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managing nitrogen fertil

CORN P

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Since the 1970s, N fertilizer recommendations for Midwestern corn production have relied on a yield-based system, whereby an expected yield goal is multiplied by a constant factor, with adjustments to account for N credits from previous cropping or the recent use of manure. This system uses a mass balance approach that assumes constant efficiency in crop uptake of fertilizer and soil N. Yield-based systems were originally intended as a first approximation in making generalized fertilizer N recommendations for long-term periods on a regional scale, but have been applied indiscriminately to fertilize individual fields in a particular growing season.

Implicit to yield-based N recommendations is the presumption that mineralization is a negligible source for crop N uptake, which would necessarily imply that yield in the absence of applied N supplies a fixed proportion of crop N uptake that is substantially less than that from fertilizer. Yet unfertilized (check) plot yields in N-response studies often exceed the yield increase obtained with fertilization, and in many of these studies, sites have been detected where corn is completely nonresponsive to fertilizer N. Such sites have often been excluded in averaging response data to evaluate yield-based N recommendations, but even so, the recommended rates tend to be excessive. This was the case, for example, with 96 percent of 193 responsive site-years analyzed by Lory and Scharf (2003), for which the recommended N rate exceeded the economically optimum N rate (EONR) by up to 227 kg ha^{-1} (200 lb/A), or by 90 kg ha^{-1} (80 lb/A) on average. More importantly, recommended and optimum N rates were not correlated significantly ($r = 0.04$) in the latter study, suggesting that yield-based N recommendations lack predictive value.

The only hope for improving fertilizer N recommendations for corn production in a humid region such as Illinois is to account for a soil's capacity to supply plant-available N through mineralization. The usual approach has been to measure soil NO_3^-, either before or after planting.

A better approach would focus on the soil's N-supplying capacity by estimating mineralizable organic N, which is subject to fewer N-cycle processes than NO_3^- and should thus be less dynamic. Research since the 1950s has supported the concept that soil organic matter is not uniformly mineralizable, but consists primarily of a passive fraction accompanied by a less extensive pool of biologically active organic N associated with microbial biomass. The latter constituents are identified largely as -amino N and (amide + amino sugar)-N, both of which have been linked to net mineralization and/or crop N uptake in pot experiments.

The objective of this study was to evaluate the effectiveness of the ISNT in differentiating responsive from nonresponsive site-years under a wide range of soil and cropping conditions. The generated database was used to assess (i) how these conditions might influence a quantitative relationship between Illinois Soil N Test values and crop responsiveness to N fertilization; and (ii) the accuracy and economic consequences of N recommendations by the PY method, primarily on a site-by-site basis. Little peer-reviewed information is available on the latter issue.

FIELD PLOT MANAGEMENT

The work reported herein involved 102 N-response experiments located throughout Illinois, largely on farmer fields. Of these experiments, 51 were reported by Brown (1996), including 11 conducted in 1990, 18 in 1991, and 22 in 1992. An additional 51 experiments included 14 in 2001, 16 in 2002, and 21 in 2003. In each case, N rates were applied according to a randomized complete block design with four replicates, by sidedressing urea-NH_4NO_3 solution (360 g N L-1) when corn was 15 to 30 cm (6 to 12 in) tall.

SOIL SAMPLES

Soil samples were collected from the experimental area at each site in late March or early April, including surface (0–18 cm, or 0-7 in) samples for routine soil fertility assessment (pH, P, and K) and profile samples for NO_3^- testing (1990–1992) or the ISNT (2001–2003).

EXPERIMENTAL SITE-YEARS

The 102 site-years studied show the soil series; the year when N response was studied; the previous crop; the tillage system in use; the source and amount of manure N applied for the growing season studied, as well as residual manuring within the previous 2 to 5 yr; plant population estimated from stand counts; a site-average ISNT value and the standard deviation (SD) computed from four (1990–1992) or 12 (2001–2003) replicate values; check-plot corn yield data; and the magnitude of the error in the PY recommendation and the corresponding economic cost.

EVALUATION OF YIELD-BASED NITROGEN MANAGEMENT

The importance of fertilizer N management in corn production is evident from the economic costs that often exceed \$100 per hectare (\$40/A). The rationale for this investment resides in the PY method, whereby crop N uptake is ascribed largely

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to N fertilization. The resulting recommendations have been adopted on the premise that yield must not be limited by inadequate N supply, yet have seldom been evaluated relative to grain yield with a lower (or higher) rate of N fertilization, or for accuracy in fertilizing individual sites where N-response studies have been conducted to determine an EONR.

In 22 of the N-response experiments reported, manure had been applied for the growing season studied, so the PY recommendation was adjusted to incorporate standardized credits for manure N. The adjustment proved inadequate, except for identifying three nonresponsive site-years where the manure credit exceeded the N requirement estimated for the yield goal. Of the 19 remaining currently manured site-years, 15 were completely nonresponsive to N fertilization, but would have received 38–159 kg N ha^{-1} (34-142 lb/A) by the PY method at a cost of $21 to $88 ha^{-1} ($8 to $36/A). Fertilization also would have been recommended for the four additional site-years where a yield response was observed. Three of the latter cases involved a corn–soybean rotation, and the combined N credits would have led to underfertilization. In contrast, the PY method would have overfertilized a responsive site-year under continuous corn, for which the manure credit was inadequate. A credit approach cannot provide a reliable basis for quantifying manure N availability, as has been reported previously.

A further problem arises because the PY method does not account for residual availability of manure N, which can persist for several years. Residual manure was more common when corn was grown continuously than in rotation with soybean. The latter difference is particularly apparent for nonresponsive site-years that were not currently manured, among which were all seven of those under continuous corn but only two of four that were in a corn–soybean rotation. The PY recommendations were always excessive for continuous corn (by 49–235 kg N ha^{-1}, or 44-210 lb/A, at a cost of $27–$130 ha^{-1}, or $11-$53/A), with or without a response to N fertilization, whereas either under- or over-fertilization occurred when there was a manure history for corn in rotation with soybean.

As with current manuring, fixed N credits are used in PY recommendations when corn is grown after a legume. The present project involved 54 such site-years that had not been manured for at least 1 year before the growing season studied, including 49 in a corn–soybean rotation and five where first-year corn followed alfalfa. Of the latter group, four site-years were nonresponsive to N fertilization, but would have been fertilized with 105 to 123 kg N ha^{-1} (94 to 110 lb/A) by the PY method at a cost of $58 to $68 ha^{-1} ($23 to $28/A), even after maximizing the alfalfa credit (112 kg N ha^{-1}, or 100 lb/A). The error was more extensive in magnitude (162–193 kg N ha^{-1}, or 145-172 lb/A) and cost ($89–$106 ha^{-1}, or $36-43/A) for four nonresponsive site-years where corn followed soybean, involving either no-till (site-years 6 and 22) or residual manuring (site-years 15 and 33). In contrast, under-fertilization often occurred when a yield response was obtained with soybean as the previous crop, whereas no such occurrences were observed with continuous corn, suggesting a greater need for N fertilization when corn follows soybean. The latter difference was substantiated, after excluding manure and tillage effects, by an ANOVA that showed significant increases in EONR and delta yield when the previous crop was soybean rather than corn. The EONR estimated for corn after soybean was significantly greater for 2001–2003 (153 kg N ha^{-1}, or 137 lb/A) than for 1990–1992 (96 kg N ha^{-1}, or 86 lb/A) site-years, suggesting that current production practices have increased the fertilizer N requirement of corn within this rotation. Such an increase is likely attributable to greater nutrient demand by improved hybrids selected for maximal yields with high planting rates.

These findings raise serious questions about the use of standardized credits for estimating the fertilizer value of legume-derived N, which ranges widely with species and environmental conditions. In the present project, a soybean credit was inappropriate for nonmanured site-years under a corn–soybean rotation, as one-third of this group would have been underfertilized by the PY method, at an average cost of $57 ha^{-1}, or $23/A.

Lacking any N credit for management history, PY recommendations were excessive for all but one of the 23 site-years under continuous corn that had not received manure for the growing season studied (although in almost 50 percent of these cases, manure had been applied within the previous 2–5 yr). Almost one-third of this group was nonresponsive to N fertilization, as compared with 10 percent of the 49 site-years in a corn–soybean rotation with no manure credit. While on average both groups were overfertilized by the PY method, the error was much more extensive (128 versus 46 kg N ha^{-1}, or 114 vs. 41 lb/A) as calculated using actual errors rather than the magnitudes reported when corn was the previous crop ($P < 0.01$), with no instances of underfertilization.

EVALUATION OF SOIL-BASED NITROGEN MANAGEMENT

The recurring evidence of serious inaccuracy in fertilizer N recommendations by the PY method has obvious economic implications for individual farmers, and also raises concern about environmental pollution. Extrapolating from the average error in these recommendations for the site-years studied ($50 ha^{-1}, or $20/A), the annual cost to Illinois agriculture would exceed $220 million, which does not include expenses associated with excessive N fertilization, such as the loss of Ca^{2+}, Mg^{2+}, and K^+ that serve as counter-ions during the leaching of NO_3^-. Such estimates emphasize the need to account for a soil's capacity to supply plant-available N through mineralization, which is the key to improving fertilizer N management in a humid region such as Illinois.

In order for the ISNT to be successful, conditions must be conducive to soil N mineralization, as well as crop N uptake and utilization. This requirement was not satisfied with four of the 19 site-years incorrectly identified as nonresponsive by the ISNT, owing to serious moisture stress that occurred for most (site-years 101 and 102) or some (site-years 76 and 79) of the growing season. The effect of this stress on interpretation of the ISNT is clearly demonstrated from a comparison of yield data for site-years 22 and 76, which involved the same location with ISNT values above the critical level, but different growing conditions.

The data leave little doubt about the need for soil-based N management, as fertilizer N requirement decreased with increase in the ISNT, while an increase occurred with plant population, reflecting higher crop N demand. The latter trend adds a new dimension to fertilizer N management with the ISNT, whereby planting rate can be adjusted to exploit soil N availability, provided that productivity is not limited by other soil properties (e.g., moisture).

CONCLUSIONS

Nitrogen fertilizers contribute substantially to the cost of corn production. These recommendations are called into question by a new study published in the January-February 2006 issue of the *Soil Science Society of America Journal* (SSSAJ), which offers a soil-based alternative that will benefit crop yields, the environment, and the bottom line for farmers.

"We evaluated the proven-yield (PY) method on a site-by-site basis for 102 on-farm N-response trials conducted throughout Illinois in six growing seasons from 1990 to 2003. It was disturbing to see how poorly this method performed, considering that it has been so widely advocated for the past three decades. In fact, on average the error itself was greater than the economically optimum N rate," said Richard Mulvaney, University of Illinois professor of soil fertility.

The PY method was developed in an era when N fertilizer was relatively inexpensive and environmental concerns were less pressing, and has often been advocated as insurance against a yield limitation due to N deficiency. Yet even with an increasingly unrealistic corn to N price ratio of 10:1, the insurance policy failed to avoid under-fertilization about one time out of six, by 46 kg ha^{-1} (41 lb/A) on average and mostly when corn followed soybean.

Saeed Khan, co-author and research specialist, said "These findings are not that surprising when you consider the 'one-size-fits-all' philosophy behind the PY method. Besides invoking standardized credits to account for N derived from legumes or manure, it assumes a constant fertilizer efficiency, regardless of timing, formulation, and method of application, weather conditions, landscape position, soil type, planting rate, and perhaps most importantly, the inherent differences that exist in soil N-supplying power."

Those differences have a crucial effect on the need for supplemental N fertilization, according to new insight provided by the Illinois soil N test (ISNT), a simple Mason-jar technique developed to identify sites where corn does not respond to N fertilization. There were 33 such sites in the SSSAJ study, and all except two were predicted correctly, assuming a critical test level of 230 mg kg^{-1} (230 ppm) as originally established. This level was less effective in identifying 50 of the 69 responsive sites, but the remaining 19 have important implications for fertilizer N management with the ISNT. More commonly, the critical level proved inadequate in applying the ISNT to sites where corn followed soybean with high plant populations. Not only would crop N demand have been increased by the presence of more plants, so would the input of C in the resulting residues, thereby promoting microbial competition for available soil N.

Yields were greatest when high planting rates were combined with N fertilization, for sites that tested high by the ISNT, suggesting that this test has potential applications for variable-rate planting as well as site-specific N management.

DETACH HERE

The need for a soil-based approach to managing nitrogen fertilizers for profitable corn production

March Self-Study Examination

1. Assumptions of traditional yield-based nitrogen fertilizer recommendations include all of the following EXCEPT

a. soil mineralization is a minor source for crop N.
b. fertilizer efficiency is constant.
c. standard credits to account for N from legumes.
d. differences in the ability of soils to supply nitrogen.

2. An objective of this study was to

a. evaluate the effectiveness of the Illinois Soil Nitrogen Test in differentiating response in a wide range of conditions.
b. determine the most cost-effective form of nitrogen to apply in corn fields.
c. establish the amount of nitrogen that carries over from season to season.
d. assess the consequences of excessive nitrogen application on the environment.

3. It is common for nitrogen fertilizer costs for a corn grower to be around

a. $20/A
b. $40/A
c. $60/A
d. $80/A

4. Soil samples for nitrogen determination by the Illinois Soil Nitrogen Test were collected at each site in this study

a. in late March/early April.
b. at planting time.
c. at the V6 stage in early June.
d. just prior to sidedressing.

5. Under-fertilization of nitrogen in this study occurred most often when

a. the previous crop was corn.
b. the previous crop was soybeans.
c. soils were heavy clay.
d. manure had been applied.

6. From the data collected in this study, the annual cost to Illinois agriculture from inaccurate nitrogen recommendations is

a. $55 million.
b. $110 million.
c. $220 million.
d. $500 million.

7. A characteristic of this study includes all of the following EXCEPT

a. 102 N-response studies located in Illinois.
b. randomized complete block study design.
c. a mixture of previous crops, tillage, and manure application at each site.
d. urea/ammonium nitrate solution applied to N plots.

8. When using the PY method, nitrogen credits are utilized in determining recommendations for corn when

a. following another corn crop.
b. manure was applied in a previous year.
c. following a legume crop.
d. planting in no-till fields.

9. The greater demand of nitrogen noted in this study when corn follows soybeans can be attributed to

a. improved hybrids and higher planting rates.
b. greater nitrogen loss in areas where soybeans are grown.
c. a higher ratio of soybean grain to stover with higher soybean yields.
d. nutrient cycling in soybean residue.

10. Costs of excessive nitrogen applications in addition to the unnecessary expense include

a. luxury consumption of P and K.
b. poor grain quality.
c. leaching of basic cations with nitrate loss.
d. decreased earthworm populations.

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Rating Scale: 1=Poor 5=Excellent

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