Losses of Fall-Applied Nitrogen

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Applying N fertilizer to some fields in the fall instead of the spring offers several benefits to corn producers and fertilizer suppliers. Benefits for producers often include paying less for fertilizer, reducing the amount of field work that must be accomplished in the spring, and avoiding soil compaction associated with application of fertilizer on wet soils in the spring. Benefits for suppliers include more time for movement of fertilizer materials from the manufacturers to the producers and more acres per year covered by each fertilizer applicator.

A disadvantage of fall applications of N is greater potential for losses of fertilizer N before it is needed by the crop. The potential for losses of fertilizer-derived N, either by leaching or denitrification, clearly increases with increase in time between fertilizer application and crop need. The immediate importance of these losses can be expressed in dollars paid for the lost N plus dollars not earned as a result of any yield-limiting deficiencies that follow. The long-term importance of these losses, however, may be expressed through environmental impacts not easily expressed in dollars.

There have been many discussions concerning the advantages and disadvantages of fall applications of N during corn production in Iowa. A major problem in these discussions has been lack of convincing evidence that losses of fall-applied N are, or are not, a matter for concern. Another major problem is the common assumption that fall applications of N are both necessary for profitable corn production and harmful to the environment. This assumption complicates discussions between persons primarily concerned with the profitability of agriculture and those primarily concerned with protection of the environment.

This report summarizes the results of recent studies showing that fall applications of N may not be as profitable for corn producers as generally believed. Some of these studies were conducted more than a decade ago, but the importance of the findings seemed questionable until examined in the light of more recent studies. Primary attention is given to anhydrous ammonia because this is believed to be the only N fertilizer that should be considered for fall applications in Iowa. Emphasis on anhydrous ammonia should not be considered evidence that other materials are better suited for fall applications.

A mechanism for rapid losses of N

Intensive field studies in the spring of 1983 revealed surprising evidence for rapid downward movement of N that was applied as anhydrous ammonia (Sanchez, 1986). The studies involved injecting N-15-labeled anhydrous ammonia (200 lb N/acre) with and without N-Serve shortly before corn was planted. When the corn plants were about 1 foot tall, soil around and below the fertilizer band was excavated by removing 50 individual soil samples to a depth of 1.5 m. Corn plants and soil samples were analyzed to determine location, form, and percentage recovery of the N-15-labeled fertilizer.

The results showed that recovery of fertilizer N was higher in plots on the lowland (Webster) soils than in plots on the upland (Clarion) soils in the same field. An average of 20% of N had been lost in the lowland soils and an average of 37% of the N had been lost from the upland plots. The distribution of N-15-labeled nitrate in the soil in the upland soils left little doubt that nitrate had moved rapidly down through the soil profile during the 45 days between fertilization and soil sampling (see Figure 1).
Figure 1. Iso-concentration (in ppm N) lines for N-15-labeled nitrate found in the corn rooting zone of two plots on a Clarion soil 45 days after spring application of N-15-labeled anhydrous ammonia with N-Serve. Labeled N recovered as exchangeable ammonium accounted for 14% of the N applied (not shown) and labeled N as nitrate accounted for 19% of the N applied.

The downward movement of labeled N occurred much more rapidly than would be predicted by models that fail to consider the importance of soil macropores in these soils. The effects of macropores deserve special attention when anhydrous ammonia is applied because the knives used to inject the anhydrous ammonia create a macropore through which water can flow. During periods of heavy rainfall, macropores created by the applicator knives can funnel unusually large amounts of water downward through the fertilizer band. Under such conditions, it is not difficult to understand how most of the anhydrous ammonia N applied in the fall could be lost from soils when large amounts of spring rainfall occur after the fertilizer N has been converted to nitrate.

Losses in conventional response trials
Occasional observations indicating significant losses of fall-applied N usually have been discounted because yield-response trials conducted in the western half of the Corn Belt usually do not provide evidence for large losses of N. As pointed out by Blackmer (1986), however, yield-response measurements usually lack the necessary sensitivity to detect losses that are economically important.

The lack of sensitivity of traditional yield-response measurements for detecting losses of N was demonstrated in a four-year study that started in 1988 in Boone County (Davis, 1992). This study
included both anhydrous ammonia and broadcast solid fertilizer applied at several rates in the fall and in the spring. Studies each year were conducted on both corn following corn and corn following soybean. Weather conditions in 1988 and 1989 were not favorable for losses of N, but those encountered in 1990 and 1991 gave considerable opportunity for such losses.

Analysis of yield response by comparisons of means gave no convincing evidence that losses of fall-applied N were greater than losses of spring-applied N. These observations seemed to agree with most studies that have been conducted in the western half of the Corn Belt. This study, however, also evaluated N availability by using the late-spring test for soil nitrate and the end-of-season test for cornstalk nitrate.

Soil samples collected when corn plants were 6 inches tall suggested that losses of fall-applied N were substantially greater than losses of spring-applied N on the two wet years. This conclusion was supported by information provided by the end-of-season cornstalk test. These observations prompted more detailed analysis of the yield response data, and the more detailed analyses provided clear support for the conclusion that losses of fall-applied N exceeded losses of spring-applied N during the wet years. Analysis of the yield response curves showed that rates of application required to maximize yields were substantially greater for fall-applied N than for spring-applied N (Figure 2).

Figure 2. Yield response curves comparing fall-applied and spring-applied N for two years having above-average amounts of spring rainfall. The vertical dotted lines indicate economic optimum rates of N fertilization as indicated by the quadratic-plateau model.

The basic problem with yield response studies is illustrated in Figure 2, which shows results for anhydrous ammonia applied for corn following corn. Application of higher-than-needed rates of N tends to mask important losses of N. Due to the normal shape of N-response curves, substantial losses of N at any rate of fertilization result in only small differences in yield. The yield differences usually are too small to detect (i.e., be "statistically significant") amid normally expected variability in yields.
The results of these field studies illustrate a dilemma when yield comparisons are used to evaluate N time-of-application effects in conventional field-plot trials. The dilemma is that experimental areas large enough to conduct such studies often contain enough soil variability to prevent detection of the effects under study. If this problem is avoided by using an unusually uniform experimental area, the results apply to only a small portion of the soil in any given region and it is likely that the soil types with greatest losses are not studied.

The economic significance of losses of fall applied N fertilizer is better illustrated in Figure 3, which shows net returns to N fertilization. The differences between fall-applied and spring-applied N are more clearly revealed in Figure 3 than Figure 2 because the costs of N losses are shown in Figure 3. The higher losses of fall-applied N reduce the potential profitability of fertilization.

![Figure 3](image.jpg)

Figure 3. Net returns to fertilization for fall-applied and spring-applied N on two years with above-average rainfall.

The costs of N losses can be especially great if time-of-application effects on fertilizer needs are not recognized and optimal rates for spring applications are applied in the fall. The resulting N deficiencies can cause economic losses that are much greater than the costs of fertilizer that was lost. Mounting evidence suggests that yield-limiting deficiencies of N due to fall applications of N may occur much more frequently than currently believed.

N losses recently detected by precision farming technologies

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 many reports of low soil nitrate concentrations in fields that had been fertilized in the fall with anhydrous ammonia. 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 producer applied an additional 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 producer's yield-monitoring combine showed that the extra N produced an average yield increase of about 15 bu/acre.

The findings at these sites 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.

Aerial photographs taken in August clearly showed that responses to the extra N tended to occur more in some locations than in others within the same field. The responses in each field tended to be greatest on soils located at the higher elevations, where losses of N by leaching are most likely to occur. The responses tended to be least on soils at the lower elevations, where denitrification is most likely to occur. These observations support the conclusion that spatial variability in soils should be considered a major problem that limits the value of information about N time-of-application effects derived from conventional field experiments where only yields are measured. They also indicate that remote sensing techniques should help identify where N losses tend to be most important.

It is noteworthy that losses of fertilizer N from these fields were detected only because the late-spring test was used. Although readily detectable by aerial photography and yield monitoring after additional N had been applied in strips, the effects of these N losses were not detectable by casual observations. Such losses, however, can be detected easily by using the end-of-season test for cornstalk nitrate.

Implications

The commonly accepted notion that a pound of N applied in the fall is equally effective as a pound of N applied in the spring can be very costly to producers. Producers electing to apply N in the fall should recognize that greater average losses reduce the profitability of crop production and increase the average amounts of N lost to the environment. Fall applications greatly increase the risk of severe yield-limiting deficiencies of N on some years. Emerging precision farming technologies offer great potential for quantifying the risks associated with losses of fall-applied N under a wide variety of conditions. They also offer the potential for new ways to avoid these risks. Mounting evidence suggests that practical ways to avoid large losses of fall-applied N should help producers increase average yields while decreasing average rates of N fertilization.

References Cited

