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Potential Benefits of Biological Products in Nutrient Management

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Biological products can play a significant role in integrated nutrient management, but producers are encouraged to learn as much as possible about these products before including any of them in their farming operations.

Nutrient management in crop production

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and micronutrients are essential to crop production. Choosing the right nutrient source and applying the right amount, at the right time, using the right method (4R Stewardship) are important to efficient nutrient use. These decisions affect yield and producers' profits but also affect whether there will be soil nutrient excesses or deficiencies. Excesses add to the potential for nutrient loss to surface water and groundwater through leaching, erosion, or runoff. To use nutrients efficiently and ensure optimum and profitable yields while minimizing negative environmental impacts, it is essential to follow best management practices.

Integrated nutrient management

Integrated nutrient management (INM) involves good agronomic practices to minimize environmental pollution from applied inorganic and organic nutrients. The concept of INM is to combine non-synthetic natural and human-made sources of plant nutrients and/or biological products and materials with a reduced amount of chemical fertilizers to improve nutrient use efficiency. The role that biological products and materials can play in INM is addressed in this publication. The purpose of INM is not to eliminate chemical fertilizers but to optimize their use. This may involve using less chemicals, but still achieving high yields comparable to conventional practices as well as improved economic and environmental sustainability. The concept of INM is consistent with the 4R nutrient stewardship, which promotes enhanced nutrient use through the right source, rate, time, and place for plant nutrient application.

The need for the INM system and how it might fit in the conventional crop production system is illustrated

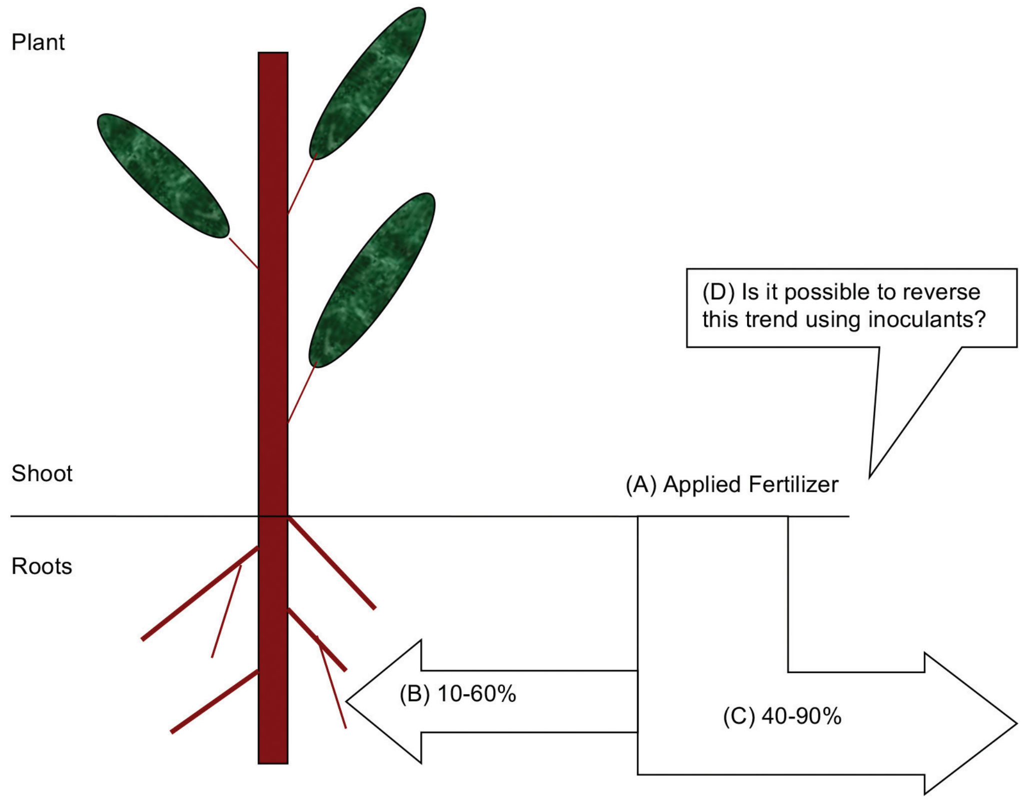

Figure 1. Model for improved plant nutrient use efficiency with biological products. (A) Total amount of fertilizer or manure applied to plants, (B) 10 percent to 60 percent of the applied fertilizer or manure is taken up by plants, and (C) 40 percent to 90 percent of the applied nutrient either remains in the soil or can be lost to the environment. In Nebraska, the situation with N uptake is relatively better than in many locations, but P applied at current P removal rates is likely to result in a slow increase in soil test P over time. Further improvement in uptake efficiency in Nebraska is essential and will enhance profitability.

(The figure, which was revised for this publication, was initially published in Adesemoye, A. O. and Kloepper, J. W. 2009. "Plant-microbes interactions in enhanced fertilizer use efficiency." Applied Microbiology & Biotechnology 85: 1–12).

by *Figure 1*. Due to the complex nature of soil nutrient cycling and soil-plant relationships, it is not realistic to expect 100 percent efficiency of applied fertilizers. Hence, specific to each nutrient, the use and amount of a specific fertilizer (A) is dependent on research determined quantities needed to maximize yield potential. This is greater than the amount of the applied nutrient taken up by plants (B), which ranges from 10 percent to 60 percent, depending on soil properties and processes, fertilizer type, and the plants. The part of the applied nutrient that is not removed by the plant either remains in the soil or can be lost to the environment (C) and could be in the range of 40 percent to 90 percent of the original amount applied. For the most part, the majority of unutilized nutrients remain in the soil.

Nitrogen is most likely to be lost through runoff, erosion, volatilization, denitrification, and leaching. Nitrogen can be sequestered by microbes and other plant use, although most of this will be released in time. Phosphorus and some micronutrients can be "fixed" in the soil, depending on the soil pH, so that they are in forms unavailable to the plants. Phosphorus can be lost through erosion and runoff. Potassium can leach.

In Nebraska, the situation with N uptake is relatively better than in many locations, but P applied at current P removal rates is likely to result in a slow increase in soil test P over time. Instead of continually applying P at rates that build the soil P level, improving the utilization efficiency would reduce the annual P application rates. While 100 percent nutrient use efficiency may be unrealistic, a system that can get the nutrient program closer to this goal over time is desirable.

Biorationals and biological products and how they work

Many new products are now available in the market that are natural nutrient sources or biologically derived fertilizer additives. These products promise to deliver cost-effective sustainable solutions that have little to no negative environmental impacts. These products will be better used as components of INM. The products are broadly categorized as biorationals or biological products and marketed under many different names such as biostimulants, phytostimulants, biofertilizers, and soil enhancers.

Biorationals can be defined as non-synthetic input materials in agriculture that are derived from natural sources such as microorganisms, biochemicals, minerals, organic materials, and plant extracts. Biorational is a broad term that has two components, (1) biological products, and (2) natural, nonbiological but environmentally nontoxic products. The associated different terms are explained in the Nebraska Extension Circular EC3019, *Introduction to Biological Products for Crop Production and Protection*.

Four mechanisms can be identified in these products. They are nutrient solubilization, nitrogen fixation, nutrient linkage, and plant physiology modification. These mechanisms are described below. Note, however, that many products combine more than one of the mechanisms, so examples given in this publication *(Table 1)* are not categorized by mechanisms. Also, many other potential product examples are not registered and are not included in this publication. It is our practice not to mention any product that is not registered or that university personnel have not tested, as we cannot confirm the product's claims. It is important to check each product's label and all the additional information provided by the manufacturer to know which of the mechanisms are applicable in a product of interest.

Nutrient solubilization

Some products are developed to solubilize nutrients that may be bound up in the soil and convert them into forms that are available for a crop's use. For instance, bacteria in some products are able to solubilize phosphorus (P) from insoluble sources such as rock phosphates or Ca- or Fe-bound phosphate. Most agricultural soils have large amounts of immobilized inorganic and organic P that is unavailable to crops. Phosphorus from fertilizers may also get immobilized after application to the soil. One reason is because P is highly reactive and forms complexes with metals such as iron (Fe), aluminum (Al), and calcium (Ca). In acid soils (pH 6.0 or less), Fe and Al form complexes with P. In alkaline soils (pH 7.0 or greater), Ca forms complexes with P. These complexes lead to the precipitation or adsorption of 75–90 percent of P in soil, leaving a small percentage of total soil P available for plant uptake. These reactions have implications for the soil chemical equilibrium dynamics. A microbial product containing microorganisms that can effectively compete with the resident soil microbial communities, colonize, and solubilize such P can potentially reduce the need for added phosphorus fertilizer. These products will indicate on their label that they contain phosphorus-solubilizing bacteria.

Nitrogen fixation

Some products contain nitrogen fixers that are effective colonizers, which can potentially increase nitrogen fixation over the resident soil nitrogen fixing rhizobia. Products containing *Azotobacter* species as an active ingredient are examples. These organisms, which are active ingredients in the biological products, may be naturally present in the soil but using the products should increase the populations and make them more effective.

Nutrient linkage

Some products may contain a fungus that has hyphae (branching filaments), which can spread wider than the crop roots. The hyphae will acquire more nutrients than may be available to the roots and transfer the nutrients to the roots. The organisms, e.g., mycorrhizae, act as links between the plant roots and the soil. Products that contain mycorrhizae fungi as an active ingredient are examples.

Plant physiology modification

Biologicals may positively affect the plant's natural physiological processes, leading to increased root growth and architecture, increased plant development, better nutrient uptake, and enhanced nutrient use efficiency. Physiological changes may also help plants tolerate abiotic stresses such as cold, heat, drought, excess water, and/or salt stress. Products that contain plant hormones are examples of this mechanism.

Concerns and emerging issues about nutrient enhancement products

Results of field testing on these products in many locations have been mixed. Some products have shown to be

Figure 2. Field trial where soybean was treated with various rates of a commercial product at planting. Differences between treatments were noted in late August as plants neared maturity, though visual effects don't always produce yield improvements.

Figure 3. Field trial on corn with a combination of a plant growth promotion biological product and chemical fertilizers.

Figure 4. Smooth brome growth response comparison with various biological products.

active or effective in better plant growth and nutrient use, with plants showing improved growth and vigor *(Figures 2–3)* while the same products may prove to be ineffective in other conditions. Some products do not show desired outcomes such as improvement in crop growth and development *(Figure 4)* and/or yield. An excellent resource for field trial results can be found at the Compendium of Research Reports on Use of Non-Traditional Materials for Crop Production (http://extension.agron.iastate.edu/compendium/). The database of results of studies conducted over the decades through the Nebraska On-Farm Research Network could also be helpful in answering producers' specific questions (http://cropwatch.unl.edu/on-farm-research).

Much of the research on these products is conducted or funded by the company producing the products. Sometimes the experimental protocols don't include a complete set of treatments that allow the appropriate comparisons to be made. For example, a trial that compares the conventional practice of a full fertilizer rate as one treatment with a biological product plus the full fertilizer rate as another treatment may not answer the important question of the need for integrating the biological into a producer's fertilizer operation. Instead, the question might be better answered if the study comprises at least three treatments: (1) conventional practice with full fertilizer rates, (2) biological product integrated with a reduced rate of the fertilizer, and (3) a reduced fertilizer rate only.

A related important question that may be answered in a different trial is: What is the appropriate reduced chemical fertilizer rate to be combined with a specific biological product? This can involve testing several rates of fertilizer with and without the biological product. In INM, biorationals/biologicals should not be an addition to full fertilizer rates as this will add to input costs. Effective products should facilitate the availability of nutrients and help achieve better nutrient use efficiency with less fertilizer, if the implementation of INM systems in producers' operations is well planned.

Recommendations for biological products for nutrient management

- Seek as much information as possible about each product before integrating it into farming operations. This is imperative for producers because the U.S. Environmental Protection Agency (EPA) does not require registration for many biorational or biological growth promotion and nutrient enhancement products, and the products are not regulated. Detailed information on their efficacy may not be easily available, and they might not have undergone sufficient independent testing. Producers need these pieces of information to know if a product is good for their program.

- Understand the proposed mechanisms of the product to be used and the location where it will be used as these can affect efficacy. For instance, a product in development was tested in corn for a company during the 2016 growing season in two locations in Nebraska. In one location, the pH was 7.3 and the P level was 6 ppm Bray #1 while in the other location the pH was 7.6 and 18 ppm Olsen P. A treatment for P solubilization and growth promotion showed a significant effect in the location with 6 ppm Bray #1 but not in the other location. At this soil P levels, crop response to P is expected without any amendments. In order to determine if the solubilization agent was effective, the treatment set needed to include the appropriate controls. This shows that it is important to have well designed research and to consider as much information as possible before making any management decisions to include these products.
- Consider getting involved in the Nebraska On-Farm Research Network to test any product of interest and determine if it works before it is fully integrated into producers' operations. In such a test, Nebraska Extension specialists and educators can help with the study design and determine the data that should be collected, depending on the producers' interests. For example, if a product is to solubilize P and increase uptake, it might be important to take plant samples early for analysis, as well as conducting soil tests.

Product application methods and examples of biorational/biological products

Nutrient enhancers are usually applied as a preplant seed treatment, in-furrow, or foliar spray. Some preplant products are planter box treatments that can be added at the planter box just before planting while some are highly concentrated liquid formulations that are recommended for commercial seed treaters only. Examples of commercially available biorational/biological products for plant growth promotion and/or nutrient management registered in Nebraska is presented in *Table 1.* Additional information on related products may be found in the Nebraska Department of Agriculture or Kelly Solution's website (www.kellysolutions.com/NE). Some products that are not registered may not be listed on the websites.

DISCLAIMER

Reference to commercial products or trade names is made with the understanding that no discrimination is intended of those not mentioned and no endorsement by Nebraska Extension is implied for those mentioned.

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Table 1. Specific examples of biorational/biological products for nutrient management

Microbial Inoculant and Manufacturer	Active Ingredients	Registered Crop and Application Method
Accomplish® LM Loveland Products	*Bacillus licheniformis*, *B. megaterium*, *B. pumilus*	Corn, soybean (in-furrow program)
AdvantigroTM Wibur-Ellis Co	Cytokinin, gibberellic acid, IBA	Corn, sorghum, soybean, wheat (foliar treatment)
Ascend® Winfield Solutions LLC	Cytokinin, gibberellin, IBA	Beans, corn, soybean, sugarbeet, sunflower, wheat (seed/foliar treatment)
Carbon power® FB Sciences Inc	Complex Polymeric polyhydroxy acids (CPPA)-plant regulator	Beans, beets, corn, sorghum, soybean, wheat (soil/foliar treatment)
Cell-TechTM Monsanto	*Bradyrhizobium japonicum*	Soybean, chickpea, pea, lentil (in-furrow program)
Dyna-Start Max® Loveland Products	*Bradyrhizobium japonicum* Lipo-chitooligosaccharide (LCO)	Soybean (seed applied)
Graph-Ex SATM ABM, Inc	*Bradyrhizobium japonicum Trichoderma* sp.	Soybean, dry beans (seed applied)
HiStick®N/T BASF	*Bradyrhizobium japonicum Bacillus subtilis*	Soybean (seed applied or in-furrow)
JumpStart® Novozyme	*Penicillium bilaii*	Chickpea, corn, dry beans, sorghum, soybean sugarbeet, sunflower, wheat (seed applied)
Legacy® SePro Corp	Flurprimidol, trinexapac-ethyl, others	Turf grass-growth regulator (foliar treatment)
Optimize® liquid soybean Monsanto	*Bradyrhizobium japonicum* LCO	Soybean (seed applied)
Quickroots® Monsanto	*Bacillus amyloliquefaciens Trichoderma virens*	Alfalfa, corn, sorghum, soybean, sugarbeet, sunflower, wheat (seed applied)
Rhizo-Flo® BASF	*Bradyrhizobium japonicum*	Soybean (seed applied)
Ryzup® Valent Biosciences	Gibberellic acid-3 plant regulator	Corn, wheat, sorghum, grasses (foliar)
SabrExTM ABM Inc	*Trichoderma* sp.	Corn, wheat, sorghum, rye, oats (seed applied)
Stimplex® Biostimulant Acadian Seaplants Ltd	Cytokinin, others Plant regulator	Beans, corn, sorghum, soybean, tomato, wheat (foliar treatment)
TagTeam® LCO Monsanto	*Bradyrhizobium japonicum Penicillium bilaii*	Pea, lentil, soybean, dry bean (in-furrow)
Torque® ST Monsanto	Lipo-chitooligosaccharide (LCO)	Corn (seed applied)
Vault® SP BASF	*Bradyrhizobium japonicum* (inoculant)	Soybean (seed applied)

Note: Products shown on this table are specific examples of those registered in Nebraska.