Nitrogen use in corn – What long-term data tells us

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Introduction

Nitrogen continues to be an important input for achieving high corn yields. Use decisions tend to be short-term focused (this years' crop), without thinking about implications on the long term. However, fields typically receive N each year corn is grown. Therefore, N is really a long-term (on-going) input in every field that routinely has corn produced. Long-term research trials provide interesting insights into several aspects of N use in corn production: corn yield response and variability across time, residual effect of historical N application, N rate guidance evaluation, rotation cropping effect, and expectation of rate decision impact on long-term profitability. Seven long-term N by crop rotation study sites at Iowa State University Research Farms provide data across a 17-year period to help inform about N use in corn (Northwest, Northern, Northeast, Armstrong, McNay, Southeast, and Ag Engineering/Agronomy). In these studies, N fertilizer was applied to corn spring preplant or early sidedress as urea or urea-ammonium nitrate solution at seven N rates (five rates at one site), with continuous corn and corn in rotation with soybean.

General corn yield response to N rate

When no N was applied to corn across the seven sites during the 2000-2016 period, the yield in continuous corn (CC) was approximately 60 bu/acre and in corn following soybean (SC) 110 bu/acre (Figure 1). The mean yield response (increase in yield due to N) was 177% in CC and 70% in SC. These are remarkable yield responses and highlights the important need to supply N (fertilizer or manure) to supplement the soil N supply. Or conversely, the poor corn yield potential if N cannot be applied or applied at inadequate rates. The figure also shows the commonly observed (and known) higher N rate requirement for CC compared to SC. Also, the figure indicates a higher yield potential with rotated corn than continuous corn (more on that later in the paper). The across sites and years response presented in the graphic provides a mean response, and it is known that some regions require higher N rates than others. For example the Corn Nitrogen Rate Calculator (CNRC, http://cnrc.agron.iastate.edu/) provides a different (higher) MRTN rate and Most Profitable N Rate Range in Southeast Iowa (SEIA region) than the rest of Iowa. The point made in the graphic is that N input is required for high and profitable corn production, but also that rates more than optimal do nothing for further increasing yield – past the symbols indicating the economic optimum rate (EONR) for each rotation. This is why N rate is an important management component related to both economic return and water quality.

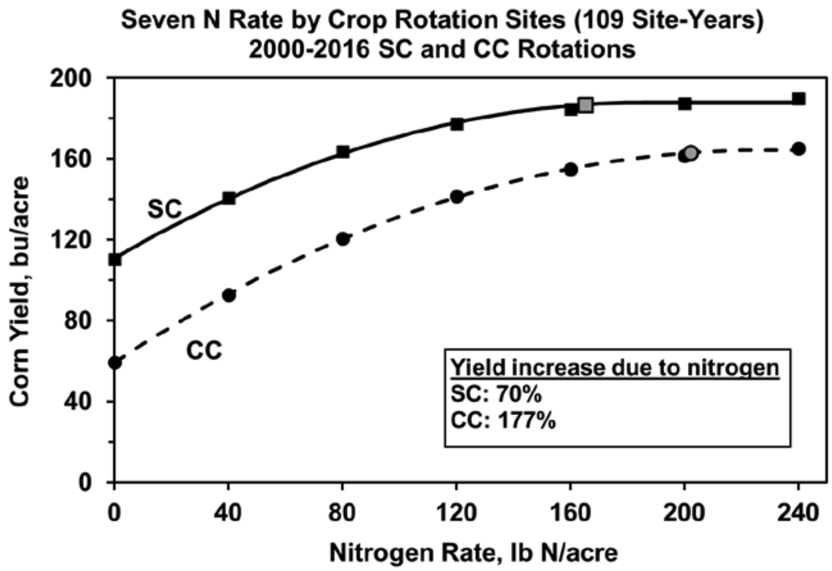

Figure 1. Mean corn yield response to fertilizer N application rate (actual fertilizer N rate applied to corn in each rotation) from seven sites in Iowa across 11 to 17 years for corn following soybean (SC) and continuous corn (CC). Light colored symbols indicate mean optimal N rates for this dataset. Sawyer et al. 2019.

Residual effect of historical N application rate

After 11 to 17 years of N fertilizer applications, N was not applied in 2017 and corn was grown on all plots. That is, corn yields would be a reflection of the historical N rates. Interestingly, an effect of prior N rate on corn yield was non-existent with corn following soybean (the SC rotation), and only a small yield increase in CC at rates greater than approximately the 80 lb N/acre historical rate (Figure 2). Also interesting is that the effect of soybean in the rotation was gone after one year of corn, that is, in the SC rotation there was no difference in corn yield or yield response to historical N application compared to CC when the 2017 corn was grown after the 2016 corn in the SC rotation. In all cases the yields were low, indicating that the soil supplies N, but the N fertilization effect is transitory and that an application cannot be done once for multiple years like can be achieved with P and K fertilization. In other words, the soil is an important supply of crop-available N (from soil organic matter), but the soil does not do a good job of holding “available N”. At these sites, there as only a small nitrate-N increase in the two-foot soil depth across N rates in the late spring with CC, 8 lb nitrate-N/acre from historical no N to 240 lb N/acre, and no difference following soybean. That nitrate amount does help explain the small yield increase when corn followed corn in either historical rotation (corn before the next corn crop in both rotations), but not fully as there would be some soil organic-N differences and perhaps nitrate deeper in the soil profile. However, no matter either potential N source, one year of soybean negated that N supply from historical applications. In other words, N fertilization is a yearly requirement/decision for corn (unless following a forage legume like alfalfa where often no N application is needed).

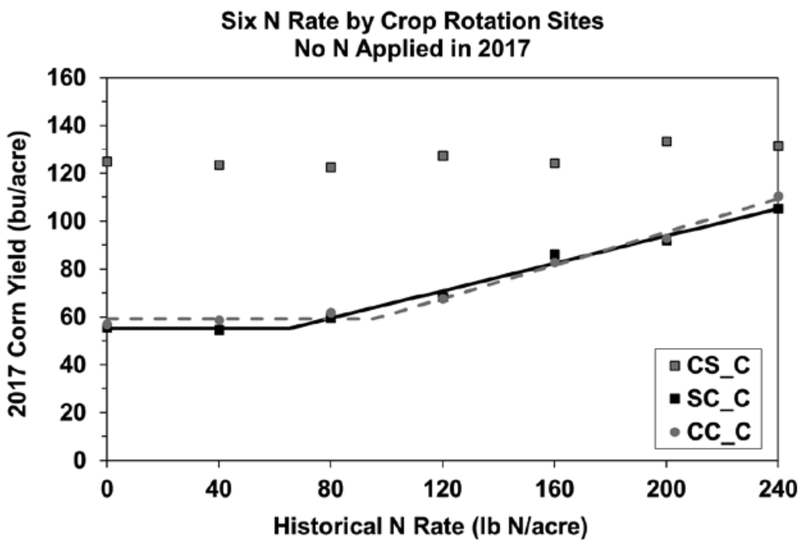

Figure 2. Impact of historical N application rate (after 11 to 17 years) on corn yield in 2017 (for six sites with the same N rates). The soybean-corn rotation had either soybean (CS_C) or corn (SC_C) in 2016 (second letter indicates crop in 2016 and last letter indicates corn in 2017). No N applied in 2017. Sawyer et al. 2019.

Nitrogen and corn yield variability

Applying N increases yield, up to a maximal response plateau (Figure 1), but does not dictate yield level as many factors make up the final yield in a given year – hybrid, environment, precipitation, etc. all interacting. As N rate and concurrent yield increases, the variability (as measured by standard deviation) also increases (Figure 3). At research sites from 2000-2016, the mean corn yield standard deviation was 22 bu/acre with no N applied and 44 bu/acre at 240 lb N/acre for CC, and 29 and 37 bu/acre for SC with the same two N rates. Therefore, farmers should not expect high N rates, including those above optimal rates, to even out yield (reduce variability) across time – other factors have considerable impact. Another statistical metric for yield variability is indexing the standard deviation by the mean yield (called coefficient of variation, Figure 4). That indexing results in a decrease in variation as N rate increases (due to the increase in mean yield), but the variation flattens out (due to the yield plateau at high N rates, Figure 1) and does not decrease at above optimal N rate. Basically the same result with both measures of variation; CC has greater yield variation and increasing N rate does not result in greater across-year yield stability.

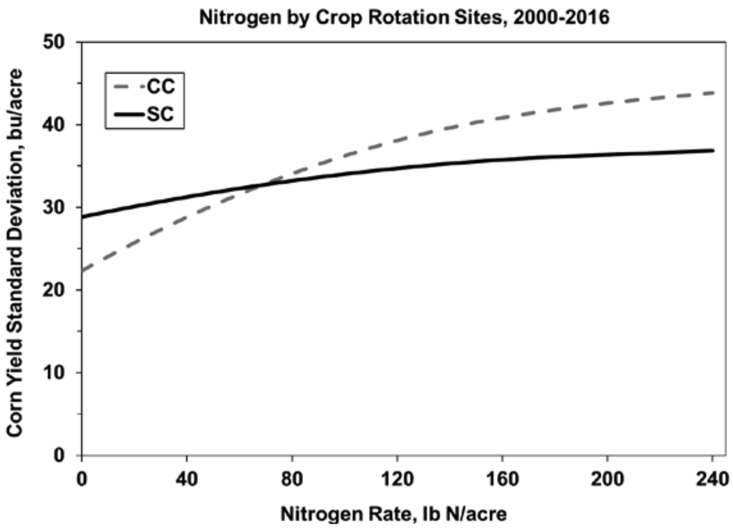

Figure 3. Impact of N application rate on corn yield variation across sites and years (mean standard deviation across 11 to 17 years of N rate applications at seven sites) for corn following soybean (SC) and continuous corn (CC), Sawyer et al. 2019.

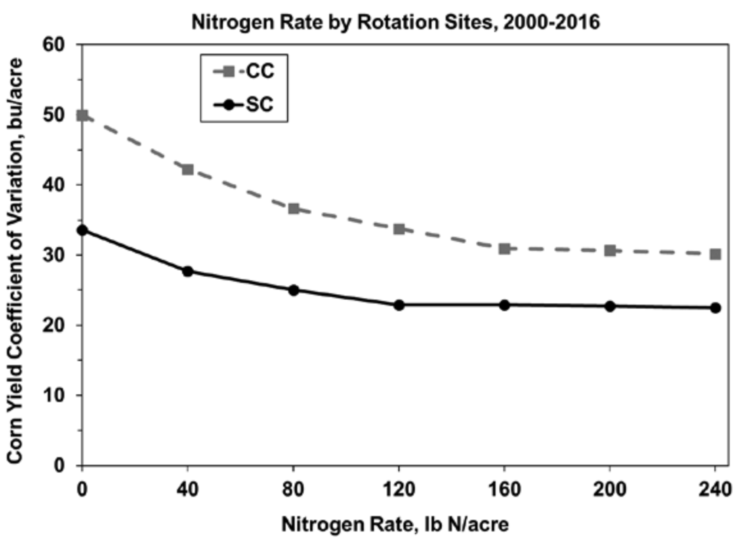

Figure 4. Impact of N application rate on corn yield variation across sites and years (mean coefficient of variation across 11 to 17 years of N rate applications at seven sites) for corn following soybean (SC) and continuous corn (CC). Sawyer et al. 2019.

An interesting aspect of corn yield variability is the effect on the rotation yield difference between CC and SC (Figure 5), using the yield at the agronomic optimum N rate. Across site-years, the mean yield was 13% higher for SC compared to CC. However, as the site-mean yield increased (averaged SC and CC yield each site-year, with a range from 60 bu/acre to 266 bu/acre), the difference between the two rotations decreased significantly. This result means that in high-yield environments, there was little to no yield difference between continuous corn and corn grown after soybean. Conversely, when there were stress conditions and lower yield (ex. dry season), the impact on yield was greater with corn following corn.

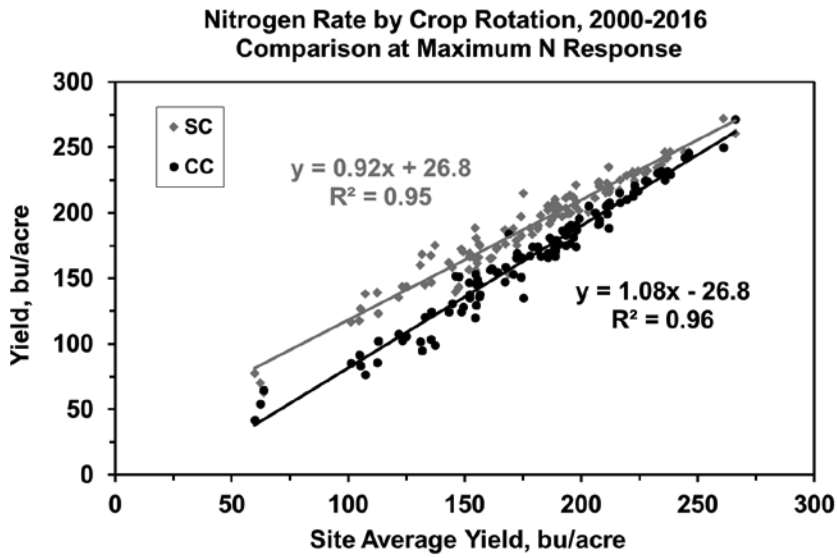

Figure 5. Corn yield comparison between corn following soybean (SC) and continuous corn (CC) at each site-year average yield. The mean yield was 13% higher for SC than CC. Seven sites in Iowa across 11 to 17 years. Sawyer et al. 2019.

Nitrogen response across time

As noted above, corn typically has a large yield response to N fertilizer application. It appears the yield increase has gotten larger across time (Figures 6 and 7), and greater response with CC than SC. Part of the increased yield response is due to a slight decrease in yield in the control (no-N application and reliance on soil N supply), but more due to a larger yield increase with N applied. Also, within the increased N response could be hybrid yield potential enhancement that expresses with applied N, and an increase in precipitation resulting in more reliance on applied N. The increase in yield response points out what many have noticed in recent years, greater sensitivity to deficient N, that is, notice of corn showing N stress. The increase in yield response also points out the enhanced economic sensitivity stress (farmer yield concern) in more recent years.

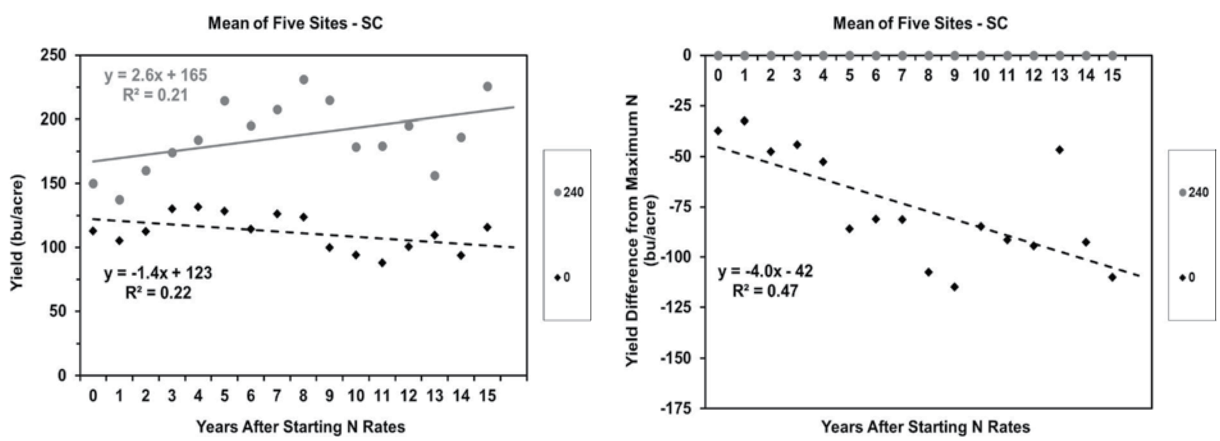

Figure 6. Relationship between corn yield with 240 lb N/acre and no N applied across time for corn following soybean (SC) at five sites. Left graph shows the yield trends and the right graph the yield difference between 240 lb N/acre and no N applied. Sawyer et al. 2019.

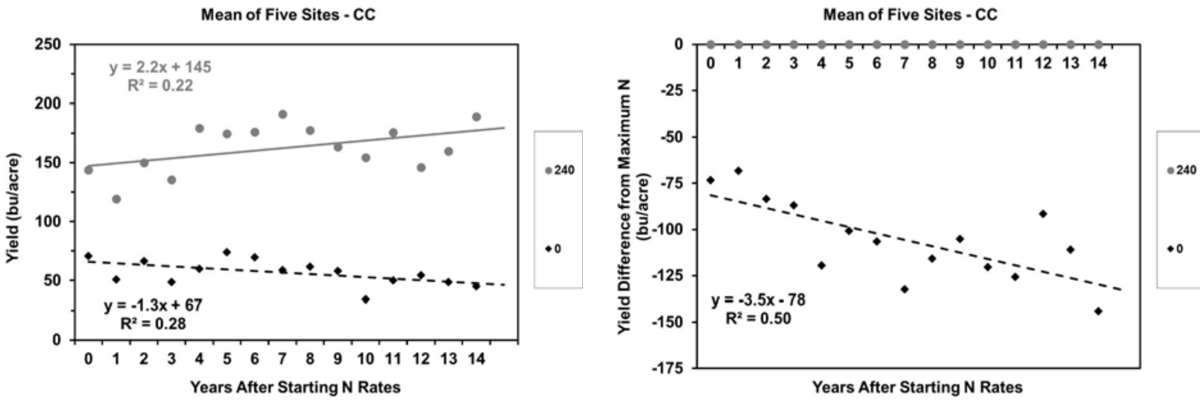

Figure 7. Relationship between corn yield with 240 lb N/acre and no N applied across time for continuous corn (CC) at five sites. Left graph shows the yield trends and the right graph the yield difference between 240 lb N/acre and no N applied. Sawyer et al. 2019.

Options for N rate guidance?

Base N rate guidance on grain N removal?

From an environmental perspective, applying a nutrient like N at the amount removed in harvested grain has perceived merit. However, with an open soil system (to air and drainage water) and a nutrient form subject to multiple loss mechanisms, management (replacing nutrient removed) that can be done with “immobile” nutrients (ex. P and K) at optimal soil test levels does not hold for N. There is also the need to maintain soil carbon and N resources (organic matter), which is important for many nutrient cycles, soil properties like water holding capacity, and overall soil health. Therefore, the expectation should be that optimal N application rates need to be greater than that removed in grain harvest. For SC, depending on the database and analysis method, the EONR rate varies between 32 to 58 lb N/acre more than the N removed in grain harvest. Therefore, basing a recommended N rate on grain removal would underestimate actual needed N application rate. Not an optimal economic outcome.

Nitrogen response or prior-year crop yield?

Research at the seven long-term N rate by crop rotation sites show no strong relationship for: the prior year soybean yield and the next year difference between optimal N rate in CC and SC (i.e. no variable soybean “credit” amount); prior year corn yield and next corn crop optimal N rate; or the prior year corn optimal N rate and the next corn crop optimal N rate. The corn yield response (relative yield of a no-N control, that is, yield with no N applied divided by the yield with a non-limiting or optimal rate) has a relationship with the CC and SC EONR, but the relationship is weak (Figure 8) and that year EONR does not relate well to the next corn crop needed N rate. As one would suspect, the many factors that influence corn productivity, N use efficiency, and N supply cause these types of relationships to be weak or non-existent.

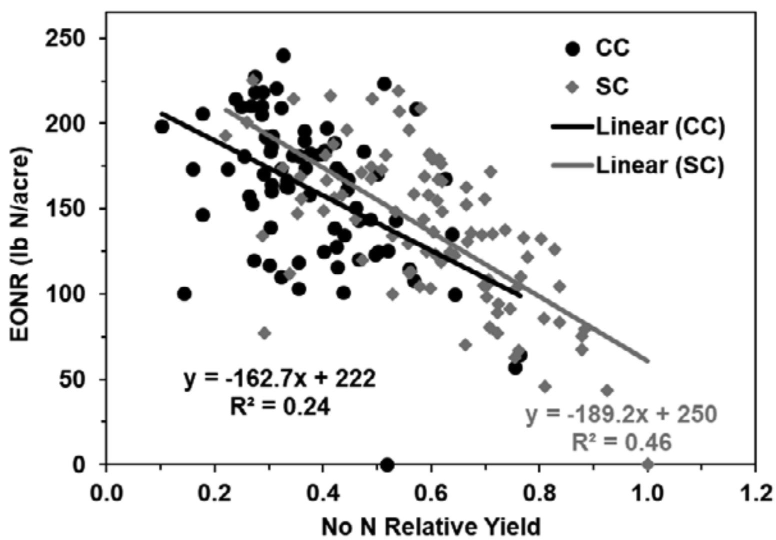

Figure 8. The relationship of economic optimum N rate (EONR) with corn yield response to applied N (relative yield of a no-N control, that is, yield with no N applied divided by the yield with a non-limiting rate). Seven sites in Iowa across 11 to 17 years for corn following soybean (SC) and continuous corn (CC). Sawyer et al. 2019.

Fertilizing at the exact yearly EONR and long-term profitability

While being able to know and apply the perfect field-specific N rate each year is a lofty goal, would that capability provide increased long-term economic return compared to using a consistent rate like the MRTN rate or a rate within the Most Profitable N Rate Range provided by the CNRC? Using the MRTN rate for SC and CC as a comparison, the impact of knowing the exact EONR for each site each year for the long-term study sites is possible to compute. One must remember that no decision process can be economically better than the site-year EONR, so comparisons always show a higher economic return for the EONR across time.

For the research farm sites within the MAIN region of Iowa (CNRC region), a perfect knowledge of needed N application (EONR) would theoretically increase yearly net return by $15.85/acre with SC and $16.23/acre with CC (using $0.35/lb N and $3.50/bu, 140 lb N/acre SC and 188 lb N/acre CC MRTN rates). There would be a concurrent theoretical overall decrease in N rate of 2 lb N/acre for SC and an increase of 1 lb N/acre for CC. Most of the economic difference comes from the yield change, being slightly higher long-term with the EONR rate. This is an effect that farmers know well, yield protection is important, and one way to help with that is to make certain N is adequate. If there is concern about using an MRTN rate (i.e. risk of being short of N and yield loss), then consider using the upper end of the most profitable N rate range. Using those rates (152 lb N/acre for SC and 203 lb N/acre for CC), there would be a gain of approximately $1 to $2/acre compared to the MRTN rates, but an application increase of 12 and 15 lb N/acre. In situations with more poorly drained soils and higher precipitation which results in greater yearly variation and more wet/high N loss years (ex. SEIA region), and therefore more years with EONR well above the MRTN rate, there would be greater potential long-term economic gain from a yearly-specific rate determination.

There are limits to yield protection by applying high N rates on an on-going basis. For example, if very high N rates were considered essential or needed for producing exceptional yield goals, for example 250 bu/acre (old yield-based calculations would be at 300 lb N/acre for CC and 250 lb N/acre for SC) – the long-term net loss compared to the yearly EONR in the MAIN region of Iowa would be in the range of $35 to $45/acre for both rotations at those N rates (loss due to much more than needed N applied across many years). More than double the "loss" than using MRTN rates or the high end of the most profitable N rate range from the CNRC, and does not include significantly elevated environmental impacts related to nitrate.

These theoretical calculations do not include cost for yearly-specific rate prediction or implementation of varying applications, which would reduce or even eliminate positive returns depending on actual cost – as would less than perfect yearly-specific rate predictions (and if before or when within the season can rates be reliably determined). Looking at many N response trial datasets, it is clear that the greatest yearly-specific economic improvement comes from identification of "extreme" years, that is, when much less or much more than a recommended rate is needed – especially the year when much more N is needed and yield suffers. This is why use of the springtime precipitation total is suggested to help decide if an extreme wet and high N requirement year is occurring.

Summary

Long-term research data show that corn yield and N response are quite dynamic, nothing really new to farmers and crop advisers. Also, N fertilization is needed to avoid low corn yields and residual effects from prior N applications are very transitory. This means that Iowa corn production systems will continue to have N applied in order to achieve high (and hopefully optimized) yield. A few key points should be kept in mind: 1) applied N does not decrease or eliminate corn yield variability – instead allows expression of yield potential each year which varies; 2) optimal N rates vary across time and space, but only the years with extreme variation from rate guidance (like the MRTN rate) can significant economic return be improved by varying yearly N rates – thus the need to recognize when those years are occurring and in time to alter N input, especially in high N responsive (wet) years; 3) areas of Iowa with more poorly drained soils and high precipitation have more challenges with item 2; 4) the difference in corn yield between CC and SC narrows or goes away in high yield environments; 5) yield response to applied N has increased across time; 6) estimating corn N application need by N in harvested grain, prior-year crop yield, or prior-year corn yield response are not viable approaches; 7) there is room for yearly N rate estimation, and thus long-term economic improvement, with methods to better match yearly EONR – however, the dollar amount improvement is smaller than many expect, will cost money to estimate/determine, and no approach will be perfect and thus achieving all of the potential site-specific gain will not be possible. Because N must be applied to optimize corn production, no matter the approach used, there will be resulting environmental impacts. On-going challenges for N use in corn.

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