Nitrous oxide (N₂O) is a potent greenhouse gas that can result in nitrogen loss from the soil. The scientific literature is deficient in studies that measure N₂O emissions, NO₃ leaching, and crop performance across multiple sources of nitrogen fertilizer and changes in field practices. However, there are tools and strategies available to consultants and producers to improve nitrogen use efficiency and reduce N₂O emissions while not decreasing yield. Earn 0.5 CEUs in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/543

By Sally Flis, Ph.D. and CCA, Director of Agronomy, The Fertilizer Institute, Washington, DC

Nitrous oxide (N₂O) is a potent greenhouse gas, and under the right conditions, it is a product of the nitrogen cycle from nitrification followed by denitrification in the soil. While not usually significant, nitrous oxide formation can result in nitrogen loss from the soil. For plant-based products, fertilizer has been recognized as the biggest contributor to emissions, and as a result, agriculture is under increasing pressure to reduce N₂O losses. Relative to climate and sustainability discussions, consumer-facing companies are assessing their supply chains and setting goals to reduce their carbon footprints in response to consumer and investor pressures. One example is that Walmart has set a goal to work with suppliers across the entire value chain to reduce greenhouse gas emissions by 1 gigaton between 2015 and 2030 (Walmart, 2017). Fertilizer use is part of meeting this goal, and Walmart reports working with 17 suppliers in developing fertilizer optimization plans and sharing best management practices on a reported 76 million committed acres of U.S. farmland by 2025 (Walmart, 2017).

In a recent meta-analysis, a statistical analysis of the results of multiple studies, on fertilizer management and environmental factors that drive N₂O losses in corn, three
important findings were determined (Eagle et al., 2017b). First, yield, \(\text{N}_2\text{O}\) emission, and nitrate (\(\text{NO}_3\)) leaching each respond differently to fertilization practices. For example, a practice that decreases \(\text{N}_2\text{O}\) loss may not decrease \(\text{NO}_3\) loss. Second, regional-scale environmental drivers have effects on \(\text{N}_2\text{O}\) emissions and \(\text{NO}_3\) leaching that match or potentially exceed the effects of fertilizer application rate and other field practices. Finally, the scientific literature is deficient in studies that measure \(\text{N}_2\text{O}\) emissions, \(\text{NO}_3\) leaching, and crop performance across multiple sources of nitrogen fertilizer and changes in field practices (Eagle et al., 2017b). This creates a challenging landscape for consultants and producers working to meet their goals for production while decreasing losses. However, there are tools and strategies available to consultants and producers to improve nitrogen use efficiency and reduce \(\text{N}_2\text{O}\) emissions while not decreasing yield.

**Nitrification and urease inhibitors**

Nitrification inhibitors are additives that slow the conversion of ammonium (\(\text{NH}_4\)) to nitrate in the soil and may reduce the risk of nitrate leaching or denitrification. They can be combined with ammonium-based nitrogen fertilizers, such as anhydrous ammonia, urea, urea ammonium sulfate solution, or urea ammonium nitrate (UAN), to slow the conversion of ammonium to nitrate after fertilizer application (Habibullah et al., 2017). Nitrate can be taken up by plants, leached to groundwater, or converted to \(\text{N}_2\text{O}\) through denitrification. The two most commonly used nitrification inhibitor products are dicyandiamide and nitrapyrin.

Urease inhibitors are used on urea-based fertilizers or blends, and they act to delay the hydrolysis of urea to ammonium, which can be taken up by the plant, lost as volatilized ammonia (\(\text{NH}_3\)), or converted to \(\text{NO}_3\) through mineralization and nitrification. The most commonly used urease inhibitor is \(\text{N}-(\text{n-butyl})\text{-thiophosphoric triamide (NBPT)\).}

The majority of research on the effectiveness of nitrification inhibitor products to reduce \(\text{N}_2\text{O}\) loss has been conducted in the Midwest Corn Belt (Eagle et al., 2017b). A meta-analysis of this work found that \(\text{N}_2\text{O}\) loss can be reduced by an average of 32% in Midwest corn systems when a combination of nitrification and urease inhibitors are used on urea or UAN (Eagle et al., 2017b). Recent work on corn in California reported similar results with the addition of a nitrification inhibitor and urease inhibitor to UAN decreasing \(\text{N}_2\text{O}\) loss (Waterhouse et al., 2017). While the study did not indicate an increase in grain yield, it did report an increase in grain nitrogen concentration (Waterhouse et al., 2017). Relative to climate and soil conditions, the performance of these products can vary across geographies; therefore, additional work is needed to understand their potential across all geographies.

In order to meet the goals of all farms and the supply chain, research on the use of these products in other crops is necessary. A recent study in spring wheat production in Minnesota reported similar results to those of the meta-analysis in corn systems and corn in California—\(\text{N}_2\text{O}\) losses were reduced with the use of urea treated with a nitrification inhibitor and urea treated with both a nitrification and urease inhibitor (Thapa and Chatterjee, 2017). In addition, this study reported weekly \(\text{N}_2\text{O}\) flux emissions. Flux measurements were made using static chambers, and sampling was conducted twice a week in the first week and weekly through the growing season (Thapa and Chatterjee, 2017). A single peak in \(\text{N}_2\text{O}\) flux emissions occurred 18 days after fertilizer application for urea and urea treated with a nitrification inhibitor while urea treated with both nitrification and urease inhibitors peaked at 18 and 33 days after application. The use of a nitrification inhibitor only on urea reduced flux emissions by 55% (130 lb N/ac) and 59% (150 lb N/ac) compared with untreated urea (Thapa and Chatterjee, 2017). The use of a combination of a nitrification and urease inhibitors further reduced \(\text{N}_2\text{O}\) flux emissions by 62% (130 lb N/ac) and 64% (150 lb N/ac) compared with untreated urea (Thapa and Chatterjee, 2017).

As has been reported in studies with corn, when using a nitrification inhibitor, urease inhibitor, or a combination of the products, \(\text{N}_2\text{O}\) loss was decreased and yield was not different among the treatments that received nitrogen fertilizer application (Thapa and Chatterjee, 2017). Cumulative emissions of \(\text{N}_2\text{O}\) were calculated using all sampling days. Cumulative \(\text{N}_2\text{O}\) emissions were significantly higher from urea (2.0 lb \(\text{N}_2\text{O}-\text{N}/\text{ac}\)) and urea treated with a nitrification inhibitor (0.94 lb \(\text{N}_2\text{O}-\text{N}/\text{ac}\)) compared with urea treated with a nitrification inhibitor (1.14 lb \(\text{N}_2\text{O}-\text{N}/\text{ac}\); Thapa and Chatterjee, 2017). These losses are a fraction of the cumulative loss of \(\text{N}_2\text{O}\).
and NH$_3$ measured from the plots. Cumulative loss of N$_2$O and NH$_3$ was 8.94 lb N/ac for urea, 9.7 lb N/ac for urea treated with a nitrification inhibitor, and 5.97 lb N/ac for urea treated with a nitrification and urease inhibitor (Thapa and Chatterjee, 2017).

### 4R practices to reduce N$_2$O loss

While using a nitrification or urease inhibitor or a combination of the products can reduce the loss of N$_2$O, the rate, time, and placement of the application can also influence the amount of emissions. Rate of nitrogen fertilizer application has been reported as having a positive relationship to N$_2$O emissions with emissions increasing with increased fertilizer application, especially when nitrogen is applied above crop requirements (Han et al., 2017; Eagle et al., 2017b). However, the response curve is highly variable and is influenced by other management factors and climate (Eagle et al., 2017b). In studies comparing multiple nitrogen fertilizer application rates, the increase in N$_2$O emissions ranged from 2.8 to 11.9% with each additional 8.9 lb N/ac (Eagle et al., 2017b). Higher air temperature was also found to influence the magnitude of N$_2$O loss. For example, an average rise in July temperature of 1.8°F would produce the same change in N$_2$O emissions as increasing fertilizer application rate by 89.2 lb N/ac (Eagle et al., 2017b). This makes recording and monitoring temperature around nitrogen applications an important tool for improving nitrogen use efficiency.

Other 4R practices for timing and rate, such as split nitrogen application or sidedress application, have been reported to decrease N$_2$O emissions (Han et al., 2017; Eagle et al., 2017b; Fernandez et al., 2016). Across studies, Eagle et al. (2017b) found a 23% reduction in N$_2$O emissions when compared with all nitrogen fertilizer applied during pre-plant (spring or fall). Research on corn in Minnesota compared applying 120 lb N/ac in a single pre-plant application to a split application with 40 lb N/ac applied pre-plant and 80 lb N/ac sidedressed at V4 (Fernandez et al., 2016). There was no difference in the yield of corn grain or stover, but N$_2$O loss significantly decreased by 25.8% when nitrogen was applied in a split application (Fernandez et al., 2016). However, logistics are a challenge when changing to a split nitrogen application.

### Conclusions and continued research

While there is a large body of evidence demonstrating the effectiveness of using nitrification inhibitor products, and urease and nitrification products combined in corn production, data are lacking in more diverse geographies and crops. Additional 4R practices such as split nitrogen applications and applying nitrogen rates that reflect the needs of the crop as ways to reduce N$_2$O loss and maintain yield have also been well evaluated. However, the interactions of these practices and the use of nitrification and urease inhibitors, or combinations of the products, are lacking. Additionally, in meta-analysis work, it has been reported that in studies where nitrogen rate was tested, no other 4R practices were implemented. Conversely, in studies of 4R practices, nitrogen rates were not compared across practices even when the practice was expected to improve nitrogen uptake (Han et al., 2017).

Recent reports have highlighted the challenges to collecting and evaluating the data for a meta-analysis of the practices that can reduce the loss of N$_2$O from fertilizer applications. These include only reporting one nutrient removal constituent (N$_2$O emission, NO$_x$ loss, or yield grain removal) as the response, not reporting the frequency or timing of data collection, and not reporting measure of variation within data (Eagle et al., 2017a). An additional gap or challenge to recommending practices that will reduce environmental impact and maintain or improve yield is that, as mentioned earlier, the majority of research has been conducted with only a few crops and in only a few regions.

### References


