SOIL MICROBES AND SOIL BIOLOGY

There is no doubt that soybean producers are looking for every edge to increase yield and profit, and to increase the sustainability of production in their fields. One of the more tempting avenues is to use inputs that are touted to improve the soil environment that provides the medium for soybean roots. Hopefully the following narrative will shed some light on how soil additives and/or biologicals might be a future input to accomplish this.

A soil amendment or additive is any material added to a soil to improve its physical characteristics such as water infiltration and retention, permeability, drainage, aeration, and structure, and/or its microbial activity. The goal from adding any soil amendment is to provide a better or improved environment for plant roots and soil microbes.

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 are 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.

Four Farm Progress 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.

- "Firms partner to bring 'bio' to crop production" by Willie Vogt appears in a Mar. 10, 2021 article. This article reports that FMC and Novozymes Biologicals will collaborate to research, co-develop, and commercialize biological enzyme-based crop protection products that will potentially boost efficacy of crop protection chemicals. It is touted that this technology will complement synthetic chemical products that are used to control insects and fungi.
- "Biologicals: Know what you're using before diving in" by Chris Torres appears in a Mar. 25, 2021 article. This article 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 appears in an Apr. 9, 2021 article. This article 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 appears in an Apr. 21, 2021 article. In this article, the work Pluton Biosciences is doing to find microbes that will aid in sequestering C in the soil is briefly described. Basically, the company envisions applying microbes as a cover crop–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 Farm Progress 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 good short 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–i.e., 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 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) salt content and pH of the amendment–i.e., do not add an amendment that will exacerbate these soil properties that may be problematic in soil at the site of its proposed addition; 5) how and when should the amendment/additive be applied to ensure its maximum effect; and 6) the analysis of considered soil amendments to ensure their properties/components will in fact be sufficient or appropriate to affect the intended process at the site of application.

There is evidence that biological control agents (BCA) 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" [Plant Disease 104:1949-1959 (2020)–click here for a summary of this research] provides information about how BCAs 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 BCAs 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 stated 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" that is published in the journal Nature Communications [(2021) 12:3381; https://doi.org/10.1038/s41467-021-23676-x] 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 June 2021 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.

Unfortunately, the information provided here cannot be used to provide a recommendation to producers about what new 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. The current upward trend in the soybean commodity price gives producers the opportunity to explore using inputs that might not otherwise be considered; however, producers are cautioned to have a distinct goal in mind if/when the decision is made to add any of the many "soil health" products that are touted 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 either validate or dispute the claims that are made for new biologically-based 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 this new technology and its application in crop production systems will provide the final answer.

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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 carbon [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. The article was published in the journal Global Change Biology in Feb. 2023. 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 nitrogen [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 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) cover crops–14%, and 4) N fertiliztion–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 cover crops 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 cover crops.

- 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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