ENHANCED FERTILIZER EFFICIENCY PRODUCTS

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ABSTRACT

Common nitrogen (N) fertilizer products are subject to loss from the production system through leaching, volatilization of ammonia (NH_3) and denitrification. There are a variety of products on the market that are asserted to improve N fertilizer efficiency by impacting one or more of these processes. These include nitrification inhibitors, urease inhibitors and slow and controlled release coatings. The suggested mode of action these materials is reviewed. Enhanced fertilizer products neither guarantee higher yields nor reduced costs. Some products may be considered "insurance" to reduce the loss of N and the resulting reduction in yield. Enhanced products can usually be replaced by more intensive management, but may be useful to take advantage of under-used human or capital resources. N (n-butyl) thiophosphoric tramide appears to be a proven material that can reduce NH_3 volatilization *when* conditions for volatilization exist. Polymer Coated Ureas appear to effectively release nutrients over an extended period of time and need to be applied to take advantage of this characteristic. Nitrification inhibitors need to be tested in one's own environment against standard practices. Careful evaluation is needed to weigh the extra product cost against the likelihood of reduced management cost and likely agronomic response.

INTRODUCTION

Nitrogen (N) is the most limiting nutrient in virtually every ecosystem. The major reservoir for N is the atmosphere which is composed of about 80% N. Unfortunately, this is in the form of N gas which is relatively inert and cannot enter directly into plant growth reactions. Nitrogen can be artificially combined with oxygen, hydrogen and carbon to form biologically active materials.

After N enters the soil, it is held as simple organic N, nitrate (NO_3^-), nitrite, ammonia (NH_3), ammonic (NH_4^+) ions or complex organic N. NO_3^- and NH_4^+ forms are those taken up by plants. Other forms in the soil must be converted in dynamic equilibria to these forms for plants to access them. While some of these conversions occur spontaneously, many require the intervention of bacteria, which glean a little energy from the reaction. Some of these forms are water soluble and held in the soil as negatively charged ions, which makes them subject to leaching. Others are rapidly converted to NH_3 gas which can be lost from the soil system.

Figure 1 shows we generally add N to our agricultural systems in the forms of manure or compost, ammonic or forms that quickly change to ammonic (NH_4^+), including NH_3, urea and NO_3^- forms. Nitrate forms are immediately available to plants, once in the soil solution, but are also immediately leachable. Ammonic forms like NH_3 and urea, which must change to NH_4^+ in the process of nitrification, can change to volatile NH_3 gas. Some components of the manure and urine may be quickly changed to NH_3 as well.

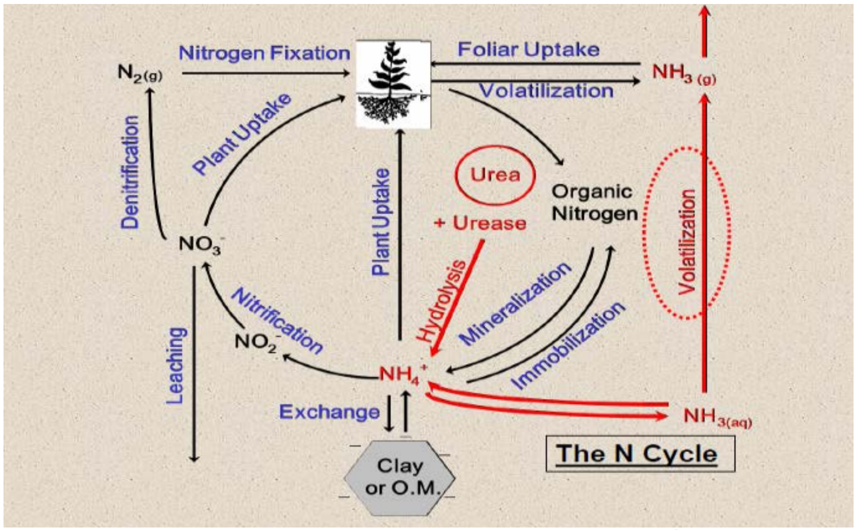

Figure 1. The N cycle, showing plant uptake as NO_3^- and NH_4^+, as well as loss pathways through leaching, volatilization of NH_3 gas and denitrification and loss as N gas.

Influencing these processes by additives could be agronomically useful as well as economically desirable. Various enhancement products are asserted to reduce volatilization of N from the soil in the form of NH_3, reduce leaching by slowing or restricting the conversion of NH_4^+ to leachable NO_3^- and also reduce denitrification or loss of NH_4^+ to the atmosphere as N gas. If we lose less of the N already in the soil and less of the N that we apply to the soil that could mean more N for crop production. This could theoretically increase fertilizer efficiency and reduce the amount and consequently the cost of fertilizer that would have to be applied.

We know that the closer to the time of use that N is applied, the more efficiently it is utilized. In Figure 2, from spring wheat, we see that the majority of N uptake occurs between 15 and 45 days after planting, during jointing. However, pre-plant fertilizer may be applied much earlier and prior to the uptake period to make use of available equipment and manpower, subjecting it to possible volatilization, leaching or denitrification. Conversely, topdressing applications must be completed, incorporated and available to the plant in a very small window of time to insure optimum performance. Enhancements that could “protect” fertilizer materials from denitrification and volatilization, delay or restrict nutrient availability for a period of time might help do this.

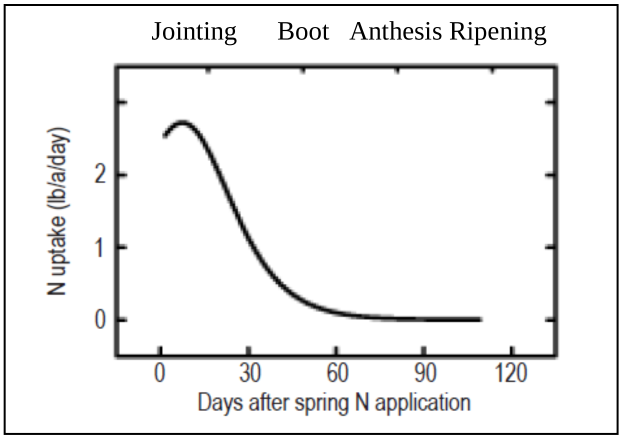

Figure 2. In spring wheat, relatively little N is required for plant growth before tillering, and the majority of N uptake occurs during jointing.

If we focus our attention on the part of the N cycle that is most impacted by fertilizations, we see that soil applied urea in the presences of water reacts to form ammonium carbonate, which is unstable. It rapidly deteriorates to NH_3 gas, carbon dioxide and water. Ammonia (NH_3), however, in the presences of water will react to form the positively charged NH_4^+ ion which can be held by the negatively charged soil particles. The conversion from urea to NH_4^+ can be expedited by the urease enzyme, which occurs ubiquitously in Nature, and where adequate moisture is not available to incorporate the NH_4^+ in the soil, the NH_3 gas will be lost from the soil surface. The equilibria of the reaction are also controlled by the soil pH as well as the concentration of the chemical species and the amount of water available.

Ammonium nitrate (A/N) used to be a favorite fertilizer material because it went readily into solution and became available for plant growth, and because of its position in the N cycle was only slightly susceptible to being lost though conversion to NH_3. After the bombing of the Oklahoma City federal building with a bomb constructed from A/N and diesel fuel, Homeland Security promulgated rules to track the manufacture, storage, sale and use of A/N down to 25 lbs. The administrative burden encouraged many fertilizer suppliers to stop offering A/N, although it can still be legally obtained for use as a fertilizer.

Enhanced N fertilizer materials work in one of four general ways: 1) Nitrification inhibitors are supposed to reduce the rate of conversion of NH_4^+ to nitrate NO_3^-, which is moderated by two families of bacteria, 2) Urease inhibitors are supposed to mitigate the activity of the urease enzyme, thus reducing the rate of conversion of urea to the unstable ammonium carbonate which readily releases NH_3 gas, until the urea can be moved into the soil by rainfall or irrigation, 3) Slow release materials depend on coating urea with another material which must be dissolved or removed to expose the urea to chemical processes, 4) Synthetically constructed polymers which literally control the access of water to the urea as well as the rate which urea can leave the polymer capsule.

NITRIFICATION INHIBITORS

Since nitrate (NO_3^-) is negatively charged and can be carried into the plant with the water for transpiration, a majority of N uptake is from nitrate. While plants do take up NH_4^+, this requires an active transport mechanism. The nitrification inhibitors work by inhibiting or killing the bacteria that convert NH_4^+ to nitrite and from nitrite to NO_3^-, so that the availability of NO_3^- in the soil solution will be delayed.

Nitrapyrid is a material that has been around since the 1960's. It kills the nitrosomonas bacteria preventing conversion of ammonic N to NO_3^-. It is marketed as N-Serve® and more recently Instinct®. **Dicyandiamide** (Guardian®) and nitrapryrid are reported to slow or reduce the conversion of NH_4^+ to NO_3^- for 4-6 weeks. **Ammonium thiosulfate** may reduce conversion for 2-3 weeks. **Dimethylprazole phosphate** (ENTEC®) and **Maleic-itoconic copolymer** (Nutrasphere®) are also reported to inhibit nitrification.

In the Midwest, NH_3 is the common form of applying N for corn production. It is applied preplant and in large quantities. Long-term data collected by University of Nebraska, where nitrapyrin has been used for a long time, suggests that environmental conditions between application and plant uptake determine the usefulness of the product. Cool wet weather delays plant growth and N uptake, making the preplant N more susceptible to leaching and denitrification. Warmer weather with adequate but not excessive moisture could accelerate plant growth, and possible result in inadequate N at tillering in some other years. Long-term data from the mid-west supports the effectiveness of nitrapyrin under challenging conditions, but the challenging conditions were not very frequent on the average. Data from Oregon on winter wheat did not statistically support the use of a nitrification inhibitor nor was it any better than split N applications.

UREASE INHIBITORS

Urea has always been one of the lowest cost N fertilizer materials, and with the loss of A/N as commonly available material, the use of urea has expanded. Urease occurs almost everywhere in Nature, inside and outside plants. This enzyme rapidly causes the hydrolysis of urea to ammonium carbonate, which is unstable and deteriorates into NH_4^+, carbon dioxide and water. If the soil pH is high, and the reaction occurs on live or dead plant material, or on the soil surface, the NH_4^+ loses a hydrogen ion and is converted to NH_3 and is lost to the atmosphere. The process is driven by high pH, moisture and temperature, but perhaps less by temperature than previously thought as it can occur in frozen soils.

Urease inhibitors are purported to retard or block the hydrolysis of urea to NH_4^+ or to reduce the conversion from NH_4^+ to NH_3. The materials include **N(n-butyl) thiophosphoric tramide** (NBPT) (Agrotain®), which competes for active sites on the urease enzyme for about 10 days, depending on the weather conditions. **Maleic-itoconic copolymer** (MICP) (Nutrisphere-N® by SFP Specialty Products) is reported to work by tying up soil nickel which is a critical constituent of the urease enzyme. **Ammonium thiosulfate** (15-0-0-20) (ATS) is also reported to inhibit conversion of urea.

In laboratory and field experiments where conditions were considered favorable for NH_3 loss, NBPT appears to fairly consistently reduce loss of N as NH_3. In trials in North Dakota, Kansas, Minnesota, Illinois, Arkansas and Mississippi at 25 locations, positive results were observed for MICP in only 6 of the trials and 4 of these were at the same location. In a barley trial in Idaho, MICP raised yields, but not N uptake. In spring wheat studies in Idaho, MICP did not raise yield or protein.

SLOW AND CONTROLLED RELEASE MATERIALS

Slow release N fertilizer materials depend on reduced solubility of the material to prevent the material from entering the soil solution and becoming active in the N cycle. This group of materials includes **magnesium-ammonium phosphate**, **isobutylidene durea** (IBDU) and **methylene urea** in mixture with urea-formaldehyde. Alternatively, the N is tied up in complex organic components that require time, temperature and often soil flora to release the N. Included in the slow release materials are **compost, manure** and **plant residues**, which depend on organisms to release the organic N. **Urea-formaldehyde** (N-Fusion®) also falls in this group.

The controlled release materials have been around since at least 1967. These included polymer coated urea (PUC) products, where the fertilizer component is impregnated inside an engineered polymer, designed to regulate the access of water to the fertilizer product and the exit of the dissolved nutrient. These products include ESN®, Osmocote®, Trikote®, Polyon® and Duration®. Sulfur coated urea products are also included in this category, for example Nu-Grow®, although the "control" is usually not as good as with the polymers.

As with other products, the value of the PCU materials seems to be related to environmental conditions. Conditions favoring N leaching tend to provide superior results. Under drier conditions these materials were either of no effect or detrimental. Experiments, in some locations, looked at blends of PCU and naked urea, finding variable results as well. Timing of application and moisture appear to be the factors that most influence results.

CONCLUSIONS

Enhanced efficiency fertilizer products (EEFP) do not guarantee higher yields, reduced fertilizer rates or lower costs. In some cases these materials, such as Nitrapyrid in the mid-west, may be applied as insurance to prevent N loss under adverse environmental conditions. Products that reliably delay the release of nutrients must be applied carefully to insure that nutrients are available when needed by the crop. Use of the EEFPs generally can be replaced by more intensive management, but may also make it feasible to take advantage of under-used resources.

N (n-butyl) thiophosphoric tramide appears to be a proven material that can reduce NH_3 volatilization when conditions for volatilization exist. PUCs appear to effectively release nutrients over a period of time, and need to be applied to take advantage of this characteristic. Nitrification inhibitors seem to be more variable in their response and should be tested carefully in one's own environment before being use on a widespread basis.

Perhaps most important is that since the performance of these materials depends on trying to manage the N cycle to our economic and agronomic advantage, there can be no single recommendation. The operator's goals, resources, product efficacy in one's own environment, and the management alternatives that can easily be as agronomically effective as many of these products, should determine their use in individual situations. Approach the use of EEFPs thoughtfully, and test them in your environment on a small scale.