ENHANCED EFFICIENCY NITROGEN FERTILIZER: COATED UREA

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ABSTRACT

Nitrogen (N) is the most common fertilizer. However, a large percentage is lost to the environment—resulting in pollution and depletion of natural resources—representing economic losses. Enhanced Efficiency Fertilizers (EEF) help mitigate these problems by reducing the time N is in forms most susceptible to loss, increasing uptake efficiency and, often, yield and/or crop quality. One example of N EEF are coated urea fertilizers, such as polymer coated urea (PCU). Research studies show reduced loss to the environment and increases in yields and/or crop quality. The delayed release was longer than with sulfur (SCU) and polymer-sulfur (PCSCU) coated urea. The N release is hastened when surface applied. While EEF often cost more, they require can results in less fertilizer use and/or increases in the amount of crop grown per unit of N applied.

INTRODUCTION

Nitrogen (N) is an essential plant nutrient and N fertilizer is an essential component of global food security (Hopkins, 2020). Of all plant nutrients, N is sold in the largest volume because of its large impacts (Geary et al., 2015; Zhang et al., 2015). Nitrogen is needed in relatively large quantities in plants. There is a large store of N in the soil, mostly occurring as a component of soil organic matter (SOM). However, only about 2-5% of this is mineralized to become plant available annually. Given this, and the high demand for N in plant tissues, N fertilizer nearly always needs to be applied to crops in order to achieve maximum economic yield.

The effective use of N fertilizer has been elucidated in a wide body of research for the "4 R's" of fertilizer stewardship to apply the Right source at the Right rate at the Right timing and Right placement. These efforts have resulted in steady improvements in yields and uptake efficiency (Bruulsema et al., 2012). However, N fertilizer impacts the environment through resource consumption and pollution (Bruulsema et al., 2012; Hopkins, 2020).

Pollution is a major concern with N fertilizer use. A large percentage of fertilizer N added to soil is either emitted to the atmosphere as ammonia (NH_3), nitrous oxide (N_2O) or other gaseous forms, or finds its way into surface or groundwater as nitrate (NO_3) (Kibblewhite, 2007).

There is potential for improving N fertilization, as can be seen in a recent review by Omara et al. (2019) who estimated N uptake efficiency in cereals at about 33% with some farmers achieving levels as high as 41%. Significant advances enable growers to simultaneously achieve maximum economic yield while minimizing environmental risks (Bruulsema et al., 2012).

NITROGEN LOSS MECHANISMS

It is vital to understand the N loss mechanisms in order to achieve maximum economic yield and minimize environmental risk. The main loss mechanisms for N fertilizer include: NH_3

volatilization, denitrification/ nitrification of N_2O, and NO_3 leaching (Snyder et al., 2009; Van Groenigen et al., 2010; Venterea et al., 2016; Canter, 2019).

The urea in fertilizers rapidly hydrolyzes when applied to soil, converting it to NH_3 gas. Ideally, this gas quickly converts to ammonium (NH_4) in the soil solution. However, some volatilizes to the atmosphere. Although relatively safe from volatilization, NH_4 can revert back to NH_3, especially in alkaline soils. Otherwise, the NH_4 converts to NO_3 rather rapidly. These NO_3 molecules are subject to denitrification/ nitrification losses, especially under saturated conditions. They are also subject to leaching because they are negatively charged and soluble. Thus, the forms of N most susceptible to loss to the environment are NH_3 gas and NO_3 in soil solution.

The most commonly applied N fertilizer is urea, which is highly soluble and converts rapidly to NH_4 and then NO_3. Traditional NH_4 based fertilizers, such as ammonium sulfate, are also soluble and quickly convert to NO_3. The NO_3 containing fertilizers, such as potassium nitrate, are immediately subject to losses via pathways for which it is susceptible. Timing and placement are critical for improved efficiency for these traditional fertilizers. It is important to understand plant uptake patterns for N and ensure that N in plant-available forms (NO_3 and NH_4) is present when plants need it. In addition to applying at the right rate, timing, and placement; using Enhanced Efficiency Fertilizers (EEF) can positively impact yields and the environment.

ENHANCED EFFICIENCY FERTILIZERS

The N EEFs increase plant N uptake percentage, ideally improving crop yields and/or quality, while minimizing losses to the environment (Hopkins et al., 2008; Hopkins, 2020). These EEFs are divided into slow-/control-released and inhibitors/stabilizers (Fig. 1; Hopkins, 2020).

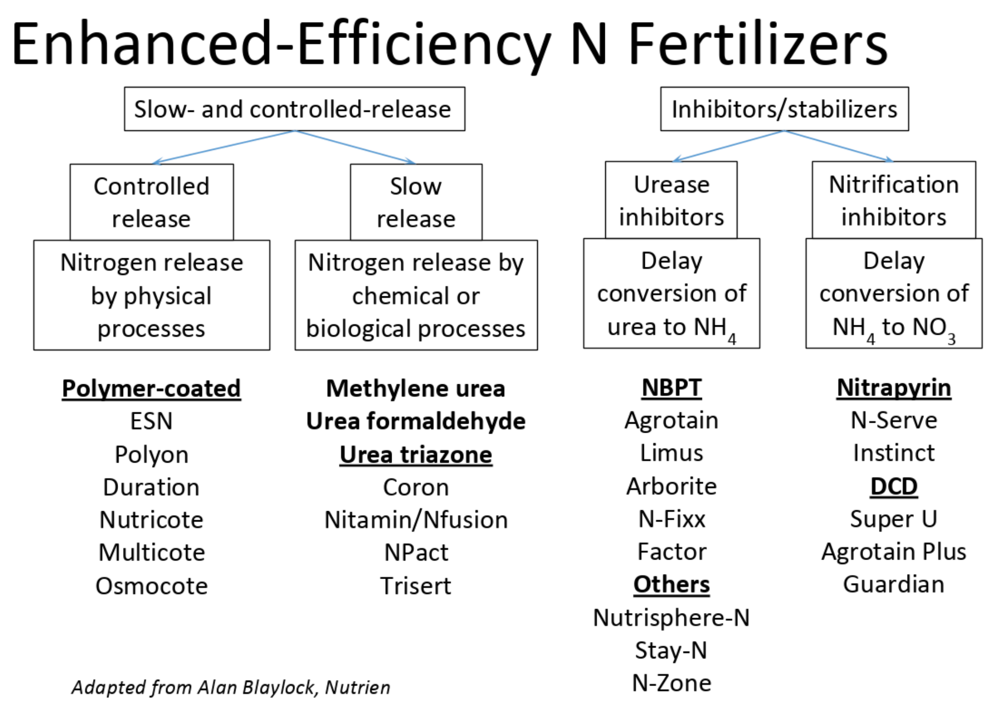

Fig. 1. Enhanced-Efficiency N Fertilizer types (inclusion does not endorse effectiveness)

Slow-release fertilizers involve chemical or biological N release process. For example, urea-formaldehyde, methylene urea and triazone based-fertilizers consist of long chain molecules containing N, which is slowly released with microbial breakdown. This minimizes volatilization, denitrification, and leaching by avoiding a flush of N. These products depend on microbial activity and are affected by factors like extreme soil temperatures. Generally, they do not supply N adequately during cool conditions. And, their breakdown can be slowed after fumigation. These sources tend to not last the entire season, especially in warmer climates with long growing seasons. Some of these EFF are available in liquid form and can be applied via fertigation, foliar applications, and in concentrated fluid fertilizer bands.

Another strategy is applying a sulfur coating on dry fertilizer. Sulfur coatings are used alone or in conjunction with polymer coatings. The N is released as the sulfur coating is oxidized into sulfuric acid by microbial action. They have the additional advantage of releasing sulfur into the soil. Again, release is affected by temperature and fumigation. Sulfur coated products also tend to not last the entire season, especially in warmer climates with long growing seasons.

Control release fertilizers rely on physical processes for N release. As an example, polymer-coated fertilizers (most commonly urea) absorb water through a porous coating. This swells the particle, and eventually the nutrients diffuse through the membrane as molecular diffusion speeds increase with warming temperatures and the sizes of the pores become large enough for passage due to the swelling and/or microbial degradation. The release rate is primarily impacted by temperature and the thickness of coatings. Granules can be designed to release nutrients at differing times, ranging e.g. from 45 to 360 days. As such, polymer coated products can last the entire growing season if conditions are correct and they are handled carefully to avoid cracking the coatings.

Inhibitors increase N efficiency as they slow conversion from one form of N to another. Urease inhibitors [e.g., N-butyl-thiophosphoric triamide (NBPT)] inhibit the urease enzyme, which catalyzes the hydrolysis reaction converting urea to ammonium bicarbonate and then to NH_3 gas and finally to NH_4. The NH_3 gas phase renders the N very vulnerable to volatilization loss if not captured by the soil. This gas loss is greatly minimized if the conversion from urea is slowed by use of an inhibitor, allowing the soil to capture the N more effectively. Although it does nothing to prevent other losses once the transformation takes place.

Urease inhibitors can be effective in all soil types, but especially with high pH soils and/or low cation-exchange capacity (CEC). They are particularly important if urea is not incorporated into the soil using tillage/injection or irrigation techniques, or in conditions which maximize losses to the atmosphere such as open crop canopies, application of liquid urea on thick crop residues or in hot, humid and windy conditions or losses below the rooting zone due to excessive water movement through soil. These inhibitors can be used with dry or fluid fertilizers

Nitrification inhibitors [e.g., Dicyandiamide (DCD), 2-chloro-6 (trichloromethyl) pyridine (nitrapyrin), N-butyl-thiophosphoric triamide (NBPT), 3,4-dimethylpyrazole phosphate (DMPP), and pronitridine] were developed to slow the oxidation of NH_4 to NO_3 by inhibiting the activity of *Nitrosomonas* spp. bacteria responsible for this conversion process. Conversion results in a molecule with a negatively charged ion that is repelled by soil and is thus subject to leaching losses, particularly with excessive precipitation/irrigation. Nitrate is also subject to gaseous loss via denitrification/nitrification. A nitrification inhibitor preserves the N in the NH_4 form which minimizes the period it can be lost in its NO_3 form. Their effectiveness has been evaluated by Burzaco et al. (2014). Inhibitors are especially effective in low CEC soils, soils prone to rapid percolation of water, shallow-rooted crops, and in water-logged or heavily leached soils. These inhibitors can be applied to both dry and liquid fertilizers.

Normally, urea hydrolysis to NH_4 is complete within 2-4 days; a urease inhibitor slows it to about 7-14 days. Conversion of NH_4 to NO_3 normally is complete within 7-21 days; a nitrification inhibitor slows that to about 25-55 days. Using both inhibitors extends the range to about 50-65 days. Slow release products vary widely in their release timing, but generally are released within about 14-50 days. Because they can be more precisely engineered, polymer-coated products vary widely, depending on quality and thickness of the coating, with release timings ranging from 45 to 360 days.

COATED UREA

There is considerable data available on N EEF. Here we focus on the coated urea fertilizers, such as sulfur-coated urea (SCU), polymer-coated sulfur-coated urea (PCSCU), and, especially, polymer-coated urea (PCU). We have conducted many trials on maize, wheat, sugarbeet, dry bean, and other crops with positive results in many circumstances.

Potato is an example of a species that is particularly suited for PCU (Hopkins et al., 2020). Potato is very sensitive to either deficient or excess N, as well as being very sensitive to spikes in availability during the growing season. Most growers apply N in multiple pre-plant and in-season applications, with often weekly applications injected into the irrigation water. Our trials show that a single application of PCU can suffice—often with improvements in yield and/or tuber quality/size because the PCU releases N at a rate that somewhat matches its uptake needs (Hopkins et al., 2008).

In a recent study, all PCU combinations, even at no or reduced in-season applied N, produced yields statistically similar to the grower standard practice with multiple applications, including in-season rates driven by petiole NO_3-N analysis (Carlock et al., 2019). Among the treatments with statistically superior yields, a half rate of N applied as PCU with no in-season N resulted in superior tuber size with no loss of yield or tuber quality. Thus, the PCU treatments, especially with no or lower in-season N, were overall superior to the grower standard practice. Previous trials showed increases in yields and/or tuber quality (Hopkins et al., 2008). These data support other findings that N in the coated urea is protected from loss and, thus, is more efficient. The PCU used in this study, Environmentally Smart Nitrogen (ESN), was an effective enhanced efficiency fertilizer source in these trials. Similar yields with better tuber size was achieved with significantly less N applied. However, previous experience/research shows that it is vital that the PCU is handled carefully to avoid cracking of the coatings. Also, adjustments were required in the interpretation of the petiole analysis (Carlock et al., 2019).

Additionally, based on four years of trials on irrigated barley, a 50%-50% blend of PCU (ESN) and urea significantly increased yield at a moderate rate of N (Fig. 2). The yield increase for this treatment and rate was greater than any other treatment, including those with urea applied alone (Fahning et al., 2019). However, the high rate with this blend resulted in yields decreasing significantly, stressing the importance of realizing that less N is lost and, thus, care needs to be taken to adjust rates downward if excess is a problem. In regards to protein, which was a concern that the PCU would drive it too high, source had no impact on concentration. In summation, these results show that ESN is an effective source of N for barley, although it is seemingly important to avoid blends with too high of a rate or too high of a percentage of PCU.

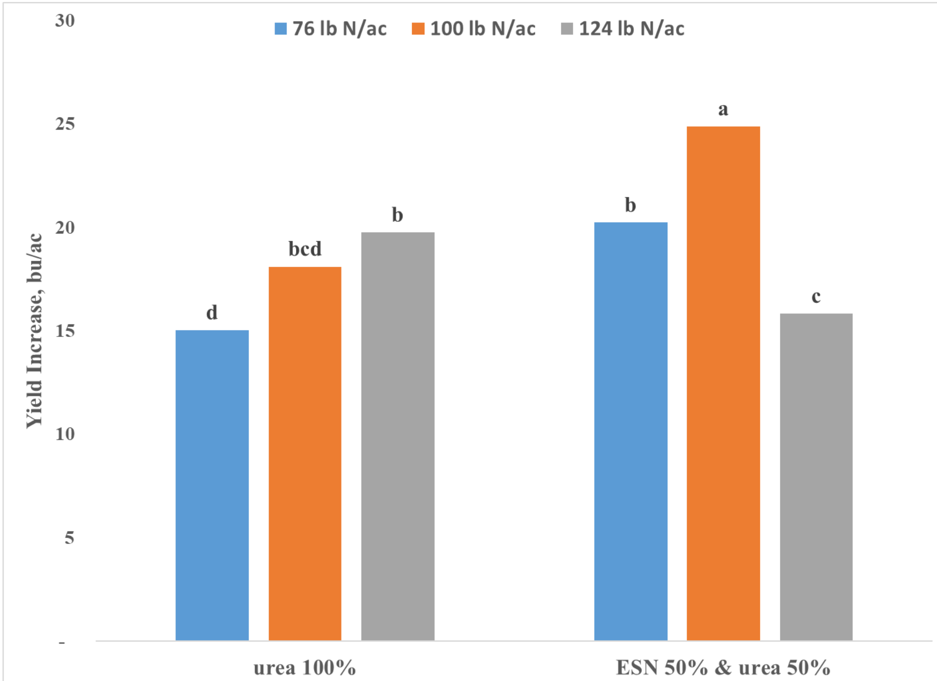

Figure. 2. Barley grain yield increases relative to an unfertilized control averaged over four years (2015-18) for a polymer coated (ESN) urea fertilizer trial in Idaho. Fertilizer was applied at three rates, with each rate applied as 100% urea or 50% ESN & 50% urea. Data bars sharing the same letter(s) are not statistically different from one another. $P = 0.10$

In other studies PCU, applied as Duration, and other coated ureas in Kentucky bluegrass grown as a lawn grass. The PCU was found to reduce NH_3 and N_2O losses to the atmosphere, as well as NO_3 leaching (LeMonte et al., 2016, 2018). The reduced losses enabled lower N rates to be used. We found that two applications (early spring and early fall) were equivalent to spoon feeding monthly when using a 2/3 PCU with 1/3 ammonium sulfate blends. However, we also discovered that the release rates from the PCU were far faster than expected when surface applied because temperature drives release rates and surface soil temperatures are much higher than internal soil temperatures. All of the PCU products applied released >80% of their N within ~40 days—even if they were rated at 180-day release (Ransom, 2014). We also evaluated SCU and PCSCU. The ones we tested did show slow release properties, but they released much faster than PCU with >80% N release in <10 days (Ransom, 2014). The slow release still resulted in reduced loss, but the longevity of availability through the season would be greatly reduced.

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