The goal of nitrogen (N) application is for crop uptake, resulting in improved yield and quality of the crop harvested. However, N fertilizer applications are also susceptible to emission losses, as ammonia (NH₃) and nitrous oxide (N₂O), and surface and groundwater losses as nitrate-N (NO₃⁻). In the past, research has focused on the rate of nutrient application on yield, quality, and N losses. As producers look to improve nutrient use efficiency, the need for research to address other factors in nitrogen application has grown.

Specifically, a growing number of researchers are looking at how the 4Rs of nutrient application—source, rate, time, and place—affect crop uptake and yields. The fertilizer industry established the 4R Research Fund to help establish sustainability indicators and environmental impact data for implementation of 4R nutrient stewardship across North America.

Improved N use efficiency can be achieved through combinations of rate, source, time, and place. A recent roundtable meeting identified as a goal “broadening the focus of applied research beyond N rate to move toward more integrated agricultural systems,” and cited the 4R nutrient stewardship approach as a step to help represent...
the complexity of the farming systems (Reimer et al., 2017). Research continues to broaden the focus of nutrient research to address the 4Rs and not solely application rate.

Enhanced-efficiency fertilizers as part of a 4R strategy

Enhanced-efficiency fertilizers (EEF) include slow- or controlled-release N fertilizers that are coated or encapsulated or fertilizers treated with nitrification and/or urease inhibitors. Selecting the use of an EEF in a crop management system encompasses the right source, right time, and right place components of the 4R nutrient stewardship concept (Snyder, 2016).

The rate and source part of the equation was evaluated in a summary of research projects using EEFs in multiple management systems. The use of polymer-coated urea (PCU) can reduce N loss as nitrous oxide (N₂O) and ammonia (NH₃) volatilization when managed correctly (Hopkins, 2016). In a recent summary of the use of PCU N fertilizer compared with untreated urea, Hopkins (2016) at Brigham Young University reported N₂O and NH₃ losses across three management systems in laboratory, glasshouse, and field studies. The fertilizer treatment rates ranged from 80.3 to 401.5 lb/ac across the potatoes, corn, and Kentucky bluegrass cropping systems (Hopkins, 2016). The results in the report focused on the different source on N applied across application rates and management systems.

When uncoated urea was applied, losses as a percentage of total N applied were 13% as NH₃ and 2% as N₂O (Hopkins, 2016). The use of a PCU versus uncoated urea resulted in lower NH₃ and N₂O emissions. On average, NH₃ emissions decreased by 300%, with a range of 64 to 574% (Hopkins, 2016). The percent reduction in N₂O loss was lower, 120% on average, with a range of 38 to 201%, and was significant for 11 of the 12 treatments (Hopkins, 2016). In addition to loss as NH₃ and N₂O, N applied as urea can convert to nitrate (NO₃⁻) through nitrification and be taken up by plants, accumulated in the soil, or lost to leaching. In eight of the 12 treatments, PCU use resulted in less NO₃⁻ accumulated in the soils (Hopkins, 2016). Plant performance in these studies was not negatively impacted using PCU versus uncoated urea.

4R NH₃ mitigation strategy results

Meta-analysis, which is a systematic review of available research studies, is used to provide information to answer larger questions. In agricultural systems, one question that needs to be approached this way is mitigation strategies for NH₃ volatilization because individual studies are sometimes inconclusive (Pan et al., 2016). Understanding the relationships of mitigation strategies for NH₃ volatilization is critical to improving global fertilizer N use efficiency, environmental quality, and climate change mitigation (Pan et al., 2016).

One recent meta-analysis identified 171 studies with 886 observations that could be evaluated (Pan et al., 2016). The observations were evaluated by N source, rate of application, timing, or frequency of application as well as surface versus deep placement of N fertilizer. The source of N fertilizer was evaluated two ways: First, as the type of fertilizer relative to urea, and second, as fertilizers treated with urease inhibitors and fertilizers treated with nitrification inhibitors (Pan et al., 2016).

Source. The source of N, when evaluated as the type relative to urea, affected NH₃ volatilization. When a urea-mixed or non-urea fertilizer was used, there was a 75 and 31% decrease, respectively, in NH₃ volatilization compared with when urea was used as the N fertilizer (Pan et al., 2016). Additionally, the use of a urease inhibitor or a controlled-release fertilizer decreased the loss of NH₃ by 54 and 68%, respectively (Pan et al., 2016).

Rate. The rate of N application was evaluated relative to the lowest N rate reported. Increased rates of N application increased NH₃ volatilization (Pan et al., 2016). On average, increased N application rates increased NH₃ volatilization by 186% (Pan et al., 2016).

Timing. Split applications of N fertilizer had a neutral effect on NH₃ volatilization (Pan et al., 2016).
**Meta-analysis of N₂O and NO₃⁻ losses**

The fertilizer industry’s 4R Research Fund supported three meta-analyses that examined the literature for the effect of 4R management on the loss of N₂O and NO₃⁻ in primarily corn and soybean systems in North America. Across these reviews and others, the lack of simultaneous volatilization, leaching, and N₂O emissions measurement was noted (Snyder, 2016).

The effects of 4R management strategies on NO₃⁻ leaching losses to tile drainage discharge over 40 years of research in the Midwest was considered in the update of the Measured Annual Nutrient Loads for Agricultural Environments (MANAGE) database meta-analysis project (Christianson and Harmel, 2015).

**Timing.** Timing had variable results depending on the type of N loss measured, N₂O vs. NO₃⁻.

**Place.** Placement had variable results for N₂O and NO₃⁻ losses.

The 4R Research Fund has field studies in Kansas, Iowa, and Illinois measuring the influence of different 4R practices on the losses on N₂O and NO₃⁻ in corn and soybean cropping systems. Broad-scale evaluations like these meta-analysis are useful to identify the major trends in how 4R management impacts N cycling in the soil, plant, and water system, but site-specific implementation based on good data collection is necessary to maximize N use efficiency at each location.

**References**


