Microbes and Soil Health

It All Begins (and Ends) with Soil Fertility

In one of our earlier articles, Humic Acid and Healthy Soil, we noted that there are three basic types of soil: Clay, Silt (Loam) and Sandy. Soil fertility is also made up of three basic components:

1. **Biological Fertility**: Biological Fertility refers to the many varied organisms and microorganisms that live in the soil and interact with the other two fertility components. These organisms live on soil particles, on organic matter, and on other larger organisms within the soil (think worms). They are responsible for many vital processes in the soil, including advancement of the nutrient and carbon cycles. By and large, few soil organisms are considered pests.

2. **Physical Fertility** Physical Fertility refers to the physical properties of the soil. These include the following:
    - **Soil structure.** The arrangement of aggregates (particles of clay, silt and sand), plus voids and other spaces determine soil structure.
    - **Soil texture.** This is the relative amount of clay, silt and sand particles.
    - **Water absorption & holding capacity.** This component is made up of four factors; three that refer to water movement via rain or irrigation and active gravitational flow (infiltration, permeability, and percolation), and one that refers to water movement once gravitational flow has stopped (capillary action).
    - **Root penetration.** The ability of plant roots to grow and move within the soil (degree of difficulty).

3. **Chemical Fertility** Chemical fertility refers to the nutrient levels and chemical conditions such as acidity, alkalinity and salinity in soil. Components are:
    - **Macronutrients:** examples are Nitrogen, Phosphorous, Potassium, Calcium, Sulphur, Magnesium, Carbon, Oxygen, Hydrogen.
    - **Micronutrients:** examples are Boron, Iron, Chlorine, Manganese, Zinc, Copper, Molybdenum, Nickel.
    - **Toxic Heavy Metals:** examples are Arsenic, Aluminum, Chromium, Mercury, Lead, Cadmium (note that some micronutrients are also heavy metals, but are not considered toxic in normal concentrations.)

In this article we will focus on **Biological Fertility**, the least understood fertility component, especially among growers. Over the years and numerous crop cycles, many agricultural soils have been stripped of much of their microbial content. In essence, changes in **Physical** and **Chemical Fertility** due to overuse of inputs, tillage practices, etc. have caused an imbalance of these two components with **Biological Fertility**. There can be billions of microbes in a thimbleful of fertile soil. Most numerous of the soil microbes are bacteria, then (in decreasing numeric order) the actinomycetes, fungi, algae, protozoa and viruses. Nematodes also play a role.

Each group of soil microbes has different characteristics that define the organisms and different functions in the soil it lives in. And most importantly, these organisms do not exist as independent players; they interact with all other groups and these interactions influence soil fertility as much or more than the organism's individual activities.

Bacteria:

Bacteria are single celled, microscopic organisms, and are the most abundant microbes in the soil. There are bacteria species that are weak and may be killed off by slight changes in the soil environment. Populations of bacteria can explode or be devastated in just a few days in response to changes in soil moisture and soil temperature. Conversely, other types of bacteria are much tougher, and are able to withstand severe heat, cold or drying. Some bacteria are dependent on specific plant species. Bacteria can be subdivided into the following four functional types:

Decomposers:

Most bacteria are decomposers that eat dead plant material and organic waste, releasing nutrients that other organisms consume, an essential component in early stages of the nitrogen cycle. Some decomposers can break down pesticides and pollutants in soil. Decomposers are especially important in immobilizing, or retaining, nutrients in their cells, thus preventing the loss of nutrients, such as nitrogen, from the root zone.

Mutualists:

- **Nitrogen fixers:** these extract nitrogen gas from the air and convert it into forms that plants can use. Visible nodules are created where bacteria infect a growing root hair. The plant supplies simple carbon compounds to the bacteria, and the bacteria convert nitrogen (N_2) from air into a form the plant host can use. When leaves or roots from the host plant decompose, soil nitrogen increases in the surrounding area.
- **Nitrifying:** these change ammonium (NH_4^+) to nitrite (NO_2^-) then to nitrate (NO_3^-) – a preferred form of nitrogen for grasses and most row crops. Nitrate is leached more easily from the soil, so some farmers use nitrification inhibitors to reduce the activity of one type of nitrifying bacteria. Nitrifying bacteria are suppressed in forest soils, so that most of the nitrogen remains as ammonium.
- **Denitrifying:** these convert nitrate to nitrogen (N_2) or nitrous oxide (N_2O) gas. Denitrifiers are anaerobic, meaning they are active where oxygen is absent, such as in saturated soils or inside soil aggregates.

Pathogens:

Pathogenic bacteria cause diseases in plants. They compete for the same nutrients and water with their non-pathogenic neighbors. When soils have high microbial activity, there are more non-pathogenic bacteria present than the pathogenic type. Healthy soil bacteria populations will produce antibiotics that hold the pathogenic types in check.

Lithotrophs:

These are non-carbon consuming bacteria, getting their energy from compounds of nitrogen, sulfur, iron or hydrogen instead. Some of these species are important to nitrogen cycling and degradation of pollutants. In well-aerated soil conditions, these bacteria will make sulfur more available to plants, and conversely, in low oxygen soil conditions they will make sulfur less available.

Actinomycetes:

A fifth functional group that is typically grouped in with Bacteria are the Actinomycetes. These are single-cell organisms like bacteria but also exhibit some of the characteristics of Fungi. They decompose or degrade the more resistant organic substances, such as cellulose, polysaccharides, protein fats, and organic acids. Actinomycetes are vital in breaking down humates and humic acids in soils to help form a stable humus, enhance soil structure, and improve water retention. These are the organisms that give freshly turned soil its characteristic “earthy” smell.

Fungi:

Neither plant nor animal, soil fungi are microscopic cells that can be either single celled (e.g. yeast), or grow in long threadlike structures (hyphae) that make a mass called a mycelium. They can be symbiotic with plant roots, and are generally not as dependent on specific plant species as bacteria. In most cases they are helpful to soil organisms, but can in some instances be harmful. On the helpful side, fungi can attach themselves to plant roots in a beneficial relationship called ***mycorrhizal***. The fungi help the plant by giving it needed nutrients and in return the fungi get carbohydrates from the plant. However, fungi can also get food by being parasites and attaching themselves to plants or other organisms for destructive purposes.

Fungi function as:

- **Decomposers** – *saprophytic* fungi – convert dead organic material into fungal biomass, carbon dioxide (CO_2), and small molecules, such as organic acids.
- **Mutualists** – the *mycorrhizal* fungi – colonize plant roots. In exchange for carbon from the plant, mycorrhizal fungi help to make phosphorus soluble and bring soil nutrients (phosphorus, nitrogen, and micronutrients) to the plant.
- **Parasites:** The third group of fungi, *pathogens* or *parasites*, causes reduced production or death when they colonize roots and other organisms.

Algae:

Algae are soil organisms that are capable of photosynthesis, and are present in most of the soils where moisture and sunlight are available. They are capable of fixing nitrogen.

Functions of algae in soil include:

- Becoming additional organic matter and increasing organic carbon in soil when they die.
- Binding soil particles and thereby reducing and preventing soil erosion.
- Helping to increase the water retention capacity of soil.
- In flooded areas, providing submerged aeration via photosynthesis, releasing bound up oxygen.
- Helping to check the loss of nitrates through leaching and drainage, especially in un-cropped soils.

Protozoa:

These are single-celled, animal-like organisms which are slightly larger than bacteria. They feed primarily on bacteria, but can also dine on fungi, soluble organic matter, and occasionally other protozoa. Relatively hardy in most soil conditions, protozoa can also withstand tillage and other soil disturbances better than other microbes.

Functions of protozoa in soil include:

- Maintaining microbial/bacterial equilibrium in the soil by feeding on soil bacteria.
- Can be biological control agents against organisms that cause harmful diseases in plants.

Viruses:

Viruses are the smallest known organisms in the soil. Very little is known about them as compared with other soil organisms. We do know that all viruses are parasitic, feeding off other flora and fauna. Plant, insect and human viruses can be found in most soils, and are influenced mostly by soil moisture, along with soil structure and plant roots. Soil viruses are thought to greatly influence soil microbes via an ability to transfer genes from host to host, and as a potential cause of microbial mortality.

Nematodes:

Nematodes are not microbes, but instead are tiny worms. A tremendous amount of information is known about nematode species that are responsible for plant diseases due to their obvious impact. But much less is known about nematodes that can play beneficial roles in soil. Different nematodes feed at different levels. Some feed on the plants and algae, some feed on bacteria and fungi, and some feed on other nematodes. Nematodes mineralize nutrients in plant available forms. When nematodes eat bacteria or fungi, ammonium is released, as bacteria and fungi contain much more nitrogen than the nematodes require. This provides an additional nutrient source for plants.

CONCLUSION

It’s a common refrain that the soil is the farmers factory, and that is true. But, so much attention has been paid to the **Chemical Fertility** and **Physical Fertility** of soil that the equally important factor of **Biological Fertility** is many times given little thought. The least we can do is make sure that the factory is up and running at an optimal level. As we pay attention to a seeds yield potential, let’s make sure we’re placing it in an environment that will not compromise that potential, but instead provide a place for it to thrive.

The agricultural community is rapidly realizing that the relationship between the three components of Fertility is just as important as any one component on its own.

For example, tillage of some sort is practiced by many growers. It is assumed that breaking or turning the earth in some way will increase **Physical Fertility** of soil by opening it up to more water and air, and to some extent that is true. However, many tillage practices actually damage the soil aggregates we talked about on page 1 of this article. Carbon in the soil is freed up and the microbes and other soil organisms feast on this greatly enhanced food source. Unfortunately, that feast eventually comes to an end. The web of microbes, fungi, and other soil organisms, exposed to the environment and without food, die off in great numbers and nutrients are no longer recycled. As other pests take advantage of their absence, growers react by resorting to chemical agents to counteract the pests and a negative cycle is established. Reducing the amount of tillage and tillage depth is becoming a more prevalent practice as the effects of tillage on **Biological Fertility** are better understood.

Returning the soil to a humus-rich condition is critical to **Biological Fertility**. Researchers have noted an increase in the overall activity of most types of soil microorganisms with the presence of **humic substances**. The treatment of the soil with humic substances is one of the most effective measures growers can use to restore the fertility of depleted soils, and thereby increase the level of microorganism health. Via the chelation of various elements and formation of molecular bridges, humic substances provide the energy (carbon) for soil microorganisms which have no other means (such as plant photosynthesis) of obtaining that energy. Humic substances increase soil water holding capacity and improve soil structure, increasing nutrient availability and thereby giving soil microbes optimum conditions to grow and thrive.

Balance among the three pillars of fertility is essential to establishing and maintaining the factory that is your soil, and therefore your future profitability. A continual program of testing therefore becomes the most important and effective way for growers to improve soil conditions and income potential. Testing the soil for nutrient and chemical levels is an established part of most cropping programs. It is vitally important to add testing of soil microbial health on a regular basis, particularly because that health can change so quickly due to physical and chemical activities. In many cases, problems at the microbial level are incorrectly attributed to some sort of deficiency in chemical inputs and the immediate fix of adding chemical inputs both misses the actual cause and, in many cases exacerbates the problem.

There are a number of testing methods available for growers to see how healthy their soil is from a microbial standpoint. Growers will see long-term benefits from looking to their dealers, consultants, local university extension advisors, and other experts for advice and guidance on keeping overall soil fertility at optimum levels.