.

Of the 284 N responses in the central Illinois database, 78 (37%) show EONR values (at the 1:10 N:corn price ratio) higher than the MRTN (181 lb N/acre), and 206 (63%) have EONR values less than the MRTN. The distribution of EONR values indicates that it would require almost 240 lb N/ac to reach a 95% chance of applying at least the EONR in future fields. With corn at $5.00/bu and N at $1.00/lb, using 240 lb N instead of the MRTN (152 lb N/ac) would increase yield by 7.1 bu (worth $35.50/ac) and increase N cost by 88 lb/ac (worth $88.00) for a net loss of $52.25/ac. This illustrates that adding enough N to assure near-maximum yield across all fields and seasons is not profitable. Trials showing the need for high fertilizer N rates are found over a wide range of yield levels in seasons ranging from very dry to normal to very wet. Our ability to identify fields that need additional N, at least early enough to make in-season adjustments, might improve, but this won't happen quickly.

Extending, Improving MRTN's Value and Use

While it is difficult to gauge the effect of number of trials on the soundness of MRTN values, it takes more than a handful of trials to produce sound N rate recommendations for several million acres of corn in a region. In recent years, adding new data and dropping older data from databases has resulted in MRTN values increasing in all three regions in Illinois, with a larger increase in in southern Illinois, where the corn-following-soybean MRTN (N:corn price ratio of 0.1) rose from 171 lb N/ac in 2015 to 200 lb N/ac by 2021 (Figure 4). Each year's MTRTN values are based on trials conducted before that year. Data from one year alone (2018) raised the next year's MRTN by more than 10 lb N/ac in southern Illinois. While some states may not have the means to add many trials, it would be useful to conduct a few validation trials each year to see if the MRTN based on previous data predicts current responses well.

Although the MRTN approach has been used and promoted for some 15 years, the fact that the MRTN N rate is substantially lower than yield-based N recommendations, especially as yields continue to increase, slows producer acceptance of the MRTN approach. In Illinois, we are looking at ways to build on the foundation of the MRTN to extend and improve its value and use. As an example, we are initiating a project to establish two rates—one the field rate and one higher or lower, depending on the field rate—in order to compare near-MRTN rates with rates 50 to 60 lb higher than the MRTN.

Developing a robust database on which to base N rate recommendations opens other possibilities for improving N management. As an example, N in excess of the optimum N rate can be considered both an economic and an environmental cost. Using a subset of Illinois data, we calculated the MRTN (N at $0.50/lb and corn at $5.00/bu) as previously described. We then calculated an "eco-adjusted" MRTN by doubling the cost of N to $1.00/lb, once the N rate exceeded the EONR for each trial. This adjustment lowered the MRTN N rate by 13 lb N/ac and lowered the RTN at the MRTN by $8/ac (Figure **5**). While it is not clear how such a "penalty" should be calculated, using N response data to make such an adjustment illustrates how we might build different N input decision methods onto the foundation of N response data.

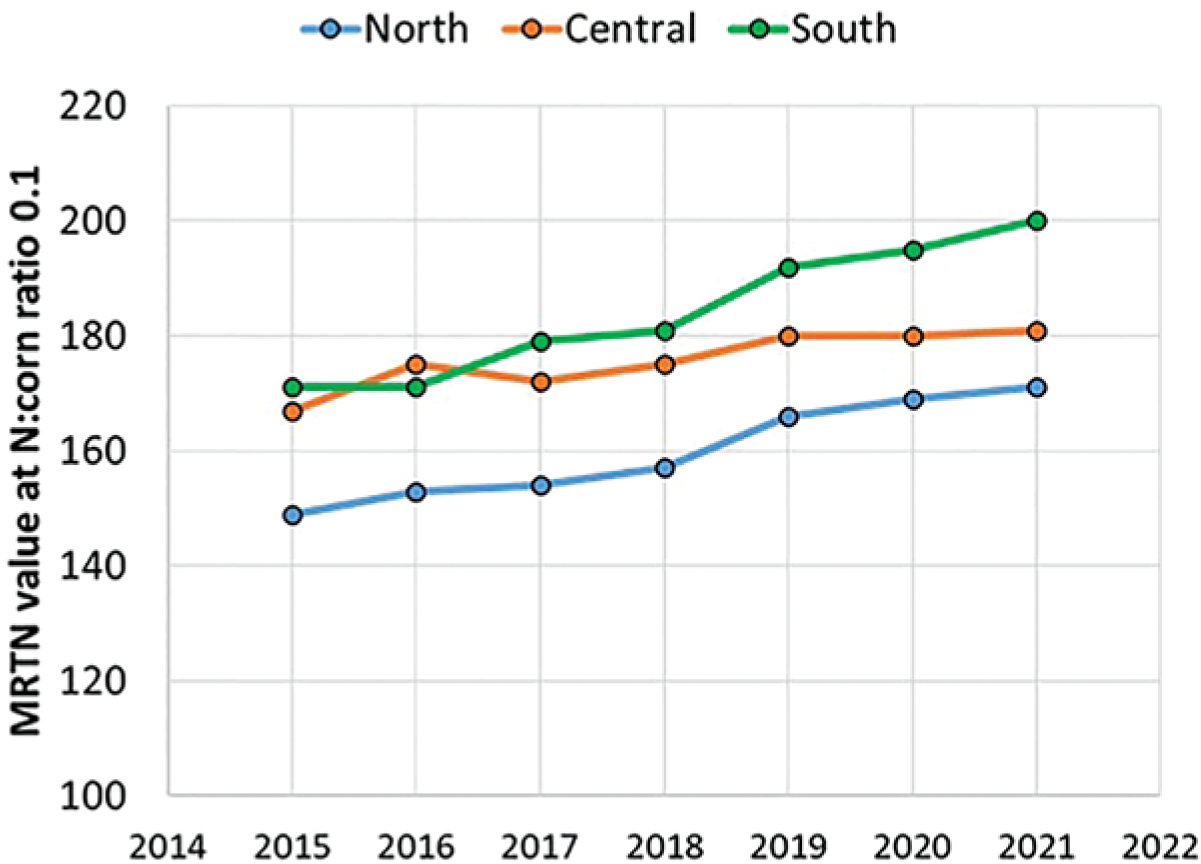

Figure 4, *Changes in the MRTN value by Illinois region, calculated at the N ($/lb) to corn ($/bu) price ratio of 0.1, over recent years as new data were added and older data dropped.*

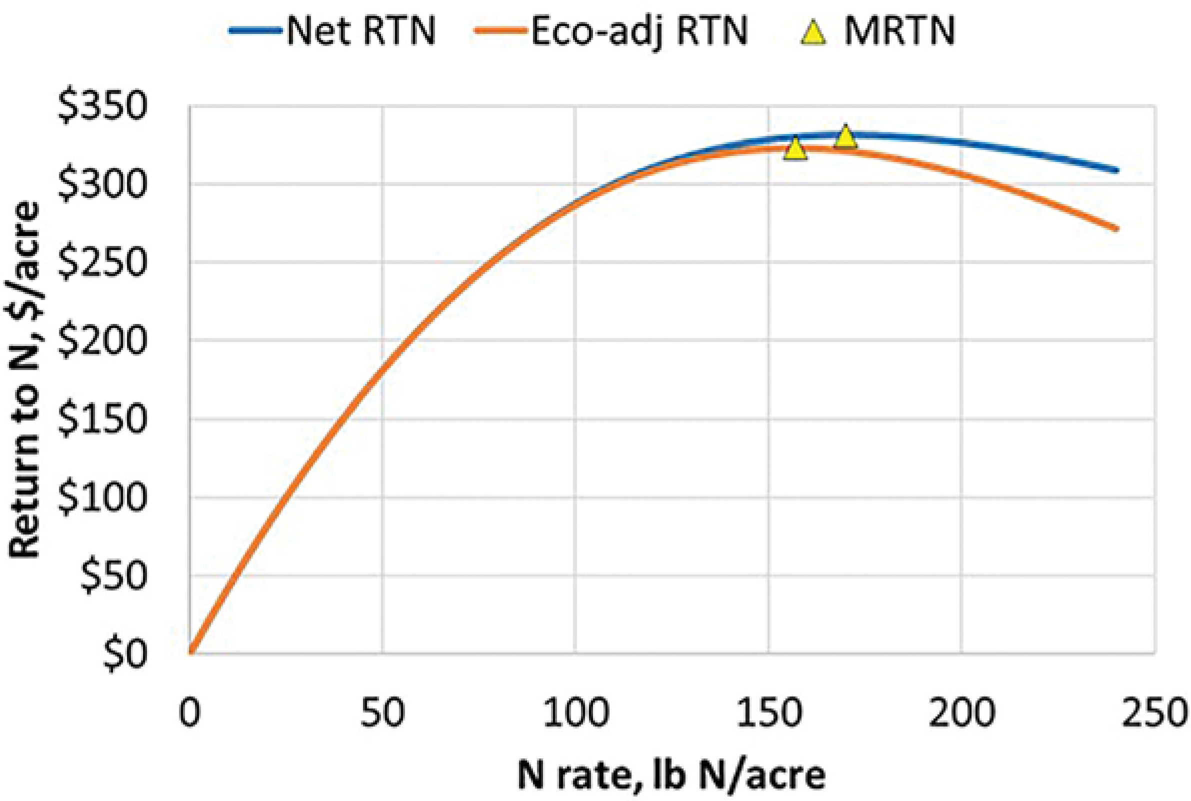

Figure 5, *Calculation of MRTN from a set of N response data, without (Net RTN) or with (Eco-adj RTN) factoring in higher costs for N in excess of the EONR for each trial. Based on corn at $5.00/bu, N at $0.50/lb, and N in excess of economic optimum rate priced at $1.00/lb.*

Separate MRTN Guidelines for Soil Groupings in Wisconsin

While Illinois, Indiana, Iowa, and North Dakota refine MRTN rate recommendations based on regions within each state, Wisconsin has developed separate MRTN guidelines for groupings of soils. The concept of grouping soils to improve N rate recommendations was developed by Vanotti and Bundy (**1994**) and was in use in Wisconsin for 15 years before implementation of MRTN. Soil yield potential categories are defined for each soil map unit using soil properties documented in the USDA-NRCS SSURGO database. Sandy (low yield potential) soils are generally defined as having a sand or loamy sand texture. This group is further divided based on whether the field is irrigated. Without irrigation, sandy soils have a lower EONR because water is more limiting than N. Medium- and fine-textured mineral soils are categorized as either high or medium yield potential based on soil drainage class, available water capacity in the upper 60 inches of soil, and depth to bedrock. Soil properties that limit yield potential to medium include very poorly, poorly, somewhat excessively, or excessively drained; or very low (< 3 inches) or low (3 to 6 inches) available water capacity; or less than 30 inches of soil over bedrock/lithic contact. If at least one of these soil property criteria are met, the soil is considered medium yield potential. High-yield-potential soils are mineral soils that do not meet the criteria for low or medium soil yield potential. If a high-yield-potential soil is located in an area that has, on average, fewer than 2,100 growing degree days (in the northern third or so of Wisconsin), it should be considered medium yield potential because length of growing season restricts corn's yield response to N.

Nitrate soil testing can be combined with the MRTN approach to further refine N rate guidelines. When the previous growing season and winter are drier than normal, residual/carryover N can be used as a N credit and subtracted from the MRTN rate. This is done by collecting soil samples prior to planting to a depth of 2 ft in 1-ft increments and measuring nitrate-nitrogen. The N credit is calculated as the sum of nitrate-N in the top 2 ft plus an estimate of nitrate in the third foot and subtracting 50 lb N/ac (background concentration). Additionally, the presidedress nitrate test (PSNT) can be assessed on a 1-ft sample collected just prior to sidedressing. The calculated N credit can be subtracted from the MRTN to determine a sidedress N rate. The PSNT can be useful for assessing N credits from manure and forage legumes.

Like North Dakota, Wisconsin has extended the MRTN approach to N recommendations for winter wheat. Because there are fewer wheat N response trials compared with corn, there are only two soil groups, sandy (defined as previously described) and loamy (not sandy). A 2-ft preplant soil nitrate test has also been directly incorporated into the MRTN guidelines should growers want to make further refinements on their N rate.

Wisconsin's MRTN guidelines for corn can be found in the "Corn N Rate" smartphone app, at the CNRC website, and in print (along with the wheat MRTN) in University of Wisconsin Extension publication A2809, *Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin* (**https://bit.ly/3oeLeHv**).

North Dakota has used the MRTN/EONR approach not only for modern corn N recommendations, but also for spring wheat/durum and sunflower (oilseed and confections), with malting barley N recommendations currently under construction. The North Dakota State University recommendations are separate from those housed at the Iowa State website: the corn calculator is at **www.ndsu.edu/pubweb/soils/corn/**, spring wheat/durum at **www.ndsu.edu/pubweb/soils/wheat/**, and sunflower at **www.ndsu.edu/pubweb/soils/sunflower/**. These calculators are also available as smartphone apps for free by searching for "ND Crop N Calculator" on Android and iPhones.

Independence of Yield and Nitrogen Rate between Sites

One of the foundations of the MRTN approach is the independence of yield and N rate between sites. Farmers are very used to developing N rates based on "expected yield." However, research conducted within the past two decades refutes this relationship.

The best visual demonstration of the independence of yield and N rate is through comparing graphs of the relationship of raw yields with N rate with standardized yields with N rate. A standardized yield, sometimes also referred to as "normalized" yield, is the yield within an experiment divided by the greatest yield in the experiment.

Standardized yield is also sometimes referred to as “relative yield.”

Figure **6a** shows the raw yield relationship with total known available N (N rate applied plus spring residual nitrate-N to 2 ft deep plus any previous crop credits from previous-year legumes or sugarbeet leaves) with an r^2 of 0.16, and Figure **6b** shows the standardized yield relationship with total available N, with an r^2 of 0.53. When a standardized yield relationship with total known available N is greater than the raw yield relationship, it demonstrates that relative yield is the most important factor, not actual yield.

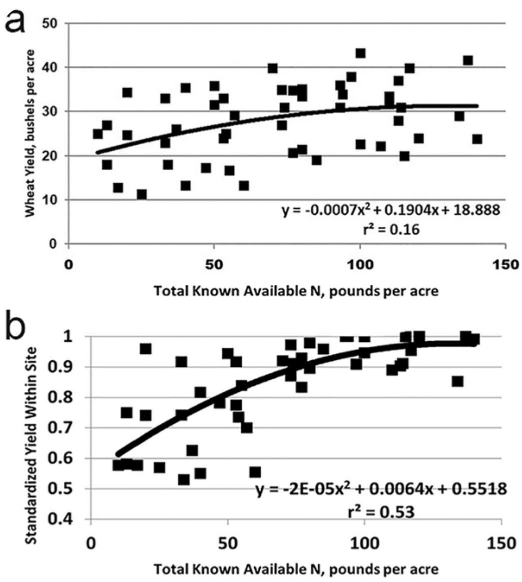

Figure 6, *(a) North Dakota spring wheat/durum yields, west of the Missouri River, compared with total known available N, conventional tillage. (b) North Dakota standardized spring wheat/durum yields, west of the Missouri River, compared with total known available N, conventional tillage.*

In wheat, corn, sunflower, and two-row malting barley, use of standardized data increased the relationship between yield and available N to the crops compared with the use of actual yield at each site. This indicates that the “cloud” of data around a raw yield vs. available N relationship is a series of nearly parallel response curves. When standardized, the data falls much more tightly around the response curve as a result of the stacking of the individual site curves; the r^2 and the real N vs. relative yield relationship of the whole is better expressed.

These phenomena may surprise crop management practitioners and farmers; however, the basis for similar recommended N rates regardless of realized yield might be explained by the sources of N availability to plants. Soil moisture acts to increase or decrease the availability of N to crops. In dry soils, N does not move to the roots with mass flow but is restricted in its path to the root, and uptake may be limited to diffusion or root contact. Also, in dry soil, N mineralization rate is lower. The result of poor N efficiency in dry soil is that the rate of N per bushel achieved is greater than in a moist soil. In a moist soil, N mineralization rate is high, and movement of N to roots is more efficient, so N efficiency is high, and higher N rates are not required to achieve higher yield. The old yield goal formulas did not consider other sources of N to crops. In N rate trials, application of zero N never results in zero yield. Nitrogen even in the absence of supplemental N is provided through mineralization of N from residue and organic matter; N is added through atmospheric deposition; N is provided in smectitic soils through release of non-exchangeable ammonium; and N is provided from the activity of free-living (asymbiotic) N fixers from several genera of soil bacteria. Conditions that increase the contributions of “natural” N sources also serve to increase crop yield. Contributions of soil N sources are apparently able to “fill in the gap” to support greater crop yield with more favorable N supply. Also, the ability of the crop to access soil N and supplemental N is increased with more favorable moisture conditions.

In designing the N calculator for spring wheat/durum, the response of grain protein was included in the industrial production function (EONR). Below 14% protein, a dockage was included, and above 14%, a protein premium was included up to 15%. In sunflower, the oil concentration with N rate was considered since oil percentage always decreases with increasing N rate. The dockage for low oil and premium for higher oil was considered.

North Dakota experiments support the use of the MRTN concept in wheat, corn, sunflower, and two-row malting barley and also indicate that use of standardized or relative yield within site may be a better factor to model with available N or N rate compared with raw yield data.

Dig deeper

Dr. Carrie Laboski, co-author of this article, recently appeared on our podcast, Field, Lab, Earth, to talk about profitable N rates for corn. Listen to the podcast by visiting **https://fieldlabearth.libsyn.com** or your favorite podcast provider.

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