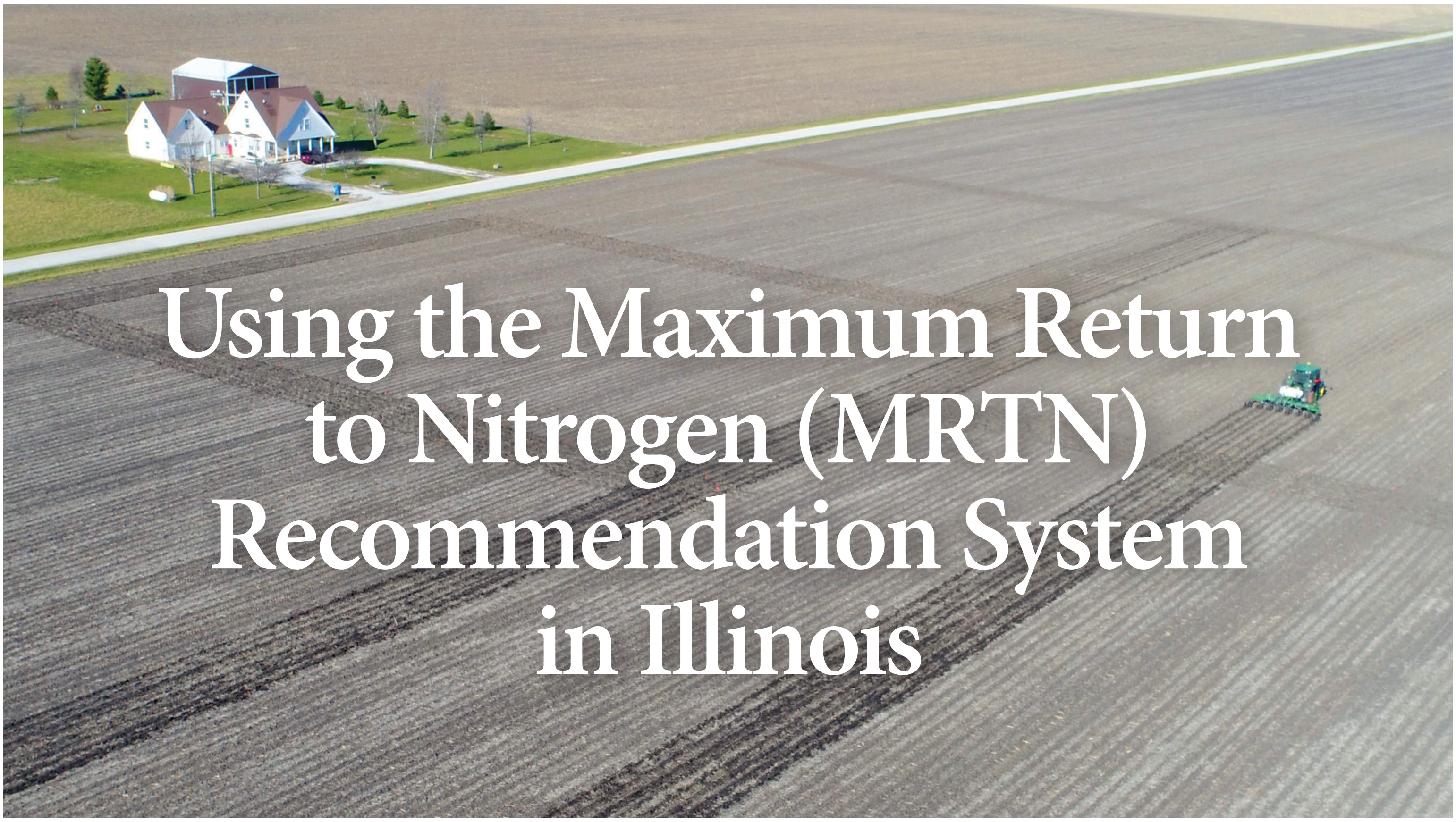

Using the Maximum Return to Nitrogen (MRTN) Recommendation System in Illinois

A Guide to Understanding the N Rate Calculator: A Responsible, Reliable and Defensible Nitrogen Recommendation for Corn in Illinois

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This guide explains how we use nitrogen research results to generate N rate recommendations (or guidelines) for corn in Illinois. This system represents a research-based but "common sense" approach to nitrogen—we have enough research to replace the "do I have enough N?" question with "what is the best strategy?" for nitrogen management on your farm.

This system is based on nitrogen rate trials performed on farmers' fields and at University of Illinois research centers throughout the state. The data from these trials are used to update the Nitrogen Rate Calculator in order to keep it current with the latest research results.

Many people understand the concept of using data from research to predict how a management factor will work the next time; that's the whole reason we do applied research. But responses to N are highly variable across even nearby fields within the same year, and across years even within the same field. This variability makes it challenging to predict how much N will be needed in any field, even in the same field from one year to the next.

Since 2012 this research has been funded by the Illinois Nutrient Research & Education Council, whose support has helped to accelerate the building of the database, and hence the improved soundness of the N rate guidelines. NREC emphasizes the importance of research that engages farmers in the research process, on their production fields. This helps assure that the results are based upon real life corn nitrogen responses.

This guide explains the terminology and the process for determining the Maximum Return to Nitrogen (MRTN), which is the N rate that maximizes the dollar return to N. We also address commonly asked questions and dispel myths about nitrogen use, all in an effort to support sound agronomic principles, and to increase economic return while respecting our environment.

Terms used in this guide

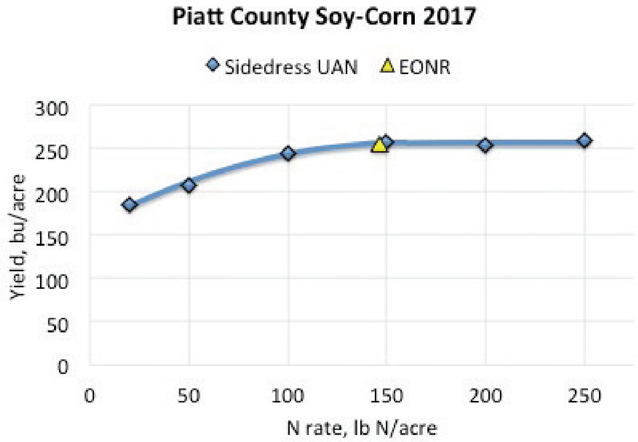
Economic Optimum Nitrogen Rate (EONR) The EONR is the point, identified in an N rate trial, at which the last pound of applied nitrogen produces just enough extra yield to pay for that pound of nitrogen. If a pound of N costs $0.40 and corn sells for $4.00 per bushel, the last pound of N needs to increase the yield by 1/10th of a bushel in order to pay for that pound of nitrogen.

Nitrogen Response Trial This is a planned experiment in which a set of N rates are applied to strips, with each rate applied to three (or more) strips to make sure the yield differences are due to the N rate and not just to which strips got "lucky" or "unlucky" by ending up in a better or worse part of the field. Yields are averaged across the strips that got the same N rate, and computer software fits a curve to the points.

The photo here is of an on-farm rate trial in which applied N rates of 0, 50, 100, 150, 200 and 250 pounds per acre are replicated three times in the field.

N Response Curve To use the results from an N rate trial, we need to know the shape of the N response, not just the yield that each N rate produces. This shape is described mathematically by an equation that describes the curve; this equation allows us to calculate the EONR, defined above.

The illustration here shows the curve developed from a rate trial in Piatt County in 2017. Twenty pounds of N was applied with the planter, so the lowest N rate is 20, not zero. The blue diamond shapes are the actual yields averaged over three strips (replicates) at each N rate, and the yellow triangle represents the EONR calculated using the response curve. This shape is very typical, although the amount of N needed (146 pounds N per acre) to produce a high yield (256 bushels per acre) is less than we often find.



The shape of this response is called "quadratic plus plateau." The shape has the equation of Yield = 161.4 + 1.198 x N rate – 0.00375 x (N rate)^2 up to the N rate of 160 lb. N/acre; the yield remains flat (at 257 bushels per acre) from 160 up to the maximum N rate of 250 lb. N/acre.

Nitrogen Rate Calculator or "Calculator" The Nitrogen Rate Calculator, located at http://cnrc.agron.iastate.edu/ is the on-line tool hosted by Iowa State University that uses the N response data from hundreds of Illinois trials to produce an Illinois N rate guideline that we call the Maximum Return to Nitrogen (MRTN) rate. We add new data and take out some older data each year to make sure that the MRTN values represent the most recent N responses under current management practices and hybrids.

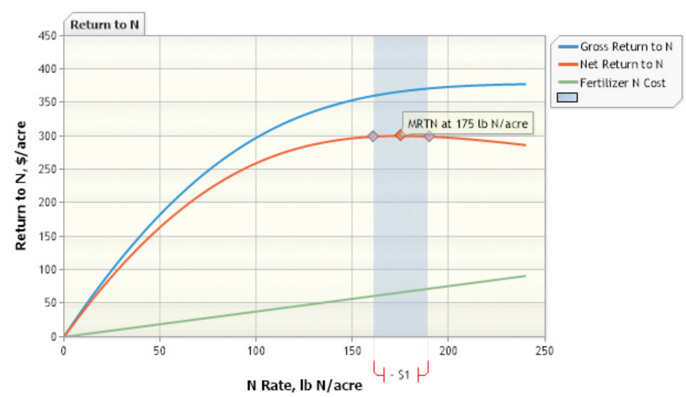
We separate Illinois results to produce separate calculations (MRTN values) for Northern, Central and Southern regions of Illinois as well as the Lake Springfield Watershed, which is a subset of the Central Illinois region. The map here shows the boundaries between regions. Trials are separated into those with corn following soybean and corn following corn, with separate MRTN calculations for each.

Return to N (RTN) This is a dollar amount per acre of how much profit (net return) nitrogen produced at a given N rate in a trial or across a set of trials. It is calculated for a given N rate by taking the yield increase from N at that rate (the yield without fertilizer N is subtracted) times the corn price, then subtracting the cost of N (the N rate times the price of N). For an individual trial, the rate producing the maximum RTN is the EONR.

MRTN "Maximum Return to Nitrogen" is the N rate at which the RTN is at its highest point across a set of trials. The MRTN, shown in the Calculator output here with N price at $0.38/ lb. and corn at $3.80/bushel, is 175 pounds of N per acre for corn following soybean in Central Illinois. Based on combined results from 267 previous N response trials, this is the N rate that the data predict will achieve the highest return to the investment in nitrogen at these prices. On the graph, the top curve is the gross return to N (yield added by N times price), the bottom line is the cost curve (N rate times N price), and the middle curve is the top minus the bottom, or the RTN curve.

State: Illinois
Region: Central
Number of sites: 267
Rotation: Corn Following Soybean

Nitrogen Price ($/lb):	0.38
Corn Price ($/bu):	3.80
Price Ratio:	0.10
MRTN Rate (lb N/acre):	175
Profitable N Rate Range (lb N/acre):	160 - 189
Net Return to N at MRTN Rate ($/acre):	$300.31
Percent of Maximum Yield at MRTN Rate:	99%
Anhydrous Ammonia (82% N) at MRTN Rate (lb product/acre):	213
Anhydrous Ammonia (82% N) Cost at MRTN Rate ($/acre):	$66.50

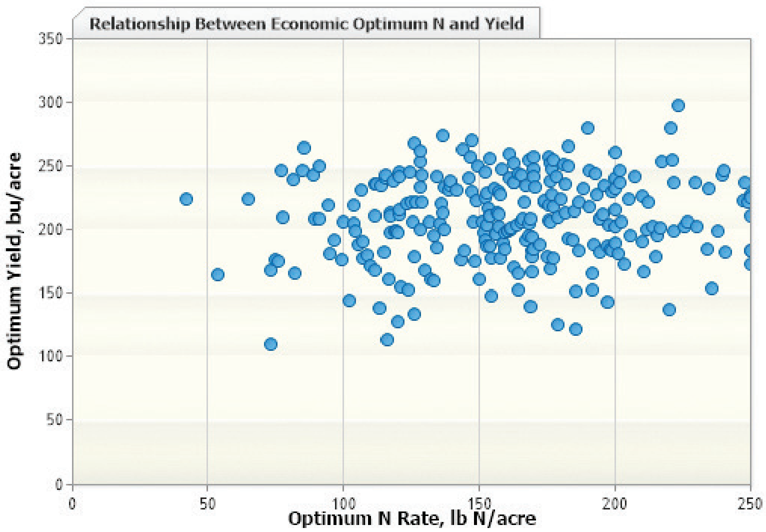


Mineralization The release of nitrogen from soil organic matter in a form that plants can use.

Profitable N Rate Range This appears beneath the MRTN value when you run the N Rate Calculator—it is 160-189 pounds of N per acre in the calculator output shown here. These are N rates below and above the MRTN that are predicted to provide a return to N that is only $1.00 per acre less than the RTN at the MRTN. This range is shaded in the graph.

What's the problem with basing N rates on expected corn yield?

The trials that form the database that the Calculator uses to produce the MRTN produce a range of yields, as we would expect for field trials over sites and years. **But after running hundreds of N trials over the past decade, we find a curious thing: across trials, the EONR values are not very much related to the yield at the EONR rate.** If you click on the "EONR vs Yield" box when looking at the N calculator output, you will see the figure here that illustrates this. This surprising fact seems to counter the logic of the yield-goal based N rate recommendation system that was in place in Illinois from the 1970s through the early 2000s.



In fact, corn that yields more does need to take up more N—we estimate that the crop takes up one pound of N for each bushel that it yields. Some measurements have shown as little as 0.8 pounds of N per bushel, in part because these measurements are often taken at harvest, and the plant may lose more N than the grain takes in during the weeks before maturity. Corn grain has about 0.6 lb. of N per bushel. **How can high-yielding corn need to take up more N but not need more fertilizer N?** Read on for some reasons why this is so.

How is it possible that high yields don't routinely need more N fertilizer than low yields?

Here are some reasons why:

1. High soil organic matter, warm soil early in the season, adequate (not excessive) water, and good drainage tend to produce high corn yields, and also produce larger amounts of mineralized N, with less N loss from soils. So the need for more available N to support high yields is partly met by the larger supply of mineralized N from the soil, meaning that a lower percentage of the N needs to come from fertilizer.

2. On the other hand, soils that are cold, dry, or wet can limit root growth and activity to the point where not all of the "plant available" N in the soil is available for the plant to take up. Such conditions also tend to have lower N mineralization rates and/or increased loss of N from the soil, even as they limit yields. Even with lower yields, such crops may need to get more of their N from fertilizer than when conditions and yields are better. Soil with less organic matter tends to hold less water, and can require relatively more fertilizer N, both because lack of water more often limits yields and because there is less N coming from the organic matter.

Because microbial breakdown of corn residue ties up some N, we tend to see a little more relationship between EONR and yield at EONR across corn following corn trials than we see with corn following soybeans. Still, these correlations are low enough that even if we knew beforehand exactly what the yield would be in a field, we would have no accurate way to guess how much fertilizer N that crop would require.

While yield-based N rate recommendations appeal to our logic, and that system was an improvement over what it replaced, the discovery that actual yield isn't linked to the fertilizer N rate needed to reach that yield was a strong signal that this system wasn't able to predict the N rate for a field very well. This is true for any N recommendation system to the extent that, in rain-fed corn production, we never have much of an idea how the crop will yield, since it's so dependent on the weather.

We also have no way to know, at the beginning of the season, how much mineralized N will be available to the crop. Using the yield without N (at 1 lb. N taken up per bushel) as an estimate of the amount of mineralized N, we have found amounts of mineralized N ranging from less than 25 lb. to more than 200 lb. per acre.

Uncertainty in how much N the crop needs plus uncertainty in how much N the soil will provide, along with never being quite sure about how much of the N we apply will get to the crop, makes it impossible to know with any precision how much fertilizer N a corn crop will need at the beginning of the season. **This is the real reason we developed the N rate calculator—it is the best estimate as to how much fertilizer N corn grown in the soils of a region will need, based on how much the crop needed in past research trials in that region.**

Does the "1.2 Is the Most You Should Do" recommendation no longer work?

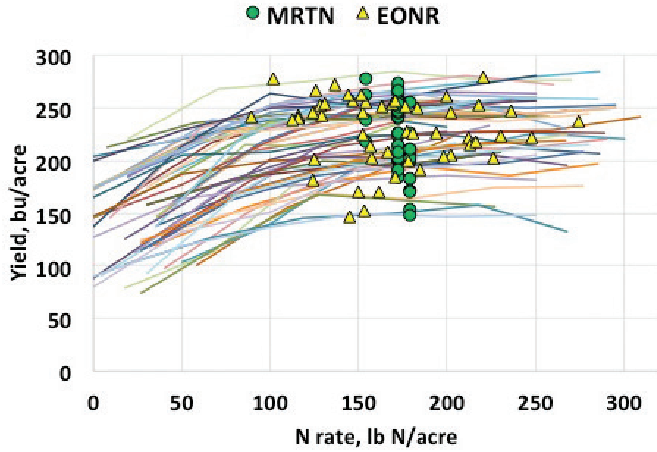
As corn yields increased through the 1980s and 1990s, yield-based N rates started to separate from the rates of N fertilizer that ongoing trials were showing were actually needed. In northern and central Illinois, yields above 200 bushels per acre became commonplace by the end of the 1990s. So the yield-based N recommendation system, which in Illinois was summarized by the slogan "*1.2 (lb. N per bushel of expected yield) is the Most You Should Do*" was recommending that producers use 200 to 250 or more pounds of N per acre based on realistic yield expectations. In contrast, in southern Illinois or in other areas with lighter soil where yields were often less than 150 bushels, yield-based N rates were not adequate to maximize profit, and most producers used more than the "1.2" in those soils.

Hybrid improvements that produced better yields, and better root systems, were large factors causing the need to change the nitrogen recommendation system. Roots became better at taking up water in the soil and the nutrients, including N, that came with the water. In lighter or low-organic matter soils, the need for N exceeded the ability of the roots to take up enough N at the (lower) recommended N rates, and there was less mineralized N available as well.

What the N rate trials and resulting response curves tell us

The figure below shows nitrogen rate responses of corn following soybean in 51 on-farm trials in Illinois in 2017.

Instead of calculated curves, this figure has straight lines connecting the yields, each of which is an average of 3 or 4 replications at each N rate. Most of these have yields increasing as N rate increases, then leveling off. Yields drop off at higher N rates in a few cases, but that's not very common with current hybrids. Note that the EONR values (one for each trial), found by fitting curves to the data, are usually located between two of the N rates.



Each set of N response data in the figure has two symbols associated with it:

- The yellow triangle is the EONR value and the yield at that N rate.
- The green circle is the MRTN N rate and the yield at the MRTN. The MRTN rates are from the Calculator with the database through 2016 (before the 2017 season); these were considered the best prediction for N rate to use in 2017.

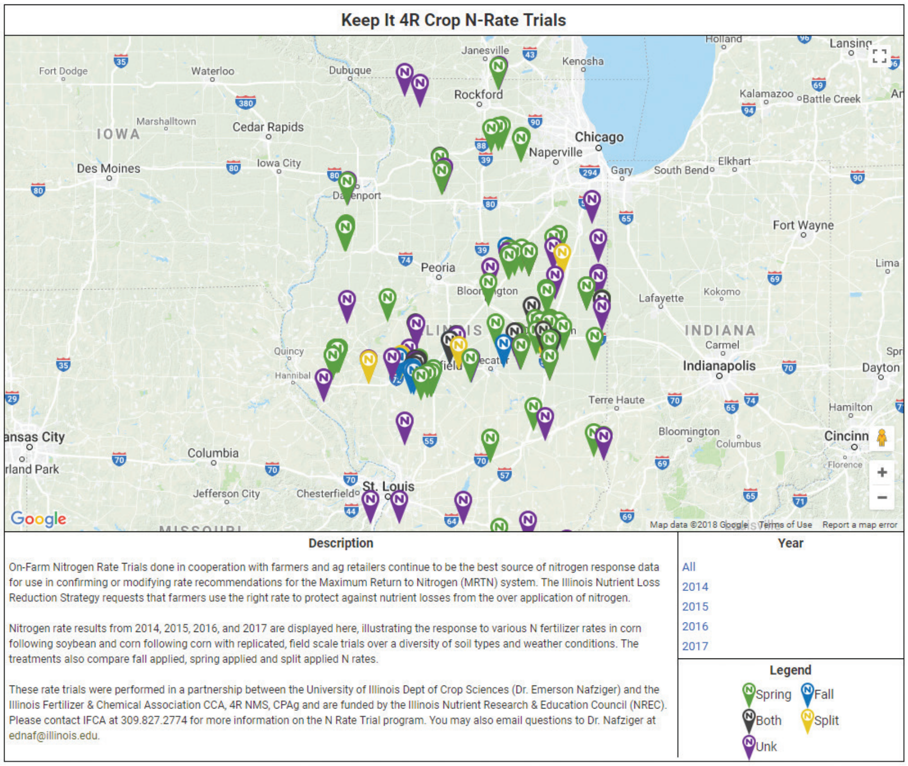
There are three vertical arrays of MRTN rates (green circles), each corresponding to the Illinois region in which those trials were conducted. These values, produced by the N Rate Calculator, decrease from the north (the green circles on the left) to central (middle set of green circles) to south (circles on the right) for corn following soybean. **The green circle shows how well using the MRTN would have done in predicting the best N rate for that field in 2017. The difference between the MRTN and the EONR values show how far off the MRTN rate was from the actual best rate (the EONR) in each field.**

At first glance, the fact that the EONR values (yellow triangles) are so spread out, and most of them are not very close to the green circle, makes it looks like the MRTN failed to predict the best N rate for most fields in 2017. Of the 51 sites, 21 of the EONR values are to the right (higher than) the MRTN values, indicating that the MRTN rate wasn't high enough. At the other 30 sites, the EONR values are to the left (lower than) the MRTN rates, meaning that the MRTN was higher than the actual N rate needed. **But across all 51 trials, the average MRTN was 172 pounds of N per acre, and the average EONR was 168 pounds of N per acre—the difference was only 4 pounds of N, and the MRTN was slightly higher than the actual best rate. The average yield at the MRTN rate was 226 bushels per acre, and the average yield at the EONR was 229 bushels per acre, or 3 bushels more.**

If we took 226 bushels as the expected yield, the "1.2" recommendation would have been 1.2 x 226 = 271 – 40 lb. (the soybean "N credit") = 231 lb. N per acre, **nearly 60 lb. more** than the MRTN. Using such a high rate would have increased yields by more than a bushel or two in only four or five of the trials, but would have lowered profitability overall. More importantly, it would have meant using more N than needed in the majority of the fields, and some of this unneeded N would have likely ended up in tile lines.

Some might focus on the EONR values (yellow triangles) on the right side of the figure and see these as a sign that the MRTN doesn't recommend enough N. Even among these trials, yields increase fairly gradually in the range of the MRTN, so using less N than the crop actually needs isn't that costly. The real message is that needing a lot more N than expected is rare enough that adding "insurance" N costs more than is justified. Using only the amount of N needed (the MRTN) also gives important consideration to the environment by avoiding the high rates that may contribute most to nitrogen losses through tile drainage water.

Examples of MRTN response curves from NREC funded on-farm trials are available to view at the Illinois Fertilizer & Chemical Association website at www.ifca.com under "Keep it 4R Crop" and "N Rate Trials."



How can a "One Size Fits All" MRTN value be the right rate for every field in a region?

It can't. We can only know what the best rate for a field (or part of a field) is if we do a trial in that field (or part of a field) and even then, we only know this was the best rate for the field in that season, after we have results.

During the development of the Calculator, those of us working on it (primarily Dr. John Sawyer at Iowa State University) sorted the N response data into groups using factors like tillage, soil parent material, productivity level, etc. and found that breaking responses into categories did not produce consistently different MRTN values for the various categories. That was somewhat disappointing but not really surprising; it's mostly a strong signal that the interaction of soil, crop and weather in each field, each year, obscures differences in N response due to factors such as tillage.

It is critical that the MRTN values be accepted as they appear in the Calculator, without making further adjustments based on previous crop. We do know that having corn as the previous crop increases the N rate needed compared to having soybean as the previous crop. Under the old yield-based N recommendation system, this was handled by subtracting a "soybean N credit" to give the recommended N rate when soybean was the previous crop. The Calculator makes this distinction as well, but the "adjustment" is built-in—we use only corn following corn trials to generate that MRTN, and only corn following soybean trials to generate the MRTN when you choose soybean as the previous crop in the menu.

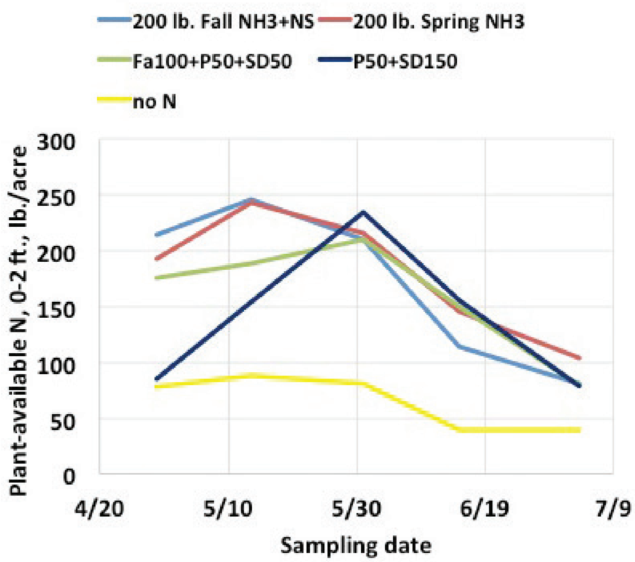
This doesn't mean that we should never do any tweaking of N rates or management based on soil or other factors within or among fields. Raising the N rate towards the top of the most profitable N rate range produced by the Calculator, for example, might make some sense for lower-organic matter parts of a field, and lowering the rate some (and possibly splitting N applications) might make sense in soils with high organic matter but poor drainage.

In other words, we can use sound principles to manage N responsibly, without resorting to the very high N rates that we now know are unsound economically and environmentally.

What about nitrogen loss?

Over the years we've spent a lot of time and energy worrying about nitrogen loss, and wondering if there's enough left to meet the crop's needs. Let's review a few common misunderstandings about N loss:

1. A high percentage of fall-applied anhydrous ammonia stabilized with N-Serve™ has typically remained in the soil to become available to the crop in the spring, even when it's been wet in the fall, winter or spring. **The NREC Funded Nitrogen Tracking Study has demonstrated that there is less loss of fall-applied N than we often expect.** This figure shows average plant-available N (nitrate plus ammonium) over three sites in Illinois in 2018. Fall and spring-applied N had similar amounts of N in the soil through May, and both had more soil N at the end of May than the treatment with 50 pounds at planting plus 150 pounds sidedressed, because it was applied after June 1. Soil N decreased as the crop took up nitrogen. In most of these trials we have found little or no difference in yield among treatments that had the full rate of N, regardless of the amount left in the soil at different times.



2. Yellow or pale green corn in early spring is often caused by cool temperatures that directly affect leaves and roots, or is a symptom of a problem with the roots, possibly due to soil conditions that don't allow roots to work well. It's seldom caused by lack of soil nitrogen, if some N has been applied. **If roots are not in a condition to take up nitrogen, adding more nitrogen will not fix the problem.** Give it time and as long as plants stay alive and diseases don't set in, green color will return as soil conditions improve and as roots get access to air and contact with more N.

3. **Ensuring there is enough crop-available N in the soil when corn is in early growth stages is critical.** NREC funded research has shown that it's more important to have nitrogen there before side-dress time than wait until side-dress to apply most or all of the N. Yields in the study (above) have in some cases been a little higher with all of the N applied early rather than waiting to sidedress most of the N. By the same token, late application of nitrogen, especially as "additional" nitrogen, seldom increases yield compared to the same amount of nitrogen applied earlier in the season. This is because the soil functions more effectively as a "reservoir" for N (into which it also pumps mineralized N) than most people think.

4. **Based on our research, we discourage the use of "insurance" or "extra" nitrogen to counteract wet soil conditions or the expectation of high yields that could mean more N uptake.** Preventing a deficiency is preferable to trying to fix a deficiency, and a crop that is deficient due to wet soils and root damage may not be possible to "fix." The soil supply of N is typically greater when conditions are good for crop growth—this often limits the response to N that is added on top of adequate rates applied earlier in the season.

Does timing of nitrogen applications make a difference?

Once you have determined the MRTN for your operation, does it matter when the N rate is applied?

It is better to manage applied nitrogen to decrease loss than to simply apply more nitrogen, especially if extra nitrogen is applied in ways that can contribute to ongoing loss. You can lower the risk of nitrogen loss by either slowing the conversion of ammonium to nitrate (using a labeled nitrification inhibitor) or by delaying application of at least some of the N to shorten the time between application and crop uptake.

Our research shows that we typically lose less nitrogen than we think between planting and early June, when nitrogen uptake increases, and the crop seems to benefit from having more (or all) of the nitrogen available at planting to minimize the chances that the crop will develop deficiency.

While we don't have convincing evidence that splitting N into several applications is usually problematic, we have found no consistent improvement in yield or lowering of the amount of N needed when we split N applications into planting-time plus side-dress applications. Most of these results are from silt loam or silty clay loam soils with more than 2.5 percent organic matter; soils with less organic matter, a course texture, or with poor drainage may show more benefit from splitting N.

Apply enough N at or before planting. It is better to apply more than half of the N early with the rest of the split-application than to reserve most of the N for in-season applications. "Spoon-feeding," which has a great deal of appeal, carries costs and risks. The risk that soils will be too wet or too dry will often exceed the potential benefit of the late application. That's especially true when the "spoon" delivers more N to the crop than the crop actually needs.

Does the nitrogen rate calculator take a cover crop into consideration?

Not yet, at least not with confidence. Some of the nitrogen tied up during the breakdown of cover crop residue will likely become available as the residue breaks down, but the amount of N that will become available and the timing of its release are unpredictable. NREC is funding additional research in this area, but for the time being we do not have enough data to determine if the cover crop residue is a reliable source of nitrogen for the corn crop that follows it. We do know that if the cover crop residue has a high C:N ratio (for example, residue from cereal rye) its breakdown initially involves taking up N from the soil, and the corn crop following cereal rye cover crop is more likely to need more fertilizer N rather than less.

What about using N on soybeans?

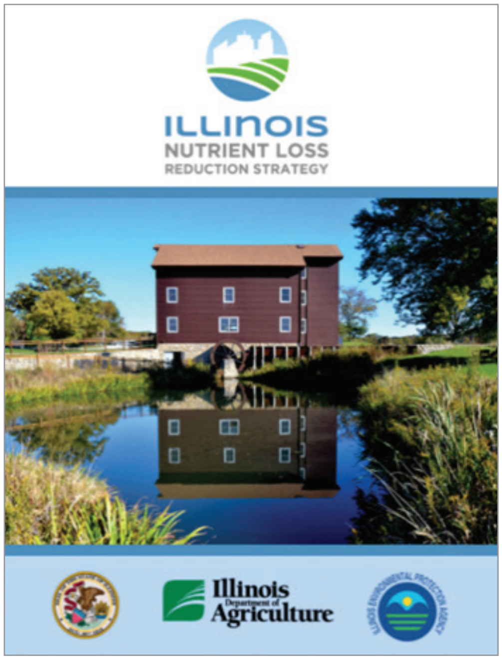
As soybean yields have increased in recent years, some have raised questions regarding the soybean crop's ability to both provide the energy (from photosynthesis) for yields of 75 or 80 bushels per acre or more, while at the same time providing the energy needed to fix the 350 to 400 pounds of N per acre that such a high-yielding crop will take up.

Our recent research on use of fertilizer N on soybeans in Illinois has shown some small increases in yield in some cases, but we find no more response to N when yields are higher than when they are just average. We did see sizeable increases in yield in two of three years on a lighter-textured, irrigated soybean field near the Illinois River north of Peoria. But adding fertilizer N has also decreased yields occasionally, depending on when and how much N we apply.

We use N fertilizer on corn because we know the crop needs it, and that it will increase yield and profits. That's not the case with soybeans, which continue to demonstrate their ability to fix all the N they need. Until and unless we discover how to predict when soybeans will consistently respond to fertilizer N, we'll be better off economically and environmentally if we do not apply fertilizer N on soybeans. **With very few exceptions, Illinois farmers who harvested field averages of 80-bushel soybean or more in recent years did not use fertilizer N. That's the lesson we should pay attention to.**

In the end, why is getting the right N rate so important – why not just use plenty?

Nitrogen fertilizer rates for corn in much of Illinois simply do not need to be as high as we think. We simply cannot justify high nitrogen rates in terms of economic return or environmental consequences. Today's corn hybrids, along with improved planting technologies, improved drainage, and seed and crop protection technologies have produced a much more efficient corn plant that can withstand some challenging environmental conditions and still produce remarkable yields in most years.



In the past we didn't give as much consideration to the consequences of "too much" nitrogen, but there are consequences. Illinois rivers and streams are being monitored for their nitrogen and phosphorus levels as part of the Illinois Nutrient Loss Reduction Strategy. Much of the nitrogen and some of the phosphorus in rivers and streams come from agricultural non-point sources, including tile drainage and overland flow.

Agricultural production across the United States, and certainly in Illinois, is challenged to demonstrate that we are incorporating sound agronomic, economic and environmental practices in the decisions that we make in producing food. The USEPA and the US Geological Survey continue to rank Illinois #1 in the amount of nitrogen loss reaching the Gulf of Mexico, and we have also seen nitrogen losses impact local water quality in our lakes, rivers and streams. The Illinois Nutrient Loss Reduction Strategy calls for a 15% reduction in nitrogen losses by 2025. To get there, we will need to reduce the amount of N coming from agricultural non-point sources.

As farmers work to meet these challenges, having a reliable and scientifically defensible method to determine a sound nitrogen rate for corn is paramount. No one knows what the future may hold, but if current consumer trends and demands for accountability in agriculture continue, responsible nitrogen use will remain in the forefront of those demands. The MRTN provides a science-based, flexible range of nitrogen rates that farmers across Illinois can use to meet these expectations. **Illinois is in an excellent position to defend our nitrogen rates and freedom to operate when farmers use the MRTN.**

The mission of the University of Illinois land grant system is to provide the best possible recommendations to Illinois farmers based on the most current, unbiased science available to us. The creation of NREC in 2012 has provided a sustainable source of funding upon which to continue scientific discovery, on actual Illinois farm fields.

For questions about this guide, please contact Dr. Emerson Nafziger at ednaf@illinois.edu.

For electronic or printed copies of this guide, please contact Julie Armstrong at NREC at Julie.Armstrong@illinoisnrec.org or visit https://illinoisnrec.org.

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