

Fall Nitrogen Management for Agronomic Response and Environmental Protection

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Economic and Environmental Concerns

As a result of improved hybrids, better crop and soil management, and changes in nitrogen (N) management, the production of corn per unit of N fertilizer has improved 32 percent since the 1980s: 0.76 bu of corn/lb of N in 1980 compared to 1 bu of corn/lb of N in 1998 (see **Figure 1**). Despite these improvements, economic and environmental issues have prompted farmers, fertilizer dealers, and crop advisers to re-evaluate nutrient management practices and to implement best management practices (BMPs) which will be cost effective and environmentally friendly. The purpose of this article is to address fall N management for spring-planted crops, focusing on corn.

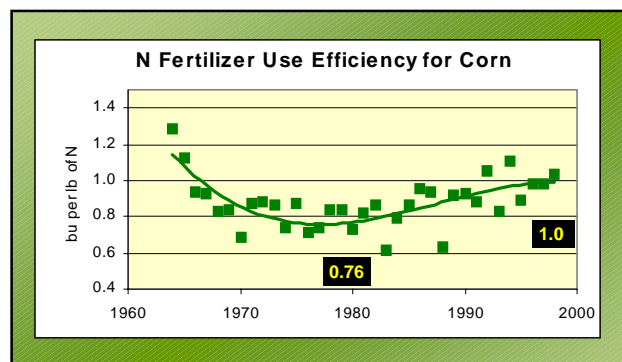


Figure 1. Fertilizer N use efficiency on corn has increased 32 percent since 1980.

State water quality and U.S. Environmental Protection Agency (EPA) reports suggest agriculture is the major contributor to non-point source nutrient pollution of surface waters. The U.S. Geological Survey (USGS) and others have reported that N discharge to the Mississippi River, and ultimately to the Gulf of Mexico, has increased since the 1950s. These reports, however, also show that the discharge of N as nitrate (NO_3) has been relatively constant in the last two decades. The USGS estimates that 56 percent of the NO_3 transported to the Gulf of Mexico enters the Mississippi River above the Ohio River, while the Ohio River basin contributes 34 percent of the total Mississippi River

NO_3 load. Too much nutrient enrichment...N, phosphorus (P) and carbon (C)...of waters can accelerate algae growth, decrease the oxygen (O_2) levels, affect aquatic life, and may increase the costs of municipal water treatment.

The consumption of N fertilizer has been relatively flat since the late 1980s compared to previous years. The issue of hypoxia, or low dissolved O_2 in the Gulf of Mexico, and its potential impact on Gulf fisheries and tourism have focused attention on areas of the U.S. where the greatest fertilizer N use occurs. Some marine scientists hypothesize that NO_3 -N discharge via the Mississippi River to the Gulf of Mexico is the major cause of the seasonally low O_2 status...less than 2 parts per million (ppm)...of near-shore waters along the Louisiana coast. They suggest that too much N stimulates excessive algae (diatom) growth, the algae die, fall to the shallow ocean floor, and decay. As the decaying process develops and persists, dissolved O_2 in the water is reduced. Public interest and concern resulting from the publicity surrounding this condition have stimulated research, monitoring, and regulatory policy development to address the causes of and remedies for nutrient discharge to the Gulf and surface waters across the U.S. Efforts to reduce harmful algae blooms and other negative water quality impacts from nutrient over-enrichment have been initiated at both state and federal levels.

Soil Drainage, Nitrate, and Nitrification

Crop uptake and removal of N in grain at harvest usually accounts for the majority of N applied to fields. Some N is lost to the atmosphere as ammonia (NH_3) through volatilization from the soil, from manure, from fertilizer, and also from leaf surfaces. Some NO_3 from soil organic matter mineralization [microbial conversion of organic N to inorganic ammonium (NH_4)], manure, and fertilizer is subject to leaching, surface runoff, and denitrification (gaseous loss of N under very wet conditions). Management to maximize crop uptake and to minimize the loss of N from fields via these loss pathways will enhance farmer profit potential and also protect water quality. Currently, NO_3 -N leach-

ing and discharge from drained fields are the greatest environmental concern. Surface runoff N losses are usually small in most corn production areas.

As a consequence of reduced tillage practices, many soils have improved tilth and aeration. Field drainage has also improved the crop production potential in many important agricultural states, especially in the Great Lakes and Corn Belt states. Total nutrient loss may be reduced as a result of subsurface drainage, but NO_3 loss from the soil profile may be enhanced. By 1920, there were 53 million acres of U.S. farmland with some form of drainage. By 1960, there were about 87 million acres of drained non-federal rural land. According to the opinions of agricultural engineers and others in a 1998 publication by Ohio State University (Bulletin 871), the acreage of drained cropland has increased in several states since the 1985 USDA survey. In 1985, there were almost 110 million acres of drained land in these states, of which about 76 million acres were used for cropland. The percent of all cropland that was drained in eight key agricultural states in 1985 and the estimate for 1998 are shown in **Figure 2**.

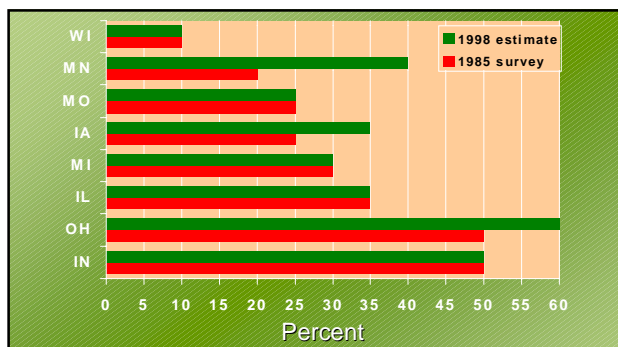


Figure 2. Percent of all crop land that is drained in eight north central states.
Source: Agricultural Drainage, 1998. Bull. 871, Ohio State University.

With increased drainage, it is also likely that the nitrification (conversion of NH_4 to NO_3) potential (and leaching potential) has risen in many soils. Soil scientists generally agree that NO_3 derived from organic matter by mineralization and nitrification is equally susceptible to leaching as NO_3 from fertilizer or manure. Several scientists have recently reported that non-growing season mineralization of N from organic matter was greater than previously expected in upper Midwest soils. Conditions optimum for crop growth – favorable soil moisture, warmth, aeration, and pH in the range for excellent root growth, and an abundant soil microbial population associated with organic matter – all favor rapid nitrification.

Fall N applications with anhydrous NH_3 and other ammoniacal sources can improve the efficiency of corn production on some soils. In those areas where N loss is minimal, fall application re-

duces the potential for compaction and seedling injury associated with preplant application. Fall application also spreads the work load so that farmers can utilize favorable, early spring days to plant in a timely manner and reduce yield losses associated with late planting. Soil temperature is a key factor to consider in making fall N applications. Soil temperature has a marked effect on relative nitrification (**Figure 3**). Experienced agronomists recognize that soil temperatures must be low enough to retard nitrification, to reduce the risk of both leaching and denitrification losses. Fertilizer dealers, crop consultants, and state agronomists typically advise farmers to avoid fall N applications for spring planted crops until soil temperatures are consistently below about 50°F at the 4- to 6-inch depth, measured at 10 a.m. Even if soil temperatures permit occasional nitrification after fall N application, this may not present a significant problem if leaching does not occur.

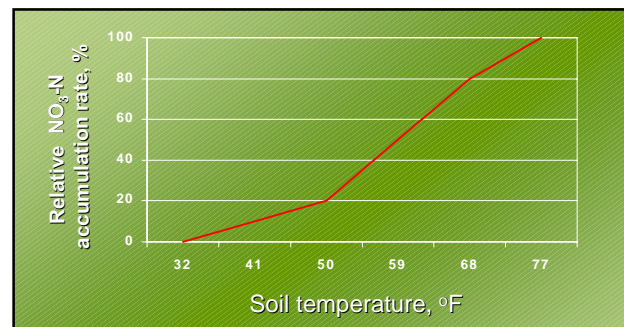


Figure 3. Relative effect of soil temperature on nitrification rates.
Source: adapted from Illinois Agronomy Handbook, 1997-98.

Fall N Rate, Timing, and Nitrification Inhibitors

Research has been conducted in several states to compare the crop and soil responses to fall versus spring N applications for corn. For example, data from a southern Minnesota study show that both rate and timing of N application can affect crop yields and $\text{NO}_3\text{-N}$ loss through tile drains (**Table 1**). Depending on temperatures and rainfall in the fall through spring, appropriate fall N use can produce corn yields equal to yields with spring N applications, but may result in greater $\text{NO}_3\text{-N}$ loss. Although ammonium sulfate $[(\text{NH}_4)_2\text{SO}_4]$ was the N source in this study, other studies have shown similar results with anhydrous NH_3 .

The preceding year's growing conditions, yield, N removal, and residual $\text{NO}_3\text{-N}$ in the soil profile should be considered when making fall N applications. According to research in Minnesota, considerable N may be stored in the soil profile in dry years and may be subject to drainage losses in wet

Table 1. Corn yields and NO₃-N lost through tile drains as influenced by rate and time of N application at Waseca, Minnesota.

N treatment		1978-82 yield average, bu/A	Average annual NO ₃ -N lost thru tile lines, lb/A
Rate, lb/A	Time		
0	—	66	7
120	Fall	131	27
120	Spring	150	19
180	Fall	160	34
180	Spring	160	26

N source was (NH₄)₂SO₄ applied after November 1.
Source: Randall, G.W. 1993. Best management practices for efficient nitrogen use in Minnesota, pp. 257-267. In: Soil Specific Crop Management. American Society of Agronomy.

years (**Table 2**). Interestingly, NO₃-N drainage losses from fallowed fields may exceed losses from cropped fields.

Crop responses from inclusion of a nitrification inhibitor with the fertilizer N application have varied with soil conditions, time of year, soil type, geographic location, rate of N application, and weather conditions. Potential crop yield benefits and likely environmental benefits are greatest during wet years. In the first four years of a study on N timing and rate in Illinois, there was no grain yield response to inclusion of a nitrification inhibitor. In the fifth year, when the month of May was wet, the application of a nitrification inhibitor with the preceding fall N increased corn yields (**Figure 4**). There will be some years when the inclusion of a nitrification inhibitor with fall N application can increase yields and possibly decrease NO₃-N leaching losses. However, the probability of benefit is not easily predicted because of the inability to accurately predict the weather.

Soil temperature can greatly affect the performance of nitrification inhibitors. Research in Illinois showed that on a Drummer soil, at least half the fall-applied NH₃ was kept in the NH₄ form for about five months when the soil temperature at

the time of application was below 55° F. When soil temperature at application was 70° F, the same amount of NH₃ was retained for only two months.

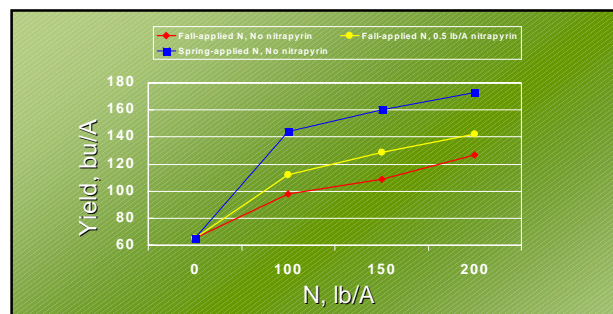


Figure 4. Effect of nitrification inhibitors on corn yields at different N application rates (Dekalb, IL).
Source: Illinois Agronomy Handbook, 1997-98.

Fall N application is not recommended on coarse-textured sandy soils with low organic matter because of the high leaching potential on these soils. Nitrification inhibitors are most likely to improve the efficiency of fall-applied N on silt loams, loams, and clays when the soil is wet in the following spring.

Region-Specific Fall N Guidelines

Northern States—

Nitrogen should **not** be fall-applied to :

- Soils with a high potential for over-winter or spring loss of N, such as coarse-textured, excessively well-drained soils or medium-textured, well-drained soils in humid regions (annual rainfall above 28 inches).

Fall N applications are appropriate where leaching losses are less likely. Based on southern Minnesota research since the late 1980s, nitrification inhibitor use is strongly suggested, especially in the higher rainfall regions. Soil temperature, which is highly dependent on latitude, and N source must be carefully considered. Long-term records show

Table 2. Effect of time of N application and nitrpyrin (nitrification inhibitor) on NO₃-N losses and corn yield, 1990-1993.

N Treatment, lb/A	Timing	Nitrpyrin	Four-year average NO ₃ -N lost, lb/A/yr	Four-year average yield, bu/A
134	Late fall	No	59	128
134	Late fall	Yes	46	137
134	Spring preplant	No	40	137
134	Spring/split ¹	No	42	143
0	Fallow	No	81	—

Data are for four consecutive wet years after three dry years. Anhydrous NH₃ was the N source.

¹ Split applications were: 54 lb N/A preplant and 80 lb N/A side-dressed.

Source: Personal communication with G.W. Randall. Paper pending publication by American Society of Agronomy.

that on average, daily 6-inch soil temperatures in southern Minnesota reach 50° F on October 13, but do not remain below 50° F until late October. The long-term research data indicate 65 to 70 percent of the annual tile drainage loss of NO₃-N occurs in April through June.

To minimize nitrification and the risk of losing fall-applied N:

- Fertilizer N should **not** be applied before October 20 to 25 in southern Minnesota and October 1 in more northern latitudes.
- Anhydrous NH₃ is the only source recommended for fall application where annual rainfall averages above 26 inches. Late fall applications of either broadcast-incorporated or band-injected urea have a greater risk of loss and have resulted in severe yield loss when fall and/or spring rainfall is above normal.
- Either anhydrous NH₃ or urea is acceptable when annual rainfall averages below 26 inches. Risks of loss are greater with urea, especially in wet springs.

—Source: Dr. G.W. Randall

Eastern States—

Fall applied N should be limited to soils that have a low potential for N loss:

- Well, but not excessively drained soils
- Soils which normally freeze for several months during the winter

Rules of thumb:

- Do not apply until soil temperatures will remain below 60° F if a nitrification inhibitor is included, or below 50° F if a nitrification inhibitor is not included
- Delay fall N until the third week in October south of 41 degrees North latitude (approximately Kankakee, IL), irrespective of temperature
- Alter fall applications an additional five days for each degree change in latitude from 41 degrees North
 - Later for each degree latitude (about 70 miles) change to the south
 - Earlier for each degree latitude (about 70 miles) change to the north

Fall-applied N should be limited to products that are in, or quickly convert to, NH₄ [(anhydrous NH₃ or (NH₄)₂SO₄]. Since (NH₄)₂SO₄ is usually not injected in a concentrated band, application should

be delayed until soil temperature at 4 inches deep is below 50° F.

—Source: Dr. R.G. Hoelt

Western States—

The western region of the Corn Belt generally receives low amounts of precipitation from November through mid-March. In Manhattan, Kansas, for example, the 30-year average precipitation from November through March is only 6.2 inches. The average yearly precipitation is 32.9 inches. With the low November through March precipitation, there is a fairly low leaching potential on most soils in this region.

Fall application of N in this region is a viable management practice, but the following guidelines should be strongly considered.

- Consider yield potential, residual soil N, cropping sequence (legume N credits), and previous manure application to determine N rate.
- Soil testing to determine residual soil N is strongly recommended.
- Fall N should only be applied after soil temperature cools to 50° F at a 4- to 6-inch depth.

Following this guideline helps ensure that the majority of applied N will go through the winter and early spring as NH₄. Ammonium is not subject to leaching or denitrification losses.

- Do not apply fall N on environmentally sensitive soils, such as coarse-textured, sandy soils or any soil overlying shallow groundwater supplies.
- Do not fall apply N near sources of water for human or livestock consumption.
- Fertilizer N and manure should never be applied to totally frozen soil.

A thorough understanding of the soil N cycle provides a good basis for development of BMPs for efficient utilization of this essential plant nutrient. Employment of BMPs for N will ensure efficient corn production while minimizing environmental concerns.

—Source: Dr. R.E. Lamond

Southern States —

Fall N application for corn is uncommon and generally not recommended in the southern states. Significant losses of fall-applied N can occur because of warm, moist conditions that persist through late fall. Rainfall in the region frequently exceeds 35 to 40 inches per year, with the majority received in winter through spring. These conditions

raise the potential for nitrification, leaching, denitrification, or runoff losses. University scientists in areas such as Missouri and Kentucky discourage fall N fertilization for corn. Experience in these states suggests that fall N application can result in more than 50 percent loss. By the time many soils in the region are consistently below 50° F at the 4- to 6-inch depth, they are too wet to support application equipment, or traffic can cause severe compaction. Soils can warm rapidly in the spring before planting or soon afterward. Rainstorms before extensive root development frequently increase the risk of high N losses.

The following guidelines should be considered when contemplating fall N application for corn:

- Fall N applications should be restricted to soils that are well, but not excessively drained (silt loams to clay loams).
- Only $\text{NH}_4\text{-N}$ sources should be used, and applications should be delayed until soil temperatures at 4- to 6-inches deep cool to and remain below 50° F through the winter (generally, north of St. Louis, Missouri).
- Any fall-applied N should be injected (knifed or coulter-applied) into the soil or incorporated to prevent volatile NH_3 losses and to reduce runoff risks.
- Nitrogen rates should be based on realistic yield goals, using results from local research or on-farm experience.
- Credit should be given to historic manure applications, N-fixing crops, and residual soil N in the cropping rotation.
- Nitrification inhibitors with fall applied N are often unsuccessful in keeping the N in the NH_4 form because of the overwhelming potential for nitrification and are therefore typically not recommended.

—Source: Dr. C.S. Snyder

N Management Tools – Implications for Fall N Management Decisions

Tools such as the basal stalk NO_3 test, the pre-sidedress soil NO_3 test, soil profile $\text{NO}_3\text{-N}$ tests, plant tissue nutrient analysis, in-the-field chlorophyll measurements on corn leaves, spectral radiometer and canopy reflectance measurements (ground, aerial, and satellite based), and grain nutrient analysis on a site-specific basis for more precise estimation of N removal may help guide N management decisions at various times in the year. A thorough understanding of the strengths and weaknesses of these tools is needed before using them. Several of the tools have a strong research

foundation while others are still being investigated for reliability. For example, because of the inability to accurately sample fields that have received injected anhydrous NH_3 , Illinois research efforts to calibrate and interpret soil NO_3 tests have been largely unsuccessful, even when the exact location of the anhydrous NH_3 bands is known. Some N management tools enable more precise accounting for residual N or in-season N contributions to crop nutrition. Others provide a “post-mortem” indication of crop N uptake efficiency. Year-round N management improvements can influence the total N applied, as well as fall N application decisions. Farmers, crop advisers, and fertilizer dealers should consider using the tools which have been locally calibrated through field research and experience.

Conclusion

Fall N applications can be used to provide economic crop production. However, sizeable quantities of soil and fertilizer $\text{NO}_3\text{-N}$ can be transported from farm fields in drainage waters in the spring before crops are well established. Monitoring and research show that much of the $\text{NO}_3\text{-N}$ loss in sub-surface drainage occurs in spring to early summer.

Complex interactions control the formation and potential loss of NO_3 from soils. Current farm economics and heightened water quality concerns require improved management of all N applications, especially fall N applications. Applying a little more fall N than really needed to compensate for leaching losses is not an acceptable practice. Fall N management must be more closely linked with an understanding of soil nitrification and leaching potentials.

The majority of farmers are good managers. They constantly seek ways to improve the bottom line, refuse to be satisfied with being classified as “average”, challenge conventional thinking, and are more conscious of environmental responsibility than ever before. Fall N management will improve as a result of greater knowledge, enhanced communication and information management, and improved cooperation among farmers, fertilizer dealers, and crop advisers. Improved fall N management will contribute to water quality improvements and an increased farm profit potential. ■

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