UNDERSTANDING ENHANCED EFFICIENCY NITROGEN FERTILIZERS

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Introduction

Crop producers traditionally work to optimize nutrient use efficiency by selecting fertilizer source, rate, timing, and placement. The greatest efficiency is obtained when the right source is used at the right rate, right time, and right placement. Enhanced efficiency fertilizers use additives or coatings to improve N-use efficiency or increase timing and placement options by controlling the speed of release or modifying soil-fertilizer reactions. Products include nitrification and urease inhibitors, uncoated slowly available fertilizers and coated N fertilizers. Uncoated, slowly available compounds are materials such as synthetic organic compounds like urea formaldehyde and methylene urea, or isobutylidene diurea (IBDU). These are used mostly in the turfgrass industry rather than in agriculture, although some new products are appearing in agriculture. Information on these products can be found at: www.fertilizer.org/ifa/news/2005_17.asp, or in a recent review by Trenkel, which provides an extensive review of enhanced-efficiency fertilizer technologies.

The Trenkel publication can be found at: http://www.fertilizer.org/ifa/HomePage/LIBRARY/Publication-database.html/Slow-and-Controlled-Release-and-Stabilized-Fertilizers-An-Option-for-Enhancing-Nutrient-Use-Efficiency-in-Agriculture.html. Under the right conditions, enhanced efficiency fertilizers can reduce fertilizer losses, slow the conversion to less stable forms, or reduce the risk of seedling damage. For any enhanced efficiency fertilizer to prove effective in a crop production system, several conditions must be met. Firstly, the product must work over the range of soil and environmental conditions present. Secondly, losses must be sufficiently large to reduce crop yield or quality. Thirdly, the product must not damage the crop, consumers of the crop or environmental health. Fourthly, benefits must be sufficient to justify the cost of the product.

Enhanced Efficiency Nitrogen Fertilizers

Enhanced efficiency N fertilizers act by reducing N exposure to the loss pathways in the plant-soil system. The greater the N losses, the lower the nutrient use efficiency. Most chemical N fertilizers supply N as ammonium (NH_4^+), nitrate (NO_3^-), or as urea, which converts rapidly to NH_4^+. Nitrogen fertilizers are subject to three major loss pathways – volatilization, leaching, and denitrification. Ammonium or ammonium-producing fertilizers applied on or near the soil surface may be lost through ammonia volatilization. Nitrate-N is susceptible to leaching and denitrification losses. Ammonium or ammonium-producing sources rapidly convert to nitrate. The magnitude and pathways of N loss depend on soil type and environmental conditions. Evaluation of these conditions is needed to determine the risk of potential loss by each pathway and select the appropriate N source for the conditions.

Urease Inhibitors

Urea fertilizer is widely used for many reasons, but urea efficiency can be reduced by ammonia volatilization if urea is applied on or remains close to the soil surface. Urease inhibitors delay urea hydrolysis, providing time for rainfall or mechanical incorporation to move urea into the soil where NH_3 will combine with water, convert to NH_4^+ ion, be adsorbed to the cation exchange complex, and be protected from volatilization. Several compounds have been evaluated as urease inhibitors, but N–(*n*-butyl) thiophosphoric triamide (NBPT, trade name Agrotain), is the most widely available.

A review of studies across the USA reported that NBPT had good potential to improve urea effectiveness (Hendrickson 1992). Volatilization and the benefit from urease inhibitors are reduced if rainfall occurs soon after fertilizer application, carrying the urea into the soil. Agrotain has been relatively consistent in reducing NH_3 loss from surface applications of urea and UAN, but yield increases do not always result. Maximum benefits of urease inhibitors occur when yield potential is high, soil N levels are low, and soil and environmental conditions promote volatilization. The primary use is where urea or UAN are surface applied without incorporation.

Nutrisphere-N is an N enhancement product designed to keep N in a plant-available form. Specialty Fertilizer Products, the manufacturer of Nutrisphere-N, claims the product functions as both a urease and nitrification inhibitor. The active ingredient in Nutrisphere-N is a maleic acid-itaconic acid copolymer with high negative charge density. The manufacturer suggests the product works by sequestering multivalent metal ions that function as co-factors to the enzymes responsible for N formations in the soil, such as nickel, copper and iron. Availability of the metals to the enzymes would be reduced, and N transformations would be slowed. There has been little conclusive research conducted on Nutrisphere-N, so its effectiveness is still being debated.

Nitrification Inhibitors

Nitrification inhibitors slow the conversion of ammonia (NH_3) to NO_3^- by interfering with the nitrifying bacteria (Frye 2005). Nitrate is highly mobile in soil, and excess water can leach NO_3^- below the rooting zone and into ground and surface water, where it can create negative environmental and health effects. Nitrate can also be converted to the greenhouse gases nitrous oxide (N_2O) and nitric oxide (NO) through the anaerobic process of denitrification. Slowing nitrification maintains N in the ammonium form longer, reducing the concentration of NO_3^- in the soil solution, and decreasing the risk of leaching and denitrification (McTaggart et al. 1997).

Nitrapyrin (2-chloro-6-trichloromethyl-pyridine) (N-Serve) and dicyandiamide (DCD) are two nitrification inhibitors that have been extensively evaluated and marketed. Thiourea (Malhi et al. 1988a; Malhi et al. 1988b), ATC (4-amino-1,2,4-triazole hydrochloride), and ammonium thiosulfate (Goos 1999; Goos et al. 1992), have also been shown to slow nitrification to some extent. The product DMPP (3,4-dimethylpyrazole phosphate) has been used in Europe and other parts of the world with good results (Pasda et al. 2001; Menéndez et al. 2006).

Nitrification inhibitors have the greatest benefit under conditions conducive to leaching and denitrification losses. The longer the fertilizer remains in the soil before crop uptake, the greater the potential benefit of an inhibitor. These inhibitors are effective at slowing nitrification, but yield improvement is often not observed.

Controlled- and Slow-Release Nitrogen

Controlled- and slow-release fertilizers can generally be classified into three types: low solubility inorganic compounds, low solubility organic N-compounds, and coated water-soluble fertilizers. The first two categories have not been widely used in agriculture because their cost is usually prohibitive for use in commodity crops. Sulfur-coated urea (SCU) and polymer coated urea are the main coated products available on the market. Nitrogen release from SCU depends on factors such as physical breakage and biological oxidation of the coating, diffusion, coating thickness, and environmental conditions. Although SCU has been available for many years, it is not widely used in commodity crops. Polymer-coated fertilizers have shown greater promise because of more predictable release and release characteristics that better match crop N demand. The release rate is determined by polymer chemistry, thickness, coating process, temperature and moisture so the release can be highly controlled and designed to match plant uptake.

Controlled release products release nutrients into the soil by diffusion at a rate controlled primarily by soil temperature. By closely matching N release timing to the crop N uptake pattern, NO_3^- concentration and the time NO_3^- is present in the soil before crop uptake are both minimized. In cotton, controlled release fertilizers have an additional advantage over other enhanced-efficiency technologies because cotton boll set and retention is sensitive to timing and amount of N supply and controlled-release products can regulate N supply to the crop in addition to minimizing N loss.

Controlled release fertilizers are most commonly used in turf-grass or horticultural crops, because they have generally proven too expensive for use in grain and oilseed production (Shaviv 2001). Currently, the only low-cost controlled release formulation commonly used in agriculture that may be cost-effective for cotton production systems is ESN® (Environmentally Smart Nitrogen® from Agrium).

Cotton is often grown warm regions of high rainfall or is irrigated. Pre-plant N applications are desirable for reasons of convenience, but excess pre-plant N can stimulate excessive vegetative growth and delay boll set. Early season N demands of cotton are small so much of the N is often side- or top-dressed before flower initiation to minimize risk of loss and prevent excess vegetative growth. Controlled-release fertilizers can eliminate the need to side-dress while still meeting these N-management objectives.

Some recent studies have been conducted with ESN® which demonstrates the potential benefits of controlled-release fertilizers in cotton N management. Figure 1 shows the results from three site-years of comparisons of pre-plant urea and ESN. Averaged over five rates and three site-years in 2010-2011, ESN produced a yield increase of 60 lbs of seed cotton. Figure 2 shows the results of a University of Missouri study at Portageville, MO. In this example, a blend of ESN and urea applied three weeks after planting produced better yields than ESN alone either at planting or three after weeks, although both of the latter treatments produced greater yields than the area standard split application of urea.

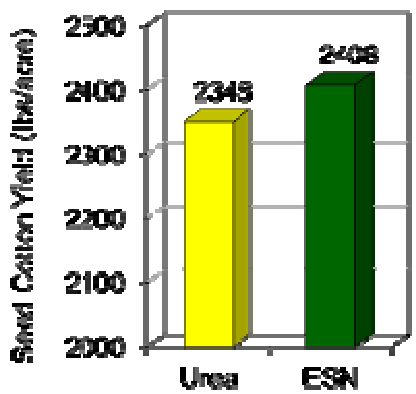

Fig. 1. Seed cotton yield from pre-plant urea and ESN applications. Yields are means of five N rates (30, 60, 90, 120, and 150 lbs N/acre and three site years. Source: Dr. M. Mozaffari, Univ of Arkansas, unpublished data.

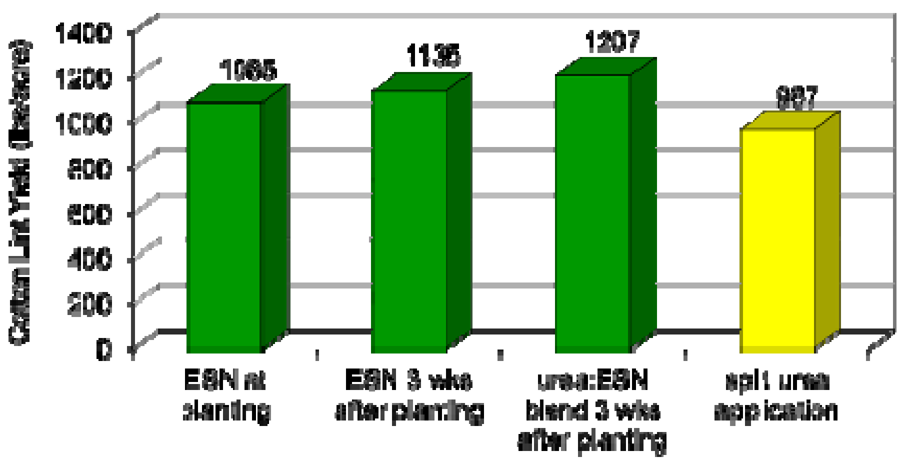

Fig. 2. Cotton response to N source and timing. Nitrogen rate is 120 lbs N/acre. Urea:ESN blend consists of 30 lbs N/acre as urea blended with 90 lbs N/acre as ESN. Split urea application consists of 60 lbs N/ac at planting followed by 60 lbs N/acre three weeks after planting. All N applications were broadcast. Yields are means of three locations in 2010.
Source: A. Jones, Univ of Missouri Delta Research Center, unpublished data.

Benefits of Enhanced Efficiency Fertilizers

As discussed previously, enhanced efficiency N fertilizers can be effective tools to chemically or physically influence the movement and transformations of N in order to reduce losses. This requires that the pathways of loss within the system are characterized so that technology can be applied where the benefits will be the greatest. While there are a number of methods of increasing NUE, use of enhanced efficiency fertilizers have some specific advantages over alternative methods from the viewpoint of the producer.

1) Minimize concentration of inorganic N in the soil solution, reducing the potential for loss and negative environmental impact.
2) Simplify/reduce field operations. Allow for one-pass seeding/fertilizing in no-till systems; eliminate the need for repeated passes and split applications.
3) Substitute for capital investment in specialized machinery. Can be used with current equipment, or may allow the use of simplified, less expensive equipment or practices (e.g. surface applications rather than in-soil band; seed-placed as compared to mid-row or side-band systems).
4) Increase flexibility in application timing; better distribution of time, equipment, and manpower resources.
5) Manage risk of untimely split applications due to poor weather, physical condition of the field or time constraints
6) Selectively supply N to the crop as NH_4^+ or NO_3^-, for crops that have a preference for a specific ratio of N form.

Enhanced efficiency fertilizers can and should be used in combination with other technologies to optimize efficiency. Site-specific applications to target products to specific areas of the field can be used to capture the value of the enhanced material on the areas most likely to benefit while avoiding the extra cost in areas less likely to benefit. Pathways and magnitude of loss are influenced by soil characteristics, weather conditions, crop management practices as well as the fertilizer source. Large variations in loss can occur on a small scale within a field, due to variation in drainage and micro-environment. Advantages of enhanced efficiency fertilizers will also vary substantially, indicating a clear benefit from the integration of enhanced efficacy fertilizers with site specific management techniques.

Cost-benefit analysis of enhanced efficiency fertilizers must consider not just the cost of the material, but also factors such as differences in machinery costs, impact on time, labor, fuel costs and efficiency of operations, differences in impact on seed-bed, soil moisture or other agronomic factors, and management skill required to apply the technologies. Adoption of technologies to increase NUE varies substantially form region to region, with varying limitations and relative costs associated with nutrient management practices. As the cost of the factors conserved increases, the relative benefit of the technology will increase. Increasing energy costs, increased cost of fertilizer N, and scarcity of labor will make enhanced efficiency fertilizers more attractive to producers.
Usually, the environmental benefits to society are not ascribed an economic value. Life cycle analysis is needed to more clearly define costs and benefits throughout the system associated with adoption of enhanced efficiency, including manufacturing, emissions on and off farm, transport, and total potential off-site impacts.

Constraints to Use of Enhanced Efficiency Fertilizers

The major constraint associated with the wide-spread use of enhanced efficacy fertilizers is the cost of the products. Most controlled release fertilizers are used in non-farm uses such as golf courses, home gardening, landscaping and nurseries, where the perceived benefit relative to the cost of the technology is high (Shaviv 2001). There is some utilization in high-value cash crops such as vegetables and fruits, particularly on light soils or where labor costs are high. Use of both controlled release fertilizers and inhibitors in rice production is increasing. However, general adoption for lower value crops is still limited by the technology cost.

Technical constraints include premature loss in effectiveness of both nitrification inhibitors and urease inhibitors. Another concern is excess delay or too rapid release of N from coated products, leading to a lack of synchrony with crop uptake (Shaviv 2001). Improved control of the release rate and clearer identification of the pattern of release required would allow for closer matching of release to crop demand.

In addition, research is still needed to define and value the advantages of each product. Quantifying the N-rate reduction possible with enhanced efficiency fertilizers is needed, so producers can recover a portion of the extra cost by using a lower application rate. Identification of the effects on other crop variables such as reduced lodging, better disease resistance, controlled maturity, effects on crop quality, and trace element content of the crop will be important in more clearly defining the benefits of the products.

Summary

Enhanced efficiency fertilizer may be used in place of or in conjunction with traditional management practices to improve the effectiveness of N fertilizers. For enhanced efficiency fertilizers to be widely used, they must have advantages both over the traditional fertilizer sources and over other beneficial management practices available. These advantages have been well documented in extensive research around the world. Effectiveness of enhanced efficiency fertilizers will be strongly dependent on the environmental conditions that influence the potential losses that the fertilizer is attempting to address. In other words, each product needs to be matched with the loss conditions the product is designed to prevent or production objective the product can meet. High cost of fertilizer inputs, fuel, and labor couple with the need to reduce the impact of crop nutrients on the environment strongly favor the use of enhanced efficiency fertilizer products. New products and new uses for existing products continue to enhance the grower's choices and opportunities to improve nutrient management practices.

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