Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming

By C.S. Snyder

THE CONCEPT of fertilizer best management practices (BMPs) is not new...it was first introduced almost 20 years ago (Roberts, 2007). Fertilizer BMPs are more important today than ever before and need to be based on a simple concept of matching the nutrient supply with crop requirements, while minimizing nutrient losses from fields. All fertilizer consumers should apply the correct nutrient in the amount needed, timed and placed to meet crop demand —**"right product, right rate, right time, and right place."** Fertilizer BMPs must be adaptable to all farming systems, since one size does not fit all (Roberts, 2007).

Properly balanced plant nutrition with fertilizer BMPs will maximize capture of carbon dioxide (CO_2) through crop photosynthesis and carbon (C) sequestration; crop productivity per unit of land area will be optimized, while also achieving farmer profitability and sustainability goals. Any fertilizer BMP that increases crop yields, nutrient uptake, and recovery of applied nutrients is likely to minimize or limit the potential for undesirable nutrient losses to water and air resources.

Science and experience show that the impact of a fertilizer BMP on crop yield, crop quality, profitability, and nutrient loss to water or air is greatly influenced by other agronomic practices such as plant population, cultivar, tillage, and pest management, as well as conservation practices such as terracing, strip cropping, residue management, riparian buffers, shelter belts, and others (Fixen, 2007). Practices that are defined enough to be useful in making on-farm fertilizer use decisions often are "best" practices only when used in conjunction with other appropriate agronomic and conservation BMPs. A best fertilizer practice can be totally ineffective if the cropping system in which it is used has other serious inadequacies (Fixen, 2007).

The discussion and guides that follow are oriented toward the central U.S. Corn Belt, but are relevant to other cropping systems with similar crop geographies. They are provided to assist in fertilizer nitrogen (N) management decisions that will help lessen the impact of fertilizer N use on greenhouse gas (GHG) emissions and help mitigate the global warming potential (GWP) – expressed as CO_2 equivalent. The three GHGs of interest to agriculture are: nitrous oxide (N_2O), methane (CH_4), and CO_2. The GWP of CH_4 is 23 times greater and the GWP of N_2O is 296 times greater than that of CO_2. Because fertilizer N use may be associated with N_2O emissions, and because the GWP of N_2O is so much greater than CO_2, fertilizer N BMPs to reduce N_2O emissions are emphasized in this practical guide. For example, fertilizer N BMPs which help minimize excess nitrate (NO_3^-) in the soil during warm, wet, or waterlogged conditions can result in lowered risks for N_2O emission. (Snyder et al., 2007).

General Principles

- *Before any fertilizer N is applied*
  - **Set a realistic production goal, based on the soil and climatic conditions for the field.**
  - **Make an inventory of: 1) existing soil fertility, 2) nutrients supplied from irrigation, manures, and legumes, and 3) total and seasonal crop nutrient demand to help identify appropriate fertilizer rates.**
  - **Identify other factors that limit the efficient use of N and manage them to the extent possible. For instance, low levels of other nutrients, poor crop establishment, weed competition, inadequate drainage, and compaction are factors that reduce the effectiveness of N applications.**
  - **Evaluate soil and environmental conditions and determine the most likely pathways and intensity of N loss for the area.**
  - **Select one or more fields for in-season monitoring of plant nutritional status.**
    - **Tissue testing typically monitors plant nutrient concentrations during peak demand, usually just prior to or during early pollination.**
    - **Chlorophyll meters require an early season application of a non-limiting N rate applied as a reference strip in the field.**
    - **Crop reflectance measurements, an area of active research, are a promising approach for adjusting N rates in-season.**
  - **Select one or more fields for post-season monitoring of plant nutritional status. Several states provide guidance for using the stalk NO_3^- test for corn. This test provides information on whether or not N rates applied during the season were sufficient, deficient, or excessive.**
  - **Identify any nutrient-related environmental concerns which may be present in your watershed or region, such as: 1) high groundwater NO_3^- concentrations, 2) eutrophic surface water bodies or water resources with noxious algae blooms, or 3) "downstream" nutrient enrichment issues like low oxygen concentrations (hypoxia).**

Equipment, Proper Application, and Application Technology

- Avoid or delay fertilizer applications when fields are susceptible to soil compaction by heavy equipment. Evaluate equipment axle loads and tire pressures and their impact on soil compaction. Increased soil compaction can aggravate or accelerate soil N_2O emissions. Consider tillage systems that reduce trips across the field and provide needed erosion and runoff control.
- Calibrate fertilizer application equipment to ensure accurate delivery of prescribed N rates and proper placement. Avoid application overlaps and off-target delivery, and ensure uniformity of application across the spreader width.

Photo Source: University of Arkansas

Use soil testing to determine pH and nutrient status. Special N tests may also be important to consider.

  If subsurface application is used, ensure proper depth of placement.
- Provide good soil closure and N retention behind the applicator with any subsurface placement of N sources.

Fertilizer Nitrogen BMPs – Achieving the Four Rights

N Sources

- Choose the N source that fits economic and logistical requirements and minimizes risks of N loss **(Table 1).** The N source selection can affect the proper rate, timing, and placement.

Ammonium vs. nitrate-based

- Wherever possible and practical, providing plant nutrition in ammonium (NH_4^+) forms rather than NO_3^- is likely to minimize total GHG emissions. This guide is not intended as a life-cycle analysis, yet it is important to acknowledge that NH_4^+ fertilizers are manufactured with less GHG emission than NO_3^- fertilizers (with the possible exception of mined Chilean nitrate). In addition, the NO_3^- form is more vulnerable to denitrification, which results in emissions of N_2O and N_2 gases (Harrison and Webb, 2001; Firestone, 1982).
- Choose ammoniacal (NH_4-based, NH_3-based) fertilizer N sources over NO_3-based sources (Harrison and Webb, 2001), when applied early in the season before the crop root system is well established. If using fertilizer N sources containing NO_3^-, do not apply to soils that typically become wet or waterlogged early in the season. Waterlogging during warm conditions (late spring through summer), while less probable than in the spring, could generate larger N_2O emissions.
- Nitrification inhibitors are discussed in the "N Timing" section.

Table 1. Relative effectiveness of management scenarios, shown as advantage of "Scenario 1" over "Scenario 2", in reducing N losses and greenhouse gas emissions. Effectiveness rating represents estimate of the relative potential N loss reduction, on-farm and within-watershed.[1]

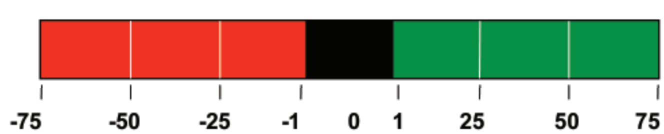
			Indirect effects on N_2O emissions			Direct greenhouse gas emission[3] N_2O
			Water discharges as NO_3^-		NH_3 volatilization	
N Source[2]	**Fertilizer N Management Practice**		**Leaching**	**Runoff**		
	Right agronomic N rate					
	Scenario 1	**Scenario 2**				
All Sources	Accounting for soil N supply and other input sources (e.g. manure, irrigation water, etc.)	No such N accounting (assumes over-application)				
All Sources	Site-specific N management (variable rate and/or source)	No site-specific management				
	Right N timing					
	Scenario 1	**Scenario 2**				
AA	Applied in the fall after soil temp below 50 ºF (10 ºC) for spring-planted crops	No waiting				
AA, AS, PA, U, UAN	Spring application, for spring planted crops (e.g. corn)	Fall application				
AA, AS, PA, U, UAN, AN, PN	Spring split or sidedress applied, for spring planted crops	All preplant applied				
AA, AS, PA, U, UAN, AN, PN	Spring or split fall-spring application, for fall planted crops (e.g. wheat, canola)	All fall applied				
AA, AS, PA, U, UAN, AN, PN	Nitrification inhibitor used	None used				
U	Controlled release technology used	None used				
	Right N placement					
	Scenario 1	**Scenario 2**				
AS, PA,U, UAN, AN	Subsurface incorporation	Surface broadcast				
U, UAN	Surface banded	Surface broadcast				
AS, PA, U, UAN, AN, PN	Shallow sidedress band – 1 in. (2 cm)	Sidedress band deeper than necessary – ≥ 4 in. (10 cm)				
U, UAN	Surface applied with urease inhibitor; abundant crop residues	No inhibitor				
U, UAN	Surface applied with urease inhibitor; minimal crop residues	No inhibitor				

[1] Relative percentage (%) advantage of "Scenario 1" over "Scenario 2," estimated from available literature and experienced observation. This rating scheme does not identify the quantity of N loss, which can be relatively small <1 to 2 lb/A (<1 to 2 kg/ha) in some conditions. Relative effects do not include emissions associated with manufacture or transport of inputs. Ratings are subject to change with research progress.

[2] N sources: AA=anhydrous ammonia, AS=ammonium sulfate, PA=predominantly ammonium containing, U=urea, UAN=urea ammonium nitrate solutions, AN=ammonium nitrate, PN=predominantly nitrate-containing.

[3] Data insufficient to allow ratings for emissions of the other two principal greenhouse gases, CH_4 and CO_2.

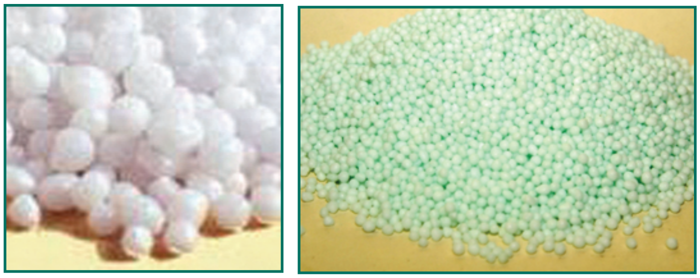
Legend for ratings in table:



Ratings can represent broad, multiple ranges (e.g. negative to positive), or a single quartile. The rating scheme is based to some extent on a conservation practice rating scheme in Table 17 in EPA SAB (2008).

Urea and urea-containing materials

- Ideally, apply urea, urea-ammonium nitrate (UAN), and other urea-containing materials when thorough soil incorporation is possible by rainfall or irrigation...at least 0.25 to 0.5 in. (0.6 to 1.2 cm)...or by tillage, within 24 to 48 hours after application. Follow this practice especially where environmental conditions are conducive to ammonia (NH_3) volatilization (Jones et al., 2007; Trenkel, 1997; Kissel, 1988).



Forms of urea with enhanced efficiency (right) are being developed and studied. Chemical or physical treatments can be used to enhance the efficiency of urea.

- Surface-banded urea applications can help reduce residue contact with the fertilizer.

- Urease inhibitors are discussed in the "N Timing" section.

N Rates

- Use appropriate N rates, in balance with other essential nutrients, to optimize crop yields and to protect the environment. Excessive rates can lead to environmental losses, reduced production, and increased costs. Manage N rates to:
  - minimize residuals of soil NO_3-N, and to
  - reduce the risk of N_2O emission (Halvorson et al., 2008b; McSwiney and Robertson, 2005), especially on more poorly drained soils

Photo Source: Case IH

Sidedress N application for corn and some other crops has several potential benefits.

- Implement nutrient management plans that consider the soil N supply and the nutrient contribution from all nutrient sources applied. Give proper credit for plant-available N from sources such as soil organic matter (SOM) mineralization, legumes, manure, irrigation water, and atmospheric deposition.

- Identify N rate requirements for your yield goals and conditions by following research based recommendations or replicated in-field N rate comparisons.

- After crop harvest, estimate partial factor productivity (PFP) and partial nutrient balance (PNB), and where possible, determine agronomic efficiency (AE) and fertilizer N recovery efficiency (RE) (Snyder and Bruulsema, 2007). Nitrogen management refinement opportunities may be identified through these estimates. *Evaluations may extend to parts of fields where distinct and definable areas are large enough to warrant site-specific fertilizer management.*

- Use in-season and post season assessments *(see those mentioned above in **General Principles** section)* to evaluate plant N nutrition sufficiency, deficiency, or any potential surplus.

N Timing

- Proper N timing is a major factor that affects crop N uptake and the potential for elevated soil NO_3^-, which raises the risks for N_2O emission.

- Delay fall N applications of ammoniacal N (e.g. anhydrous NH_3) for corn and other spring-planted crops on all soils until soil temperatures will remain below 50 °F (10 °C) at a 4 to 6 in. (10 to 15 cm) depth through the winter (Snyder et al., 2001), and where research has proven this practice is agronomically sound. Applications too early in the fall allow more of the applied N to convert to NO_3^- **(Figure 1)**, which increases the risks of NO_3^- loss and N_2O emissions.

- Do not fall-apply N to soils with a high potential for winter-through-spring loss of NO_3-N via leaching or tile drainage, such as coarse-textured, excessively well-drained soils or medium-textured, well-drained soils in humid regions with annual rainfall above about 28 in. (71 cm).

- Avoid the application of N fertilizers in the fall for spring-planted crops where soil conditions are likely to allow the following:
  - Rapid nitrification...NH_4^+ transformation to NO_3^-, generally associated with soil temperatures >70 °F (>21 °C) with adequate moisture (Schmidt, 1982);
  - Significant NO_3^- leaching and/or runoff loss... >5 to 10 lb N/A/yr (6 to 11 kg N/ha/yr);
  - The potential for significant denitrification [microbial conversion of NO_3^- to NO_2^- and di-nitrogen (N_2) and N_2O gases] losses as N_2O. For example, >0.5 to 2 lb N/A/yr (0.6 2 kg of N/ha/yr), associated with water-filled pore space (WFPS) >60%, a supply of available C compounds (e.g. som), and soil temperatures >70 °F (>21 °C) for more than 2 to 3 consecutive days.

- Time N applications to coincide, as practically and logistically as possible, with crop N uptake demand to maximize

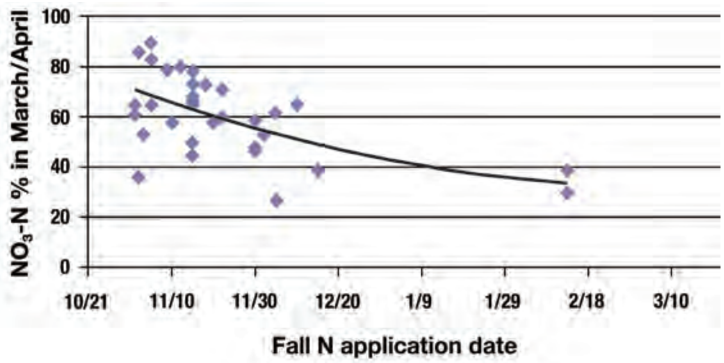


Figure 1. The proportion of fall-applied (after November 1) anhydrous NH_3-N that had converted to NO_3-N by the following March/April 2003 and 2004. (Scharf and Mueller, 2005).

crop uptake, to minimize excess residual NO_3^- and to avoid losses to air or water. Avoid applying N too early or too late, relative to crop uptake demand.

- Delay part of the fertilizer N application to a "side-dress" timing for spring-planted corn, cotton, or potatoes (e.g. growth stage V4-V6 for corn, first-square to first-flower in cotton, with hilling operations for potatoes). This will assist in reducing the risk of leaching loss and N_2O emissions, if local or regional research has shown this practice to present minimal risks of yield and economic losses.

- "Split-apply" N (i.e. two or more applications in spring to early summer) for crops and forages grown in spring through summer, to better synchronize N supply with plant uptake. Split application can increase N use efficiencies. Refer to local or regional research when comparing split applications to single pre-plant or at-planting applications.

- Avoid application of any N sources to wet or waterlogged soils especially in late spring through summer, or other warm periods, when the N source may rapidly convert to NO_3^- and be susceptible to denitrification and N_2O emissions. (An exception to this is in flooded rice culture, mid-season N application, where the rice plant's physiology and rapid N uptake characteristics can result in efficient N uptake).

- Avoid surface application of urea or ammoniacal N sources to wet or waterlogged soils (except flooded rice culture, midseason N application) to limit NH_3 volatilization, or to dry soils under conditions of high humidity and limited chance of soil incorporation within several days after application.

- Use nitrification inhibitors with ammoniacal N sources in environments where there is a high potential for NO_3-N leaching and/or N_2O emissions (Wolt, 2004; Hoeft, 1984). For example:

    - humid, high rainfall, i.e. above 23 to 28 in./yr (58 to 71 cm/yr) environments;

    - more poorly drained soils (>60% WFPS) or soil moisture greater than 60% of the water holding capacity within several weeks after fertilizer N application;

    - where high NH_4-N (includes urea-containing sources) rates are applied outside the period of rapid crop growth and nutrient uptake.

- Use urease inhibitors with urea or urea-containing N sources where significant NH_3 volatilization risks exist (no-till and reduced-till (i.e. zone-till, strip-till, chisel-till, etc.) crop systems, and in perennial forage systems). Generally for surface applications:

    - where there are high levels of crop residues on the soil surface, warm temperatures, high humidity, windy conditions;

    - where N is broadcast or dribbled on the soil surface;

    - where it is unlikely or not possible to achieve thorough soil incorporation by rainfall, irrigation...at least 0.25 to 0.5 in. (0.6 to 1.3 cm)...or by tillage within 24 to 48 hours after application.

- Use slow- or controlled-release technologies to help manage the timing of N release from fertilizer to help reduce the risk for leaching losses of NO_3^-, volatile losses of N as NH_3, and N_2O emissions. (Blaylock et al., 2005; Burton et al., 2008; Halvorson et al., 2008a and 2008b; Merchan-Paniagua, 2006; Motavalli et al., 2008; Shaviv, 2000; Trenkel, 1997). These sources may perform well for spring-planted crops where NO_3^- leaching and/or N_2O emission risks are high early in the growing season; for example:

    - humid, high rainfall environments...e.g. above 23 to 28 in./yr (60 to 70 cm/yr);

    - soils with >60% WFPS (near or above field capacity) within several weeks after fertilizer N application, or sustained wetness throughout much of the year.

- Know the N release characteristics (i.e. obtain research-proven field performance data) of the slow- or controlled-release source, and choose a source that is well-suited to the specific crop, its N uptake demand period, the prevailing soil moisture regime, and local climatic conditions.

Photo Source: Oklahoma State University

Crop reflectance measurements are being researched as a method to guide N rates in-season.

N Placement

- Follow local research-based recommendations, and place anhydrous NH_3 no deeper than 6 to 8 in. (15 to 20 cm) in most soils, to reduce the risk of both NH_3 emissions and N_2O emissions **(Table 1)**. Note: Placement of anhydrous NH_3 no deeper than 4 in. (10 cm) in medium to fine-textured soils has caused N_2O emissions to decline as much as 36% over deeper placement (Breitenbeck and Bremner, 1986).
- Placement of any N source in direct contact with plant residues may increase the risk of N_2O loss (Parkin and Kaspar, 2006).
- Avoid surface broadcast or banded applications of any N source where soils are too moist to permit adequate incorporation with rainfall or irrigation (via soil infiltration), and where there may also be a significant risk of surface runoff loss to water resources.

Photo Source: USDA-ARS

The corn stalk NO_3^- test can provide information on whether N rates during the season were sufficient or excessive.

- Use surface banding of UAN solutions, as opposed to broadcast application, to help improve agronomic efficiency and reduce potential N losses (e.g. NH_3 volatilization).
    - Consider other effects of banding action or incorporation, such as moisture loss, seedbed disturbance, weeds, and residue management.
    - One-pass systems can combine seeding and fertilizing in one operation.
- Incorporate urea or urea-containing sources beneath the soil surface (Jones et al., 2007; Kissel, 1988);
    - by subsurface banding;
    - by thorough soil incorporation via rainfall or irrigation... at least 0.25 to 0.5 in. (0.6 to 1.3 cm)... or by tillage within 24 to 48 hours after application
- Urease inhibitors are discussed in the "N Timing" section.

The following on-farm management practices offer key opportunities in the Corn Belt to reduce direct GHG emissions, and to reduce other losses (for example: NH_3 volatilization, NO_3^- leaching, and runoff) that may indirectly contribute to such emissions. Implementation of these management practices may offer the most benefits to reduce the GWP.

1. Assess the soil and climatic conditions in the field carefully to determine both yield potential of the crop and the likely paths and magnitude of N losses. Strive to apply N rates that are sufficient, but do not exceed that required for optimum crop yield and quality, accounting for soil N supply and all other N inputs.
2. Use cropping system management practices that could optimize N effectiveness and minimize N losses (for example: adequate and balanced supply of all essential nutrients, selection of crop varieties or hybrids with superior genetics, use of conservation tillage, appropriate pest management, etc.).
3. Use appropriate N application timing or source selection to minimize both direct and indirect N_2O emissions, while also minimizing potential N losses via other loss pathways (for example: shift from fall to spring N application for spring planted crops where improvement in N use effectiveness is expected and where logistically practical).
4. Use additional technologies, such as urease and nitrification inhibitors and slow- or controlled-release N sources. These technologies generally reduce the probability of N loss and increase N use effectiveness, especially where appropriate N timing challenges present significant risks of N loss.
5. Use subsurface incorporation when applying urea-containing N sources, especially under conditions conducive to NH_3 loss.
6. Use performance indicators such as plant tissue analyses in-season and post-season nutrient analyses, based on accurate farm records, to evaluate the effectiveness of N applications.
7. Make N source, rate, timing, and placement decisions with consideration of all N loss pathways that may affect crop N use effectiveness. Avoid focusing only on N_2O emissions management, since other N loss pathways may dominate the reductions in N use effectiveness, depending on geography and site-specific conditions.

Conclusions

Implementation of these BMP guidelines is encouraged to help improve crop recovery of applied N, increase crop yields and CO_2 capture, reduce risks of GHG emissions, and lower the net GWP associated with fertilizer N use. Farmers should seek more specific research-based guidance on cropping system N management from Certified Crop Advisers (CCAs), agricultural consultants, fertilizer dealers, university research and extension professionals, and government agencies. It is clear that the principle of applying the **right product, at the right rate, at the right time, and in the right place** is beneficial for minimizing N loss. More research is needed to further improve our knowledge of fertilizer N effects on GHG emissions and other environmental N losses under site-specific local conditions. **More research and monitoring are also needed to measure the impact of specific fertilizer N BMPs on sustainable development and economic, social, and ecological goals for current and future generations.** ■

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Acknowledgments: *The scientific contributions of IPNI staff members, including Dr. Tom Bruulsema, Dr. Paul Fixen, Dr. Tom Jensen, Dr. Scott Murrell, and Dr. Rob Mikkelsen and their interpretive assistance in preparation of this guide, are gratefully acknowledged. The helpful reviews of the following scientists are gratefully acknowledged: Dr. Ron Follett, USDA-ARS, Colorado; Dr. Timothy Parkin, USDA-ARS, Iowa; Dr. Dale Leikam, Fluid Fertilizer Foundation and Kansas State University; and Dr. Cynthia Grant, Agriculture and Agri-Food Canada.*

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Fertilizer Best Management Practices

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This publication is one of a series prepared by cooperators with the staff of the International Plant Nutrition Institute (IPNI). It is part of a project in cooperation with the Foundation for Agronomic Research (FAR) toward fulfilling the goals of a 3-year Conservation Innovation Grant (CIG 68-3A75-5-166) from the USDA-Natural Resources Conservation Service to identify fertilizer best management practices (BMPs). The intent of this publication is to help develop the BMP definition process in such a way that environmental objectives are met without sacrificing current or future production or profit potential and in full consideration of the newer technologies relevant to fertilizer use. The concept of applying the right fertilizer at the "right rate, right time, and right place" is a guiding theme in this series. For additional information, visit the website: www.farmresearch.com/CIG and www.ipni.net.

June 2008 Ref. # 08057 Item 30-3210

Fertilizer Best Management Practices
funded by USDA NRCS Conservation Innovation Grant

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