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YIELD MONITORS, VARIABLE-RATE APPLICATORS, AND
N FERTILIZER RECOMMENDATIONS FOR CORN

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Many corn producers are purchasing on-the-go yield monitors and global positioning systems to enable mapping of yields within their fields. The underlying assumption is that the benefits of information generated will more than offset the costs of making the maps. The benefits expected usually include increases in yields and/or decreases in expenditures for fertilizers.

Much of the interest in mapping yields is driven by the development of applicators that can vary rates of application of fertilizers as they move across fields. These usually are equipped with field maps, positioning systems, and computers that simultaneously determine positions in the field and on the map. The computers also direct applications of materials as prescribed by information linked to the map.

If it is assumed that fertilizer needs are proportional to yields, then it would be logical to conclude that yield maps generated by combines can be used to direct variable-rate applications of fertilizer. Although assessments of phosphorus and potassium requirements usually are not linked to yields, recommended rates of N fertilization usually are proportional to yields. The combined use of yield mapping and variable-rate applicators, therefore, would seem to be a sound basis for site-specific management of N.

A major problem is that extensive N-response trials for corn in Iowa during the past decade revealed no significant relationship between N rates found to be optimal and those normally recommended by considering yield levels (Blackmer et al., 1992). Such observations give reason to question the commonly held notion that yield maps can be used to guide site-specific applications of N. Such observations also suggest great need for a new generation of N recommendations for corn producers.

Studies were initiated in 1994 to develop a new generation of N fertilizer recommendations for corn producers. The studies involve simultaneous use of yield monitors on combines, global positioning systems, remote sensing, the late-spring test for soil nitrate, and the end-of-season test for cornstalk nitrate on fields of cooperating corn producers. These studies include assessments of the potential benefits of using variable-rate applicators and of how these potential benefits could be obtained. The studies are made possible by funding from the Iowa Corn Promotion Board, the Martin Marietta Corporation, Iowa State University Center for Advanced Technology Development, and Agri Industries.
Description of the Studies

The studies are conducted on fields of cooperating corn producers. Fields 1,000 to 3,000 feet in length are selected to have average to above-average amounts of variability for the region. The fields are managed by the producers using their normal practices, except that normal applications of N fertilizer often are withheld from a strip wide enough to accommodate at least twelve passes with 6-row or 8-row combines.

Soil Testing
The surface foot of soil is sampled at 15 selected areas when corn plants are about 6 inches tall. These areas are selected to capture the entire range of soil types within the field. The area sampled is a square 15 to 30 feet on each side. The samples are analyzed to determine nitrate concentrations, soil organic matter concentrations, total nitrogen content, and other relevant soil characteristics.

N Treatments
Replicated and randomized fertilizer treatments are applied on strips that are harvested as individual passes of the combines. On strips not fertilized by the producer, treatments usually are 50, 100, and 150 lbs N/acre as UAN (urea-ammonium-nitrate solution) injected between the rows when plants are 1 to 2 feet tall. Nonfertilized control strips are sometimes included. On areas fertilized by the producer, selected strips are fertilized with injected UAN at a rate of 50 lb N/acre for "over-the-top" evaluations of the producer’s normal N management practices. The fertilized strips and the areas from which soil samples were taken are positioned so that at least two N treatments are compared on each area sampled.

Remote Sensing
Color photographs are taken from airplanes of the bare soil in the spring and of the corn canopy in August. The photographs are digitized by computers to characterize color on a grid having about 50,000 cells/acre. Spatial patterns in soil color are used to help quantify differences in soil properties. The soil colors observed are calibrated, or "groundtruthed", by the results from analyses of soil samples taken from the plots within each field. This information is superimposed on digitized soil survey maps.

Spatial patterns in color of the canopy are analyzed to characterize spatial patterns in N sufficiency of the crop. This involves measuring contrasts in greenness between nearby strips having different N treatments. Corn that has adequate or excess N gives a uniform dark green color within an area of reasonably uniform soil. Corn that is N-deficient has a lighter color, and (within certain bounds) the greater the deficiency the lighter the color. By observing patterns in degrees of color contrast between strips receiving different rates of N, it usually is possible to make a map showing how fertilizer-N requirements varied with position in the field. If maps of N fertilizer requirements remain reasonably constant across years, then these maps could be used to guide variable-rate applications of N.
**Cornstalk Testing**
Samples for the end-of-season cornstalk test (Blackmer and Mallarino, 1994) are collected from each fertilizer treatment within each of the areas initially tested for soil nitrate. The cornstalk test indicates whether the corn sampled had too little, too much, or optimal amounts of N. This information is used to calibrate, or "groundtruth", information gathered by remote sensing of the corn canopy.

**Yield Measurements**
The strips are harvested by using combines with yield monitors and global positioning systems. Information gathered includes mean yields for each strip and mean yields for various segments along each strip. The yield information is used to calculate the economic benefits resulting from each application of N. The potential benefits of using variable rate applications are assessed by calculating the economic gains that would be obtained if each small area within the trial received its own optimal rate of N. The aerial photographs are used to determine the best sizes and shapes of the areas that should be considered separately.

**Synthesizing Information**
Geographic information systems, which are complex computer programs, are used to interrelate all information collected. Data from many fields are analyzed simultaneously to identify relationships that could be used as the basis for recommendations for many producers. The recommendations should be useful to producers who do not use variable-rate applicators, those considering use of variable rate applicators, and those using variable-rate applicators.

**Initial Observations**
It is too early in the study to quantitatively discuss the expected benefits of using variable-rate applicators or how these applicators can be used most effectively. However, some findings are noteworthy.

**Nonuniform Applications of N**
One unexpected finding is that the color photographs presented compelling evidence that many modern applicators do not deliver uniform applications of N. This evidence was found in fields that were incidently photographed because they were adjacent to the fields being studied. The color photographs clearly indicate strips of nitrogen-deficient corn in patterns obviously caused by the applicators not functioning properly.

The aerial photographs support the recent findings from extensive studies that revealed cyclic patterns in concentrations of nitrate in fertilized fields. The cyclic patterns often showed concentrations ranging from less than 10 to more than 50 ppm nitrate N and have periods equal to the width of the applicator used. Because optimal concentrations of nitrate-N are about 25 ppm, these observations suggest that many producers could increase yields by merely applying N fertilizer more uniformly. The problem that the aerial photography can correct is that producers currently are unaware that nonuniform applications of N are a problem.
Large Losses of N in 94

Another unexpected finding is that normal fertilization practices often result in less than maximum yields due to large losses of N between the time of application and the time of need by the crop. One field studied in 1994 had received surface-applied UAN solution at a rate of about 120 lb N/acre immediately after planting. The soil samples collected when the corn plants were 6 inches tall (and analyzed in July) suggested that most of the fertilizer N had been lost; the nitrate concentrations were only slightly higher than in the portions of the field that had not received fertilizer N.

Aerial photographs taken in August revealed a marked difference in color of strips where an extra 50 lb N/acre had been applied over the top of the N applied by the farmer. The photographs also indicated that 50 lb N/acre injected into unfertilized areas when the corn plants were 12 inches tall provided more available N than did the 120 lb N applied earlier by the farmer.

Visual ratings of corn N status made while walking though the test areas revealed marked differences between strips that had, and had not, received extra N. Although problems developed that prevented measuring yields at this site, the yields on areas fertilized by the farmer probably were only 70 to 80% of those in strips with adequate N. Perhaps the most revealing point is that the farmer did not know that most of his field suffered from N deficiencies until he saw the aerial photographs shortly before harvest.

Large Losses of N in 1995.

The weather in the fall of 1994 was favorable for application of anhydrous ammonia in many parts of Iowa. The spring of 1995, however, brought an excess of rainfall that substantially delayed planting in many parts of the state. This was followed by an unusually large number of reports that fields fertilized in the fall with anhydrous ammonia had low concentrations of soil nitrate in late spring. Studies were initiated to investigate this problem in four fields in Boone County.

Soil samples taken when the corn plants were about a foot tall confirmed that concentrations of nitrate-N were low (often less than 10 ppm). Analyses showed that the fertilizer N was not present as exchangeable ammonium. Samples representing the second foot of soil also revealed little evidence that N had been applied.

The farmer applied another 50 to 75 lbs N/acre of anhydrous ammonia, but left strips where the extra N was not applied. Aerial photographs of the field in August revealed that the strips without the extra N were lighter in color than were the strips having the extra N. Visual ratings of corn N status made while walking through the plots revealed differences between the strips that had, and had not, received extra N. The farmer's yield-monitoring combine showed that the extra N produced an average yield increase of about 15 bu/acre.

The findings at this site take on added significance when it is recognized that only 50 to 75 lbs N/acre (applied when the corn was 12 inches tall) was needed to maximize yields in nearby studies that are comparable (corn following soybean) except no other N had been applied. These observations, together with the soil-test results, suggest that most of the fall-applied N had been lost from the soil.
Likely Benefits of Variable-Rate Applicators
Some of the fields studied seemed to show so little variability in N fertilizer needs that it seems unlikely that variable-rate applications of N would be beneficial in these fields. Other fields showed enough variability that it seems likely that variable-rate applications would be beneficial. These results should not be surprising, but they underscore the obvious fact that recommendations for using variable-rate applicators must begin with recommendations indicating where they are likely to be beneficial.

Observations from fields that showed substantial variability in N fertilizer requirement underscore the need for recognizing that variable-rate applications of N are not likely to be beneficial without a better understanding of how N fertilizer needs vary within fields and among fields.

Conclusions
The advent of yield-monitoring combines will undoubtedly result in improved N management for corn production. Indeed, the first two years of study suggest that use of yield-monitoring combines may enable increases in average yields while lowering average inputs of fertilizer N. The initial value of using these combines for improving N management, however, may relate more to facilitating yield comparisons on strips having alternative N treatments than to mapping yields. Individual farmers having yield monitors can conduct several comparisons per year with minimal time or expense. Organized groups of farmers could make such comparisons on a scale not previously practical. Such comparisons probably will reveal that some commonly used practices are not as reliable as currently believed, and this new knowledge will prompt rapid improvements in N management.

References