Science Societies

Which recommendation tools are best for achieving the economically optimal nitrogen rate?

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Determining which corn nitrogen (N) fertilizer rate recommendation tools best predict crop N need would be valuable for maximizing profits and minimizing environmental consequences. To assist farmers with corn N rate decisions, multiple publicly available recommendation tools have been developed over the years. With the numerous tools available to farmers, the question arises: which of these tools consistently recommend N rates closest to the economically optimal N rate (EONR)?

Nitrogen (N) fertilizer inputs are generally necessary for optimizing corn yields, but for this crop, N is the most challenging plant nutrient to manage optimally. It is challenging because crop N need is impacted by a combination of weather conditions, management practices, and the crop's genetics. These factors, expressed through the soil and distinctive growing conditions, can change crop N need both between and within fields. Being able to manage this complexity correctly and apply the correct rate of N is paramount for optimizing profits and minimizing N lost to the environment. To assist farmers with corn N rate decisions, multiple publicly available recommendation tools have been developed over the years. With the numerous tools available to farmers, the question arises: which of these tools consistently recommend N rates closest to the economically optimal N rate (EONR)?

Methods

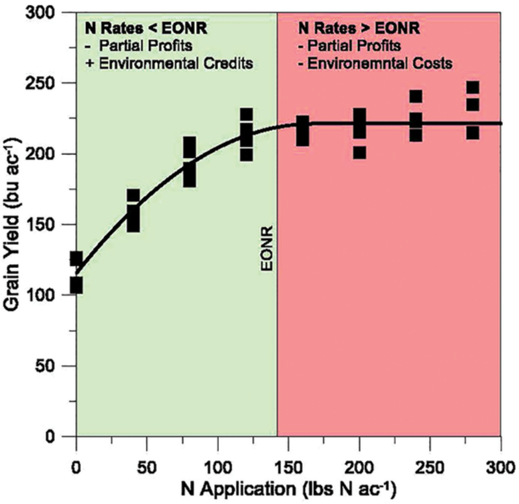

***Figure 1**, An example of corn yield response to increasing N rates. The economically optimal N rate (EONR) was calculated as the N rate that optimized the profitability associated with $4/bu corn and $0.40/ac N fertilizer.*

To answer this question, research was conducted as a part of public–private collaboration between Corteva Agrisciences and eight U.S. Midwest universities from 2014 to 2016 on 49 sites. All states followed a similar protocol for plot research, including site selection, weather data collection, soil and plant sample timing and collection methodology, N application timing, N source, and N rates. Treatments included ammonium nitrate fertilizer rates between 0 and 280 lb N/ac in 40 lb N/ac increments applied either all at planting or split where 40 lb N/ac was surface-broadcast at planting and the remaining fertilizer N broadcast at the V9 corn developmental stage. Using at-planting and split N rates and their corresponding grain yields, grain yield to added N response curves were determined, and from that, EONR values were calculated for each site and application timing (demonstrated in Figure 1). Additional information and preliminary results from this study can be found in Kitchen et al. (2017). Publicly available N recommendations tools evaluated in this study to EONR are found in Table 1. All N recommendation tools were evaluated against EONR calculated from each site. The performance of these tools was then compared with each other.

Table 1. Abbreviations of N recommendation tools and their distinctive properties. For more information about each tool, see Ransom et al. (2020)

Tools and abbreviations	Distinctive properties

Yield Goal (YG)	
General	(1.2 × YG) – (40 lb N/ac soybean credit).
Indiana (IN)	High internal N requirement (1.36 vs. 1.2).
Minnesota (MN)	Adjusted by organic matter and soybean credit.
Missouri (MO)	Adjusted by soil organic matter, CEC, and plant population.
Nebraska (NE)	Adjusted by soil nitrate, organic matter, soybean credit, irrigation credit, soil texture classification, and application timing.
State-Specific	Sites within each state only used their respective state's YG method.
Maximum Return to N (MRTN)	Grain yield response to added fertilizer N calculated over multiple years and locations and adjusted for the price of corn and N fertilizer. Recommendations are for a state, substate region, or soil yield potential.
Pre-Plant Nitrate Test (PPNT)	Soil nitrate samples were taken before planting (0–24 inches).
General	MRTN or YG adjusted for measured soil nitrate.
MN	MRTN or YG adjusted for 60% of the measured soil nitrate.
North Dakota (ND)	ND YG adjusted by soil nitrate.
Wisconsin (WI)	MRTN or YG adjusted for measured soil nitrate (0–36 inches).
Late Spring Soil Nitrate Test (LSNT)	Calculated using measured soil nitrate concentration taken at the ~V5 corn growth stage. Uses an upper critical limit. Additional adjustments made under conditions of high spring precipitation. Compared under scenarios with 0 and 40 lb N/ac applied at-planting.

Pre-Sidedress Soil Nitrate Test (PSNT)	Soil nitrate samples were taken at the ~V5 corn growth stage (0–12 inches). All PSNT compared under scenarios with 0 and 40 lb N/ac applied at-planting.
General	MRTN of YG adjusted proportionally to measured soil nitrate. Uses upper and lower critical limits.
IN	Expected yield adjusted for soil nitrate concentration.
WI	Uses upper and lower critical limits. Adjusted for soil yield potential.
Maize-N	Computer simulation of soil and crop processes to account for N uptake and removal from the root zone. Uses information based on soil, crop hybrid, management, economic inputs, and historical and daily weather.
Canopy Reflectance Sensor	Based on reflectance wavelengths measured with proximal sensors.

Results and Discussion

The amount of N needed to optimize yield across all 49 sites varied with required fertilizer N rates between 0 and 280 lb N/ac. Four sites needed very little N fertilizer to reach optimal yields (EONR < 40 lb N/ac), and six sites needed large amounts of N (EONR > 240 lb N/ac). Evaluating tools against this dataset with extreme fertilizer N need helped identify tools that were robust across a wide range of growing conditions.

One of the metrics used to evaluate these tools was how close their N recommendations came to EONR when averaged across all sites (Figure **2**). Using this metric, the best-performing tools were the MN YG, IN PSNT 40, General PSNT 0, WI PSNT 0, WI PPNT, and canopy reflectance sensing. For these six tools, all but canopy reflectance sensing used a soil nitrate sampling as a part of the recommendation. Incorporating soil nitrate into these recommendations helped reduce recommendations for sites where no additional fertilizer N was needed. On the other hand, these tools tended to underestimate EONR for sites where a large amount of N fertilizer was needed.

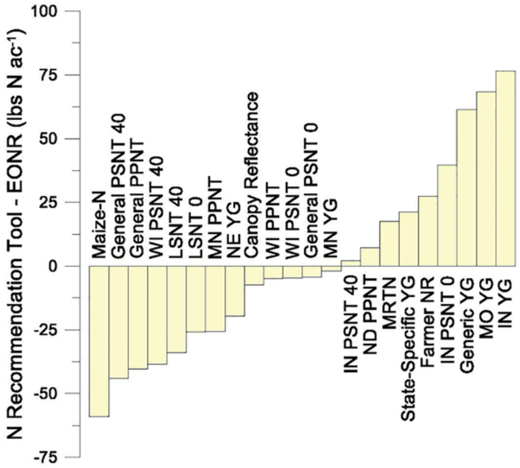

***Figure 2**, The graph shows the average difference between each N recommendation tool and the economically optimal N rate (EONR). Tools used for both planting and split N application timing were found similar, and therefore recommendations shown are averaged across timings.*

The difference shown in Figure **2** does not take into account the *error* around this value. Some tools on average recommended N approximately the same as EONR, but this resulted because the values of sites with overapplication were approximately the same as the values of sites with underapplication. Therefore, another metric used was ranking the tools based on the percentage of sites that came close to EONR (Figure **3**). Sites within ± 27 lb N/ac of EONR were considered reasonably close to EONR (or "good"). Results for at-planting tools with the highest percentage of "good" sites included MRTN, NE YG, and WI PPNT, MN PPNT, and the Farmer NR. Split-application tools are shown in Figure **4** with the highest percentage of "Good" sites including canopy reflectance sensing, LSNT 45, General PSNT 0, MRTN, and IN PSNT 45. The majority of these tools were also soil-based recommendations. The exceptions are the canopy reflectance sensor and MRTN. Both of these tools tended to overestimate sites that required little additional N fertilizer and underestimate sites where a large amount of N fertilizer was required to optimize yield. Where these tools performed well were on sites that tended to require between 120 and 200 lb N/ac.

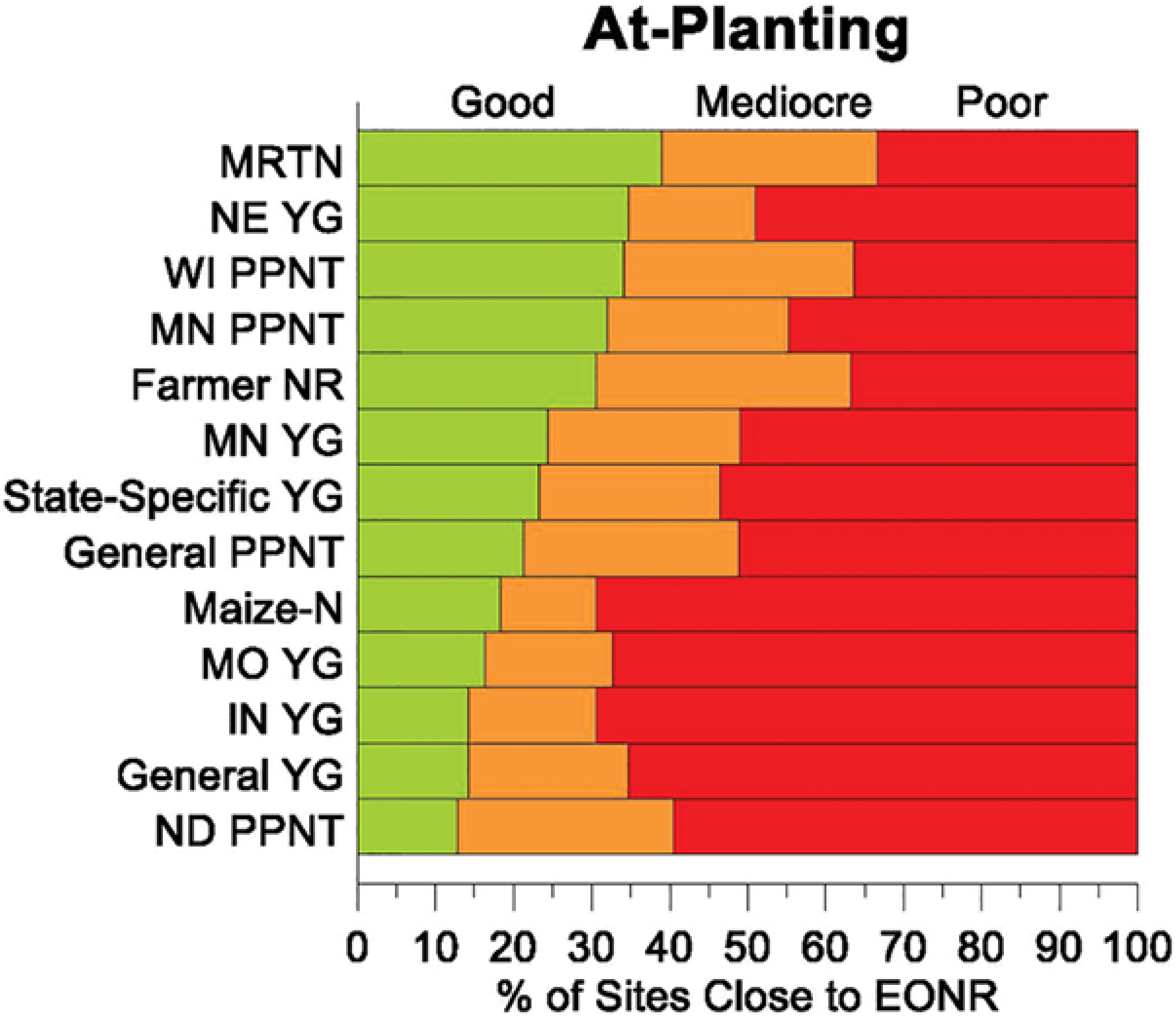

***Figure 3**, The percentage of sites for the at-planting tools' recommendations that came within: ± 27 lb N/ac of the economically optimal N rate (EONR; "Good"), ± 54 lb N/ac of EONR ("Mediocre"), and > 54 or < ?54 lb N/ac of EONR ("Poor").*

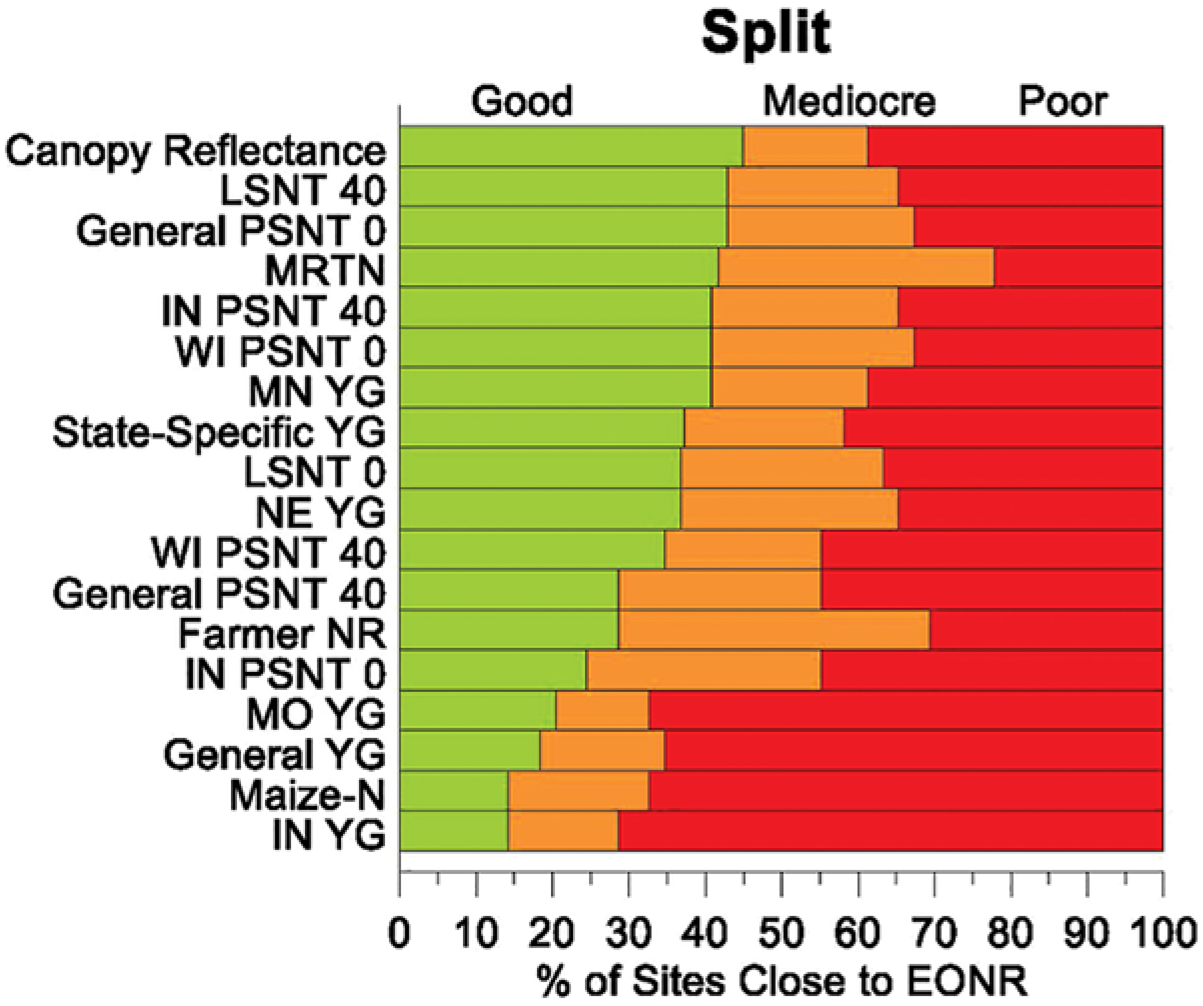

Figure 4, *The percentage of sites for the split tools' recommendations that came within: ± 27 lb N/ac of the economically optimal N rate (EONR; "Good"), ± 54 lb N/ac of EONR ("Mediocre"), and > 54 or < ?54 lb N/ac of EONR ("Poor"*

Of note, tools that did not perform well with this dataset were some of the YG-based tools (i.e., General YG, IN YG, and MO YG) and the Maize-N crop growth model. These YG-based tools tended to overestimate EONR across all sites (Figure 2) and had a minimal percentage of sites classified as "Good" (Figures 3 and 4). These findings are similar to what others have reported, and hence, why many of the Midwest states have moved away from YG-based recommendations (Vanotti & Bundy, 1994; Morris et al., 2017). The Maize-N crop growth model was one of the poorest-performing tools as it greatly underestimated EONR (Figure 2) and had one of the lowest percentages of sites classified as "Good" (Figures 3 and 4). Crop growth models show promise as they attempt to take into account weather, management, and genetic interactions known to affect crop N need. This particular crop model correctly identified two of the four sites where no additional N fertilizer was needed for both at-planting and split N applications but falsely recommended applying very little N for five at-planting and three split sites where much more N fertilizer was needed. Continued modeling efforts for N recommendations will require more calibration and validation over diverse environments.

Many different metrics could be used to evaluate these tools. Some are discussed in more detail in the corresponding *Agronomy Journal* article (**https://doi.org/10.1002/agj2.20035**), including how well these tools can predict EONR, a profitability analysis, and an environmental assessment (Ransom et al., 2020).

Conclusions

Many N recommendation tools are available to help farmers make N management decisions. No N recommendation tool was ideal for all growing conditions of this study. There were only a few tools that, when averaged across all sites, came close to EONR. However, there was a lot of error associated with these tools as no one tool that was able to recommend N rates within ± 27 lb N/ac of EONR for more than 50% of the sites. This could be the result of diverse soil and environmental conditions represented by the extensive geographic region of this study relative to the area from which the tool was developed and calibrated for N recommendations. Given these results, the most successful tools were MRTN, canopy reflectance sensing, or those based on soil sampling (e.g., PPNT, PSNT, and LSNT).

Overall, these findings demonstrate the difficulty of recommending rates close to the EONR and that while current publicly available N recommendation tools may be successful on individual fields or subregions, they were not universally reliable over the diversity of soils and weather in this study. Refinement of current tools or development of new tools that are adaptive and more responsive to soil and weather conditions have the potential for improved performance.

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