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Slow and steady

The effects of different coatings on nitrogen release in soil

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Nutrient losses from fertilizers contribute significantly to low fertilizer use efficiency. There are 14 major nutrients needed for optimum plant growth, however, nitrogen (N) is the most commonly used in fertilizers and accounts for nearly 50% of fertilizer nutrient losses, contributing to atmospheric greenhouse gas emissions, pollution of underground water, and eutrophication of surface water. Thus, most of the improvements needed and made to fertilizers have been on N-based fertilizers. One of the primary objectives of N management for improved fertilizer use is the development of slow or controlled release fertilizers. These efforts are designed to delay N release to synchronize with the crop's needs, primarily involving coating the fertilizer with a natural or synthetic material that can predict, to different degrees, the timing and rate of nutrient release from the encapsulation.

This article briefly explores examples of the materials and processes used to produce or formulate controlled release fertilizer coatings that are cost effective and that improve N uptake by plants.

Coating type

Inorganic - sulphur and polymers
Sulphur as a fertilizer coating forms an impermeable layer over urea that prevents water from penetrating to the urea granule and slowly decomposes as a result of microbial, chemical, and physical processes. Studies have shown that sulphur-coating urea could reduce ammonia volatilization from soil by as much as 43-78% and decrease soil ammonium content and nitrous oxide flux rate by 8% and 15%, respectively. Also, sulphur-induced N recovery of up to 70% from soil by plants has been demonstrated. Unfortunately, sulphur-only coatings are physically characterized by a brittle and relatively easily damaged surface, permitting water entry that dissolves the urea granules, resulting in nutrient leaching. Furthermore, sulphur is relatively acidic such that its use for coating can result in soil acidification and, thus, in nitrogen deficiency. However, these weakness in sulphur coatings can be corrected by applying a secondary coating or sealant onto the primary sulphur coated surface and liming the soil, respectively.

Compared with sulphur, synthetic polymers are reportedly more effective because they are less prone to coating disruptions caused by microbes, however, they may be subject to the deposition of residues, with hazard implications for the environment. Coating polymers are relatively hydrophobic, permitting controlled diffusion of moisture through their variably permeable membranes, thereby controlling the release of N at rates that vary with the degree of polymer permeability, composition, thickness, soil temperature, and soil moisture level.

Organic - biopolymers
On the organic spectrum of fertilizer coatings, the use of biopolymers allows for more environmentally friendly alternatives to chemical/organic polymers. Examples of biodegradable material that have been reported in literature include chitosan, neem and lignin. In a test of chitosan-starch beads for N release in water, between 70-92% of the total N was released after 14 days, dependent on chitosan-starch mass ratios.

Mode of action

Coating to inhibit urease activity
For many years, the restriction of urease activity has been viewed as the best option for reducing N losses and increasing N use efficiency, specifically the use of inhibitors to modify fertilizer release patterns based on altering the biological activities of urea-metabolizing enzymes of soil bacteria. Urease inhibitors are formulated into solid (e.g. by coating) or liquid fertilizer products or applied separately to the soil in order to reduce urea hydrolysis by ureases.

Coating for nitrification inhibition
Nitrification inhibition is based on the retardation of nitrifying bacteria that oxidizes ammonium to nitrate, which otherwise leads to both an increase in atmospheric nitrous oxide emission and nitrate leaching in soil. Because nitrification occurs for a longer period of time (20-28 days) compared to urea hydrolysis (5-7 days), nitrification inhibitors can provide a greater opportunity for synchronizing N release with crop demand, while reducing leaching and N2O emission. Examples of commonly used nitrification inhibitors include Dicyandiamide (DCD), 3,4,-dimethylpyrazole phosphate (DMPP), thiophosphoryl triamide (TPTA) and neem. It has been suggested that a combination of urease inhibitor and a nitrification inhibitor could enhance the benefits of improved fertilizers. Accordingly, patents have described slow release fertilizers simultaneously involving urease and nitrification inhibition. One particular invention involved formulating a range of macro and micro nutrients, including several N sources, among them urea, with lecithin and amidinothiourea. Release of nitrogen from the product in a cotton field was prolonged to 121 days, compared to 30 days from conventional urea. Furthermore, the uptake of N into the plants was improved by 37% over conventional fertilizer. This and other examples of nitrification inhibition provide further insight into the effects and benefits of nitrification inhibition and give building blocks for further research on the topic.

Four kinds of coating: zinc oxide and rice-bran wax (*top left*), gypsum (*top right*), polymer (*bottom left*), sulphur (*bottom right*)

(*left to right*) Zinc oxide and rice-bran wax, gypsum, sulphur, and a polymer are all types of coatings that control the release of nitrogen or other elements into the soil

Nitrogen management

Mineral nutrients
Minerals composed of nutrient elements can also play a role in reducing N loss from fertilizers when used in fertilizer coating or embedding. Such minerals include struvite and gypsum and dolomitic limestone. Gypsum is a calcium-sulphate mineral, and dolomitic limestone is composed of calcium and magnesium carbonate. In one experiment with gypsum-dolomite embedded in a N fertilizer product, Dependent on the gypsum-dolomite rate, between 10- 26% less N was released from urea, which was further reduced to 34% with addition of polyols as a sealant. Another example describes different variants of an extended release fertilizer composed of calcium (as sulphates) and nitrogen sources, with or without starch or other blocking or binding additives, absorbent materials, phosphorus, potassium and secondary and micronutrients. The solubility of this potentially balanced fertilizer product is regulated by the addition of starch, protein gel, gelling glues or other synthetic gelling compounds. The absorbent material can be derived from perlite, grind paper waste, plant bark, peat moss or other similar absorbent materials. One variant of this product containing ammonium sulphate (70%) as N source, corn starch (1%), potassium sulphate (20%), and gypsum (calcium sulphate dihydrate 20%) showed good results in terms of improving N uptake in crops, compared to another variant which N source was urea.

Nanotech
Nanotechnologies have recently been used to improve N-fertilizer use efficiency. Nanotechnology uses the polymer coating material or formulation active ingredient (nutrient element) at the nano-scale, where material size is reduced by between 1000 (1 nanometer (nm)) and 10 (100 nm) times of the size of conventional bulk (≥1000 nm) polymers or nutrient materials. Nanofilms, nanopolymers, or nanoscale additives of other nutrients have been used to modify N fertilizers, and such modifications have been shown to be able to control or slow the release of N, allowing for an increase in N uptake and plant productivity. In one example, a slow release fertilizer based on a hydroxyapatite (HAP)-urea-wood powder composite was produced. HAP is a naturally occurring phosphorus and calcium-rich mineral which can also be synthesized by wet chemistry. A subsequent N-release evaluation conducted in acidic and neutral soils showed that the nano urea-HAP composite releases the urea slowly, reducing N release rate by about 21% at pH 4.2, 27% at pH 5.2, and 44% at pH 7 after 60 days, compared with conventional urea.

Improved technologies
The reduction of N losses by increasing N uptake and use efficiency by crops is at the core of N-fertilizer improvement strategies. Reduction of N loss has the direct effects of increasing crop yields and lowering N-induced environmental abnormalities, including greenhouse gas emission and eutrophication of water bodies. As such, technologies that offer such improvements at an affordable cost to farmers, and are also profitable for the fertilizer industry, should continue to be identified and promoted in order to be able to feed the growing human population. ■