MANAGING THE SOIL AS A HABITAT

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When we are standing on the ground, we are really standing on the rooftop of another world. Soil might look like "dirt" but it is far more interesting! Living in the soil are plant roots, viruses, bacteria, fungi, algae, protozoa, mites, nematodes, worms, ants, maggots, other insects and insect larvae (grubs), and larger animals. Indeed, the volume of living organisms below ground is often far greater than that above ground. Together with climate, these organisms are responsible for the decay of organic matter and cycling of both macro- and micronutrients back into forms that plants can use. Microorganisms such as fungi and bacteria use the carbon, nitrogen, and other nutrients in organic matter. Microscopic soil animals such as protozoa, amoebae, nematodes, and mites feed on the organic matter, fungi, bacteria, and each other.

Together, these activities stabilize soil aggregates, building a better soil habitat and improving soil structure, tilth, and productivity. Agricultural practices such as crop rotation and tillage affect the numbers, diversity, and functioning of the micro- and larger-organisms in the soil community, which, in turn, affects the establishment, growth, and nutrient content of the crops we grow. Farming practices that include diversified crop rotations, increased use of legumes, cover crops, green manures, composts, agroforestry, and intercropping build the quality and quantity of soil organic matter and increase the populations and diversity of soil organisms. Increasing overall biodiversity (including plants and soil biota) increases the resistance and resilience of soil ecosystem processes to short and long-term stresses.

In this presentation you will be introduced to the activities of soil organisms (both micro and macro in size) in terms of how they affect the cycling and availability of nutrients (ecosystem processes) to crops, disease cycles, weed management, and soil tilth and erosion potential. More detailed examples with mycorrhizal fungi and earthworms will demonstrate the important role of soil biology in improving soil quality and productivity. To complete the picture, the presentation finishes with a discussion of how biological activity is influenced by soil management practices and points to ways that we can better manage and use soil biological activity to our advantage.

Introduction

Soils are formed from a stew of geological ingredients or parent materials (rocks and minerals), water, and billions of organisms. The interactions between climate, parent material, organisms, landscape, and time affect all major ecosystem processes, leading to the development of soil properties that are unique to that soil type and climate. The activities of and chemicals produced by, soil micoorganisms, and the chemicals leached from plant residues and roots can further influence the weathering of parent materials, changing the mineral nutrient content and structure of soil. Thus, farm management practices such as crop rotations, tillage, fallow, irrigation, and nutrient inputs can all affect the population and diversity of soil organisms, and in turn, soil quality.

There are three soil properties that define soil quality: chemical, physical, and biological. The chemical properties of a soil are usually related to soil fertility such as available nitrogen (N), phosphorus (P), potassium (K), micronutrient uptake of copper (Cu), zinc (Zn), manganese (Mn), etc, as well as organic matter content (SOM), and pH. Soil structural characteristics, such as aggregate formation and stability, tilth, and texture are physical properties. The biological properties of a soil unite the soil's physical and chemical properties. For instance, fungi and bacteria recycle all the carbon, nitrogen, phosphorus, sulphur and other nutrients in SOM, including animal residues, into the mineral forms that can be used by plants. By breaking down the complex carbon compounds that make up SOM into simpler compounds, soil organisms acquire their energy.

At the same time, the root exudates, hyphae of the fungi, and the secretions and waste products of the bacteria are binding small soil particles and organic matter together to improve soil structure. This makes a better soil habitat that attracts more soil animals, which further increases the amount of nutrient cycling. Fecal pellets from soil invertebrates and castings from earthworms increase the number of larger soil aggregates, allowing for more water infiltration and aeration and better rooting. The activities of soil animals mix smaller organic matter particles deeper into the soil acting to increase the water holding capacity of the soil. Thus, biological activities hold the key to maintaining or increasing soil productivity.

Soil productivity is mostly measured in terms of yield, but is a function of soil structure, fertility, and the population, species composition, and activities of soil organisms. However, health, nutrient content and value of the crops, and environmental quality both on and off the farm should also be considered as a measure of soil productivity. Studies have shown that soil bacteria and fungi regulate the destruction of toxic environmental pollutants, such as nitrous oxides, methane (greenhouse gases), and some pesticides. The speed that residues decay and nutrients are released from SOM, and pollutants and pesticides are detoxified, is largely dependent on how we manage the soil. Farm management practices and the effect they have on soil organisms, will also influence the processes that determine the health of our environment on a broader scale.

In undisturbed soil, most of the nutrient cycling, roots, and biological activity are found in the top 20 to 30 cm, called the rooting zone. The rhizosphere is characterised as a zone of intense microbial activity, and represents a close relationship between the plant, soil, and soil organisms. The rhizosphere is bathed in energy-rich carbon compounds, the products of plant photosynthesis, which have leaked from the roots. These include sugars, amino acids, and organic acids and are called root exudates. Every plant species leaks a unique signature of compounds from their roots. The quantity and quality of these compounds depends to a certain extent on the soil chemical and physical properties, but in all cases determines the microbial community of the rhizosphere. Symbionts, like the bacteria *Rhizobium* that fix nitrogen in legumes, and disease-causing pathogens may be particularly well-tuned to the composition and quantity of root exudates and be attracted to a particular plant. This means that it is also important to carefully match legume crop species with the appropriate commercial microbial inoculants.

More generally, bacteria and fungi use root exudates and the dead sloughed cells from the root to grow and reproduce, but competition for a space on or near the root is stiff. In the battle for carbon compounds, bacteria often produce antibiotics and poisonous chemicals and gases that remove the competition (which on occasion can also reduce plant growth), and/or plant growth promoting substances that increase root growth, the amount of root area available for colonisation, and root exudates. The sticky secretions from the bacteria in combination with exudates and dead and decaying root cells create tiny soil aggregates and a habitat for scavenging and predator protozoa, nematodes, and mites that feed on the large numbers of bacteria and fungi. In turn, the fecal pellets from these microscopic animals add to the structure of soil and are a rich source of nutrients for bacteria and fungi, and plants. For instance, in greenhouse studies, plants grown in soil with added bacterial- and fungal-feeding nematodes had more shoot growth and a higher yield than plants grown in soil without the nematodes. Mega fauna like earthworms feed in the nutrient rich matrix around the rhizosphere, consuming large quantities of dead plant material, fungi, protozoa, and bacteria. The castings left by earthworms are rich in available nitrogen for plants and bind and stabilise smaller soil particles into larger aggregates, improving soil fertility and structure. Plant roots can move easily through earthworm channels allowing the plant to take advantage of the available nitrogen that lines earthworm burrows. The sticky secretions and webs of fungal hyphae bind smaller soil particles, like those formed by bacteria, into larger aggregates, further improving soil structure.

In review, the rhizosphere is a partnership among the plant, soil, and soil organisms. Plants provide the carbon food source for soil organisms that bind the soil particles into aggregates and recycle soil nutrients, and soil provides the habitat, water, and mineral nutrients for both soil organisms and plants. This means that any factor or soil management technique that changes the amount and quality of carbon going into the soil, as either residue or root exudates, will change the soil biological community. Understanding and then managing rhizosphere processes could have far-reaching advantages in agriculture in terms of increasing plant growth and nutrient uptake and soil habitat structure and health, and reducing the environmental consequences of agriculture.

Management practices that affect the placement and incorporation of residues like tillage can make it harder or easier for the soil organisms responsible for cycling nutrients. Tillage directly affects soil porosity and the placement of residues. Porosity determines the amount of air and water the soil can hold. Placement of residues affects the soil surface temperature, rate of evaporation, water content, nutrient loading, and rate of decay. In other words, tillage collapses the pores and tunnels that were constructed by soil animals and changes the water holding, gas, and nutrient exchange capacities of the soil. Reduced tillage, and particularly direct seeding (no-till), reduce soil disturbance, increase organic matter content, improve soil structure, buffer soil temperatures, and allow soil to catch and hold more melt and rain water. Direct seeding soils are more biologically active and biologically diverse, have higher nutrient loading capacities, release nutrients gradually and continuously, and have better soil structure than reduced or cultivated soils.

Direct seeding dramatically increases the population and diversity of soil animals, particularly soil mites that feed on fungi. Under direct seeding, litter or residue is primarily decomposed by fungi that accumulate nitrogen in their hyphae, and in response, the population of fungal feeding mites increases rapidly, using some of the nitrogen from the fungi and releasing the remainder into the soil to be used by plants and other organisms. Direct seeding systems and rotations with perennial crops or pasture show greater resilience (they can recover faster after disturbances such as drought, flood, or tillage). The populations and species diversity of soil animals are higher, there is more SOM, and nitrogen is recycled into the system at a greater rate compared with conventionally tilled systems.

As more farmers consider the transition to conservation tillage and direct seeding, they must also contemplate the associated transition to low-input agriculture as consumers demand food that has been produced in an environmentally acceptable manner, including organic production. This means that crop species and varieties that do not compete for water, nutrients, and space could limit the productivity in low-input conservation tillage and direct seeding systems. We need to select for crop varieties that are successful in reduced tillage systems that have high soil surface retained organic matter inputs. These crops will need to extract and use mineral nutrients that are made available through soil food webs effectively and efficiently, and should be adapted to inter- and mixed cropping especially in regions where these cropping practices are routine.

In conclusion, creating a soil habitat is the first step to managing soil biota for long-term soil quality and productivity.

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