SOIL ADDITIVES AND SOIL BIOLOGY

Soybean producers are constantly looking for new ideas and technologies they can use to increase yield and profit, and to increase the sustainability of their production. One of the newer approaches is to use soil additives or amendments that are being promoted and sold to improve the soil environment that provides the medium for soybean roots.

A soil amendment or additive is any material that is added to improve a soil's physical characteristics such as water infiltration and retention, permeability, drainage, aeration, structure, and/or its microbial activity. The goal from adding any soil amendment is to provide an improved environment for plant roots that will enhance their support functions for the aboveground plant.

There has been much written about soil health and how soil amendments or additives may promote or enhance it. New technologies that are being developed for agriculture can produce benefits that include increased nutrient availability to and uptake by plant roots, increased yield or quality of marketable product, enhanced protection against root colonizing pathogens, and greater net returns because of a greater yield and/or reduced costs associated with reduced inputs.

There are two broad categories of soil amendments, organic and inorganic. Organic amendments are derived from something that was alive, while inorganic amendments are either mined or man-made. Organic amendments increase soil organic matter [SOM] which is an important energy source for microbes and other living organisms in the soil.

Soil amendment applications can benefit growers in several ways that include 1) increased nutrient availability and retention due to increased organic matter, 2) increased water holding capacity and water infiltration into soil, 3) enhanced soil microbial activity, 4) enhanced soil carbon [C] storage, and 5) more sustainable crop production systems.

Several articles provide information about the availability of and technology associated with the development and use of biologicals in agricultural settings. Links to those articles and a brief summary of each one's content follow.

- "Biologicals: Know what you're using before diving in" by Chris Torres provides a list of categories of biologicals, how they work, and how they must be matched to a field environment.
- "FBN is newest supplier in biologicals business" by Willie Vogt provides information about the expansion of the Farmers Business Network [FBN] into the biologicals market. FBN Biological's lineup includes 1) prebiotics that contain molecules that will stimulate soil microbial activity, 2) probiotics that are live microorganisms with targeted functions when applied to the soil, 3) foliar-applied stimulants that are designed to enhance a crop's photosynthetic capacity, 4) C sources that provide soil benefits, and 5) biologically enhanced micronutrient fertilizers.
- "Are microbes the next carbon crop for farmers?" by Mindy Ward highlights the work Pluton Biosciences is doing to find microbes that will aid in sequestering C in the soil. Basically, the company envisions applying microbes as a cover crop [CC]–i.e. they will be sprayed onto the soil as an amendment at harvest, at burndown, or at planting. The company will be attempting to identify and develop microbes that can store C and nitrogen [N] in the soil.

There are two approaches to improving soil microbial health and/or activity. First, beneficial microbes can be added to the soil to potentially increase soil microbial activity and the subsequent benefits that should be derived from that increased activity. Such is the approach outlined in the above article that highlights the work of Pluton Biosciences. Second, microbes that are already in the soil can be enhanced by increasing the food supply available to them. This can be done by increasing crop residues or adding an organic material such as poultry litter that will provide a C source for these microbes, or by directly applying C amendments to the soil. There is anecdotal evidence that liquid products–e.g. organic C, humic acid–will provide a soybean yield enhancement, presumably by increasing soil microbial activity that complements soil processes that increase nutrient availability to soybean roots that mine the soil for those nutrients.

A summary of why agricultural biologicals are important, how they can promote diversity in current agricultural practices, and how they might provide an alternative to chemical agricultural products is provided here. The ultimate goal from using effective agricultural biologicals and soil amendments is to enhance the growing environment of crops and to enhance soil health.

Factors that should be considered when selecting a soil amendment are: 1) the expected length of time the amendment will persist in the soil–i.e. will it have a long- or short-term effect; 2) soil texture at the site receiving the amendment since this will dictate the goal from adding a soil amendment–e.g. for sandy soils the goal might be to increase water and nutrient holding capacity, while the goal when adding an amendment to a clayey soil might be to increase porosity, permeability, aeration, and/or drainage; 3) soil salinity and plant sensitivity to salts–i.e. ensure that a soil amendment will not add to the salt content of a soil that may already be high in salt; 4) components and pH of the amendment–i.e. do not add an amendment that will exacerbate those soil properties that may be problematic in soil at the site of its proposed addition; 5) how and when should the amendment be applied to ensure its maximum effect; and 6) the analysis of the soil amendment to ensure its properties/components will be sufficient to affect the intended process at the site of application.

There is evidence that biological control agents [BCA's] can be used to lessen the effects of diseases that affect soybean. For example, an article titled "*Trichoderma* isolates inhibit *Fusarium virguliforme* growth, reduce root rot, and induce defense-related genes on soybean seedlings" [click here for a summary of this research] provides information about how BCA's such as *Trichoderma* spp. can be used to suppress *F. virguliforme* [pathogen that causes sudden death syndrome or SDS] populations in the soil and thus reduce SDS severity in soybean. The authors cautioned that for successful introduction of BCA's into crop production systems, the method of application of the BCA is crucial because this can affect how the BCA may interact with the plant and targeted pathogen. They state that research is needed to develop optimized BCA delivery systems that will allow the appropriate BCA to have a competitive advantage against the targeted pathogen.

Results from a study that is reported in an article titled "Nutrients cause consolidation of soil C flux to small proportion of bacterial community" provide the following information about the soil microbial community.

- The study was conducted because, even though soil microbial communities contain myriad microbe taxa, the quantitative contributions of the individual taxa to the processes that govern soil C accumulation and loss are not known.
- Measurements of specific properties of four soils/ecosystems [desert grassland, Piñon-juniper scrubland, Ponderosa pine forest, and mixed conifer forest] in northern Arizona were made to develop subsequent models.
- Measurements were made in the laboratory using unamended soil, soil with a supplemental C source [glucose], and soil with glucose + an N source accessible to microbes [C+N].
- Modeled bacterial respiration was positively related to total soil respiration, but not in proportion to an individual taxon's relative abundance.
- Amended soils [both added C and added C+N] elevated soil respiration, and also stimulated taxon-specific bacterial respiration.
- Of genera common to all four soils, only six were necessary to obtain >50% contributions to C cycling in the unamended and C-amended soils, while only three [*Bradyrhizobium*, Acidobacteria genus *RB41*, and *Streptomyces*] were necessary to obtain >50% C cycling in the C+N-amended soils.
- Relative C use in the soil bacterial community was more consolidated within fewer lineages than the overall distribution of relative abundance suggested. Averaged across the four ecosystems and three treatments, 76% of bacterial genera used less C than their relative abundance would indicate.
- Nutrients added to the soil diminished bacterial functional diversity, and consolidated C flow

through fewer bacterial taxa. Bacteria that used the most C that was added to the soil were also the same ones that used the most native soil C.
- Estimates of C use indicated that the addition of N to soil may disrupt the balance between native soil C use and use of a C soil amendment.
- The abundance of individual bacteria taxa alone was not a sufficient predictor of soil C flux.
- Overall, the authors concluded that it is worthwhile to determine the consistency in C process rates across the globe, since doing so may reveal a core group of soil bacteria taxa that act as dominant soil C processors.
- A narrative summary of results from the above study, with quotes by senior author Bram Stone and co-authors, can be accessed in a news release from Northern Arizona University titled "A few common bacteria account for majority of carbon use in soil".

Results from the above study, although taken from measurements of C cycling properties in non-agricultural soils, indicate that future assessment of C cycling in agricultural soils should be evaluated in relation to the microbial taxa present in those soils. In effect, knowing the major bacterial contributors to C cycling in agricultural soils might lead to recommendations for specific microbial or nutrient additions to these soils to enhance C cycling. This is an important consideration when future assessments of microbial activity in agricultural soils that have been amended with nutrients or organic matter/C source are conducted–i.e. it should not be assumed that the native soil microbial population will benefit or be affected the most when the soil environment is changed.

Nitrogen fixation is a natural biological process where atmospheric N is converted into a form of N that can be used by plants. This process is generally limited to legume species.

The majority of the world's crop plants obtain the N needed for growth and development from the soil. However, the soil-N reservoir is not sufficient to supply the amount of N needed to produce an amount of crop that is above a subsistence level. Therefore, the N needed for the vast majority of crops is added to the soil as fertilizer. The economic and environmental ramifications of N fertilizer production and use are well-documented.

Source from Sound Agriculture is promoted to reactivate nutrient cycling in the soil by mimicking a critical signaling molecule that plants naturally release through their roots. Source can be applied as a foliar spray to both corn and soybeans, and will be translocated through the plant to the soil. It is promoted to make already-present N-fixing bacteria and phosphate-solubilizing microbes in the soil more active.

Azotic Technologies Ltd. has developed Envita, which is a microbial inoculant that is applied either as an in-furrow or seed treatment. The company states that it quickly establishes itself within the plant and grows with the plant as it grows, starts to fix N very quickly, and lasts all season long.

Pivot Bio produces Pivot Bio Proven 40, a product that contains naturally occurring soil bacteria that form a symbiotic relationship with the corn plant and takes N from the air to create the N form that the plant can use. It must be applied as a liquid in-furrow treatment as the corn crop is planted. Its life cycle mirrors that of corn, and it is promoted to replace up to 40 lb. of synthetic N fertilizer per acre.

TerraMax produces microbial products that are touted to help the plant's root system effectively take N from the air and access nutrients from the soil to promote or enhance plant growth.

Corteva Agriscience produces Utrisha, a foliar-applied microbial product that is promoted to provide a variety of crops with a sustainable supply of N from the atmosphere throughout the growing season.

Phosphorus [P] availability to crop plants is important for their optimum performance. Microbes that solubilize P increase the P that is available to plants by secreting acids that release P from the soil to make it plant-available. Such additives/amendments that will increase soil P availability to and uptake by plants could reduce the amount of P fertilizer that is applied. An example product is INvigorate from AMVAC.

The benefits of returning crop residue to the soil have been detailed in a White Paper on this website. The following products are being offered and promoted to aid in the management/degradation of that residue, especially in situations where its excess or non-degraded form may pose a problem for the establishment of a following crop.

MicroChop from SPNC is a live microbial product that is applied to crop residues to enhance their degradation and their release of entrapped nutrients.

Biodyne-USA produces Environoc 401, a microbial plant stimulant that can be applied at-planting to corn and soybeans. The product contains beneficial microbes that are touted by the company to 1) enhance N fixation and soil N mineralization, 2) enhance soil P solubilization, 3) enhance soil micronutrient availability, and 4) enhance residue breakdown.

Bacteria in the genus *Bacillus* are often added to the soil to enhance residue degradation to facilitate the release of nutrients that are present in those residues. *Bacillus megaterium*, *Bacillus amyloliquefaciens*, *Bacillus licheniformis*, and *Bacillus pumilus* are bacteria that can be soil-applied to facilitate the residue degradation process.

The below points related to use of biological additives/amendments are gleaned from the following articles: 1) "'Snake Oil' or 'Viper Lipid'? How to Get the Most Out of Your Biostimulant" by Connor Sible and Fred Below at the Univ. of Illinois; 2) "What are Biologicals" by Betty Haynes featuring content provided by Connor Sible; 3) "Considering biologicals? Do your homework" by Lawrence, Workman, and Ketterings; and 4) "Biologicals: Manage Expectations" by Gregg Hillyer.

- Biologicals can be classified as: 1) plant growth regulators; 2) beneficial microbes that are living organisms–e.g. N-fixing bacteria, P-solubilizing microbes, mycorrhizal fungi; or 3) biostimulants that are "non-living" products–e.g. phosphatases [P-solubilizing enzymes], humic and fulvic acids, sugars that are added to a plant or the soil to stimulate a beneficial natural process such as nutrient availability and/or uptake.
- P-solubilizing microbes increase the P that is available to plants by secreting acids that release P from the soil to make it plant-available. Contact of these microbes with soil near the root system is important.
- Many biostimulant products are on the market, so it is important to know if these products were developed and tested with adequate science and appropriate research.
- Only with adequate understanding of what process a product is supposed to affect and how it works to affect that process can a producer select the product that meets the criteria to enhance the targeted process. Thus, a first step is to determine if a soil additive will enhance a particular process that will positively affect the crop that is being grown.
- A beneficial microbial product is applied to supplement or enhance the activity of native microbes to result in a performance that is greater than that of the native microbial population alone.
- A major challenge when using any biostimulant is knowing the exact amount needed to induce the desired positive response and the time to apply the product since both will likely vary based on the crop being grown and its stage of development, and the environmental conditions at the time of product application. This will require research over a period of years in myriad growing conditions.
- Humic and fulvic acids have a direct role in nutrient availability. They are composed of chemical structures that can 1) mimic plant hormones and stimulate root growth, 2) enhance chelation of soil cations to prevent them from binding to P so that P fertilizer is more available to plants, and 3) provide a C source for soil microbes.
- Any biological product that is promoted to enhance a soil function to improve crop performance 1) needs data from valid research to verify that it works and when it can provide a benefit to the crop being grown, and 2) should be tested across a diverse range of growing conditions to better understand when and where it is likely to provide an economic benefit.

- Transparency in the conduct of research with soil additives and the results from that research is critical if farmers are going to adopt them and industry is going to continue to invest in their development.
- Before using biologicals in a cropping system, three questions should be asked and answered. 1) Will the product increase yield? 2) Can it reduce the need for fertilizer that is commonly added to crops in the system? 3) Will using a particular product provide a positive economic impact?
- Biologicals are increasingly being applied in row crop systems as scientists discover added benefits from their use and as there is increasing demand for more sustainable crop production.
- Use of any soil additive must provide a positive return on investment to the farmer(s) who apply them.
- The biologicals market is expected to reach $14.7 billion in 2023 and $27.9 billion in 2028, and $1 billion is annually invested in their development.

Unfortunately, the information provided here cannot be used to provide a recommendation to producers about what products should or should not be applied to soybean fields to increase yield and profit from the enterprise. Rather, each individual producer will have to decide whether or not to spend the money on any of the myriad soil additives with the hope that they will provide a positive return from their addition, or will contribute to long-term improvement in soil health. Producers are cautioned to have a distinct goal in mind if/when the decision is made to add any of the myriad "soil health" products that are being promoted and sold to enhance crop production sustainability. Otherwise, it will just be adding an expense that may not contribute to increased profits or a more sustainable production system.

As with any new technology, time will be needed to conduct research that will provide results to validate the claims that are made for new soil amendments and products. However, this in no way negates the fact that soil amendments that will improve soil health, whether it be by improving physical, chemical, or microbial properties, are needed to either replace or complement synthetic additives that are currently being applied. Results from sound research that will be conducted with forthcoming new technology and its application in crop production systems will provide the final answer.

MARCH 2023 UPDATE

Dead microbes [microbial necromass or microbe corpses] are a large and significant component of soil organic carbon [SOC], and thus are crucial for long-term C sequestration and stabilization. It is reasonable to assume that cropland management practices will affect the accumulation of this material and its subsequent contribution to SOC. Just what practices have this effect and the amount of that effect are important questions to consider when attempting to increase SOC on sites where crops are grown.

Information contained in an article titled "Microbial necromass in cropland soils: a global meta-analysis of management effects" by Zhou et al. provides some answers to these questions. Major points from that article follow.

- Results in 61 peer-reviewed journal articles that were published prior to Aug. 2022 were selected for this meta-analysis. A total of 481 paired observations that reported the effects of management practices on microbial necromass accumulation were selected from these articles.
- Most of the studies were conducted in East Asia, North America, and Western Europe.
- The focus of the analysis was to determine the impact of cropland management practices that included N fertilization, application of manure from agricultural enterprises, straw [residues of myriad plant species] and biochar soil amendments, no or reduced tillage [NT/RT], and cover crops [CC's] on soil microbial necromass accumulation.
- All investigated management practices except biochar addition increased total microbial necromass C in cropland soils by 12-21%. The order of increase was 1) straw and manure additions–21%, 2) NT/RT–20%, 3) CC's–14%, and 4) N fertilization–12%.
- Bacterial necromass C was greatest with manure application, whereas fungal necromass C was greatest with straw application.

- Only straw addition and NT/RT increased the total microbial necromass C contribution to SOC.
- Responses of microbial necromass C to management depended on climate [temperature, rainfall, humidity], soil properties [texture, initial SOC content, pH], quality and quantity of C input, and experiment duration [short term (< 3 years) vs. long term (> 10 years)].
- The analyzed data from the selected articles validated that cropland management practices affected soil microbial biomass, and thus subsequently influenced the production of microbial necromass. There was a direct positive effect of microbial biomass on necromass accumulation.
- NT/RT was the most efficient practice for the accumulation of microbial necromass, followed by CC's and straw addition. N fertilization had the smallest accumulation efficiency. The accumulation efficiency of fungal necromass was about 6.4 times greater than that of bacterial necromass under NT/RT, followed by CC's.
- Overall, this meta-analysis indicated the following. 1) N fertilization and straw addition increased microbial necromass accumulation in semi-arid and cool climates, whereas NT/RT and cover crops were more effective at doing this under humid vs. semi-arid conditions [an important finding for the humid midsouthern U.S.]. 2) Microbial necromass accumulation was closely connected with the amount of living microbes in the soil and with SOC content. Thus, conservation management practices applied to cropland soils increase microbial biomass, which in turn enhances necromass formation and accumulation, thereby supporting the buildup of SOC.
- In conclusion, all commonly used conservation management practices except biochar addition increased microbial necromass accumulation in cropland soils. However, the quantity of the increase was dependent on climate and edaphic conditions at the cropping site.

When soil health is discussed, it invariably leads to/should lead to determining ways to enhance the soil microbial population that is instrumental in maintaining healthy and productive soils. The above information lends further credence to the importance of 1) the soil microbial population for enhancing C sequestration in soil, and 2) the need to apply conservation agricultural practices over a long period (~> 10 years) in order to realize their full potential for improving the environment of soil that is used to grow crops.

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