

Enhanced Efficiency Fertilizers: A Multi-Site Comparison of the Effects on Nitrous Oxide Emissions and Agronomic Performance

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Demand for increased production of crops and improved environmental quality has created an opportunity for agriculture to refine nutrient management in agricultural systems. This sentiment has been stated by Dobermann and Cassman (2002), in which they called for increased efforts on nutrient management practices that optimize profit, enhance soil quality, and protect natural resources in the context of building crop production systems that produce consistently high yields. The concept of improving nutrient management is not new. Nearly 40 yr ago Frye (1977) observed improvements in corn (*Zea mays* L.) yields with sulfur-coated compared with non-coated urea. More than a decade ago, Shaviv (2001) detailed the advances in controlled-release fertilizers and proposed these could be an effective means of enhancing synchrony between soil N availability and plant uptake demand for N.

During the past 10 yr there has been an increased interest in the use of “enhanced efficiency fertilizers” (EEFs) for their potential to reduce the environmental impact. A point of confusion that often exists is what constitutes an EEF. The term has been recently defined by the Association of American Plant Food Control Officials (AAPFCO) as “fertilizer products with characteristics that allow increased plant uptake and reduce the potential of nutrient losses to the environment (e.g., gaseous losses, leaching, or runoff) when compared to an appropriate reference product” (AAPFCO, 2013). In the AAPFCO definition, enhanced efficiency reference products are defined as “soluble fertilizer products (before treatment by reaction, coating, encapsulation, addition of inhibitors, compaction, occlusion, or by other means) or the corresponding product used for comparison to substantiate enhanced efficiency claims.” Nitrogen products that would be considered as EEFs would include nitrification and urease inhibitors, uncoated slowly available fertilizers, and coated N fertilizers.” These materials would be used to increase N availability to crops throughout the growing season while decreasing environmental impacts. The need to understand the effects of EEFs for their effect on nitrous oxide emissions and agronomic performance was the motivation underpinning this multi-location study across North

America. To accomplish this goal the research was supported by Agrium, Koch Agronomic Services, and USDA-ARS with cooperation from universities across the United States and made possible through the administrative efforts of the Foundation for Agronomic Research (Monticello, IL). Research locations participating in this study included Ames, IA; Auburn, AL; Bowling Green, KY; Fort Collins, CO; St. Paul, MN; Pullman, WA; University Park, PA; and Winnipeg, MB, Canada. All of these sites collected observations on various potential EEFs for their effect on nitrous oxide emissions throughout the year and agronomic performance of corn, cotton (*Gossypium hirsutum* L.), and/or wheat (*Triticum aestivum* L.).

These studies compared several products designed to perform as EEFs to their standard forms; the products included polymer-coated, controlled release urea (46% N) (Environmentally Smart Nitrogen or ESN, Agrium, Loveland, CO), stabilized urea (46% N) containing urease and nitrification inhibitors (SuperU, Koch Agronomic Services, Wichita, KS), and a urease and nitrification inhibitor for urea–ammonium nitrate (32% N, UAN + AgrotainPlus, Koch Agronomic Services, Wichita, KS). An additional study evaluated nitrapyrin (Dow Chemical Company, Indianapolis, IN) for its effect on corn production in the Corn Belt (Burzaco et al., 2014).

The studies commenced in 2008 and continued through 2011 with the goal of quantifying the effect of these different materials on nitrous oxide emissions and agronomic response. Similar techniques were employed to quantify nitrous oxide emissions and provide a statement on the seasonal responses of different EEF materials for their greenhouse gas reduction potential on a site-specific basis. The experimental treatments for these studies were designed to ensure the ability to statistically evaluate results and document quality assurance/quality control for each measurable attribute. The experiments were conducted with a common goal and followed the guidelines provided by Parkin and Venterea (2010), but did not necessarily use exactly the same methodologies for nitrous oxide emissions. Agronomic observations were measured with the techniques appropriate for each crop, and yield was the common parameter among sites to compare these different N materials.

Several articles demonstrate that EEF materials can affect the nitrous oxide emission rate from soils, especially during the period immediately after fertilizer application and more consistently under irrigated production systems. Research in Colorado by Halvorson et al. (2014) showed ESN reduced

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Abbreviations: AAPFCO, Association of American Plant Food Control Officials; CU, conventional urea; CT, conventional till; EEFs, enhanced efficiency fertilizers; ESN, Environmentally Smart Nitrogen; IU, urea containing microbial inhibitors; NT, no-till; PCU, polymer-coated urea; ST, strip-till.

N₂O emissions by 42% compared with urea and 14% compared with UAN in no-till (NT) and strip-till (ST) with no effect in a conventional till (CT). Using SuperU as a stabilized urea source reduced N₂O emissions by 46% compared with urea and 21% when compared with UAN. Comparison of a stabilized UAN source, UAN+AgrotainPlus, reduced N₂O emissions by 61% compared with urea and 41% when compared with UAN. A slow-release UAN source, UAN+Nfusion, reduced N₂O emissions by 57% compared with urea and 28% when compared with UAN. UAN reduced N₂O emissions by 35% compared with urea. A linear increase in N₂O emissions with increasing N rate was observed for untreated urea and UAN. This was confirmed by the results of Asgedom et al. (2014) in which they found N₂O emissions were related to the NO₃⁻ intensity and yield, and they suggested that emissions scaled to yield would be a valuable parameter to compare among studies.

In Iowa, Parkin and Hatfield (2014) observed that EEF materials increased the N₂O emissions during the growing season and attributed this effect to the episodic nature of rainfall events during the growing season, which may limit the effectiveness of these materials in humid climates with increasing rainfall. The seasonal trends of emission rates depend on the soil temperature and soil water dynamics of the growing season, suggesting that application of EEF materials as a method to reduce nitrous oxide emissions will be environmentally dependent. The seasonal results, however, do demonstrate that EEF materials are effective in increasing N to the plant later in the growing season as evidenced by the larger fluxes of nitrous oxide late in the growing season and the agronomic response.

The study in Minnesota (Maharjan et al., 2014) compared polymer-coated urea (PCU) and urea containing microbial inhibitors (IU) to conventional urea (CU) for corn production under both irrigated and dryland conditions in a coarse-textured soil. In this study, the CU was applied in three split-applications during the growing season, which is a recommended best management practice for this production system. The IU product performed as well as split-CU with regard to both N₂O emissions and nitrate leaching. However, neither product achieved the same grain yields or N use efficiency as split-CU application. This study also highlights the importance of expressing environmental impacts on a yield-basis, since after accounting for significantly increased yields with irrigation, dryland production actually had greater N₂O emissions and the same level of nitrate leaching as irrigated production.

The results overall showed an inconsistent effect on crop production, which has been noted in previous studies comparing EEF to non-EEF materials. In cotton production in the southeast, there was no effect of EEF materials on yield or fiber quality (Watts et al., 2014). The majority of the studies evaluated the effect of EEF materials on corn yield and showed inconsistent effects on grain yield (Dell et al., 2014; Halvorson and Bartolo, 2014). The use of EEF materials caused an increased greenness in corn canopies in Iowa and increased grain yield because of the delayed senescence of the plant canopy (Hatfield and Parkin, 2014). The use of a chlorophyll index or the plant senescence index revealed that the increase in grain yield could be attributed to an increased duration of green leaf area of the corn crop during the grain-filling stage. In all crops the use of EEF materials increased the N use efficiency of the crop,

which demonstrates that EEF materials will have both positive environmental and agronomic responses.

Enhanced efficiency fertilizers exhibit mixed results for their combined impact on N₂O emissions and crop production. The primary factor limiting a consistent response among locations is the variation in the seasonal weather during the growing season. In general, the effect of EEF materials on N₂O emissions is positive during the period immediately following application compared with non-EEF materials; however, the rainfall pattern during the remainder of the growing season determines the overall efficacy of these materials. Overall, the materials evaluated in this study across multiple locations revealed that these fertilizer materials function as enhanced efficiency fertilizers.

The experiment approach generally taken in these studies was to apply the same rate of fertilizer N using both the EEF and reference fertilizer products. Future studies could evaluate whether applying lower N rates with EEFs could be used to achieve the same grain yields and possibly lower rates of N loss compared with reference products using standard N rates. Additional economic analysis is needed to account for variations in costs of different EEF and reference products together with resulting yields and additional costs associated with multiple split applications of reference products. More studies are needed similar to Maharjan et al. (2014), which simultaneously evaluated effects of fertilizer formulation on both air and water impacts.

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