Soil health: farming to feed microbes

—by Sarah Hargreaves

Healthy Soil Starts with Soil Organic Matter

Soil health is the foundation of resilient agricultural systems. An ambiguous term, my favourite definition of soil health is "*the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality and maintain plant and animal health*".[1]

At the heart of soil health is soil organic matter (SOM), which is stabilized – or stored – in soil aggregates. SOM is important for building and maintaining soil structure, infiltration, water and nutrient holding capacity, and resistance of soil to erosion from wind and water. In essence, SOM turns "dirt" into "soil".

SOM is the heart of soil health and soil microorganisms are its soul

SOM is a mix of living organisms, fresh and actively decomposing organic materials (such as crop resides) and humus.

The formation of SOM is similar to digestion in our guts. Decomposers breakdown dead plants, animals and microbes (think *'food'*): macrofauna physically decompose organic material (think *'chewing'*) and soil bacteria and fungi chemically decompose organic material by releasing enzymes into the soil matrix (think *'digestion'*). As a result, nutrients are made available and taken up by plant roots and microbes (think *'absorption'*). The remaining mostly-decomposed organic matter is stabilized as humus in clumps called aggregates (think *'poo'*). While all types of decomposers are important, fungi and bacteria are the real powerhouses of decomposition because their digestive enzymes release nutrients into the soil, help stabilize aggregates and lead to the formation of humus.

Farming to Feed Microbes

How does what we do on the farm promote SOM formation and its related benefits? While other factors (such as soil properties, parent material, topography and climate) are important — what we "feed" microbes is our biggest influence on SOM formation. That is, what and when we plant and how we manage is how we direct soil health.

Extended crop rotations and cover crops provide a balanced diet for microbes

Links between crop rotations and soil health are becoming clearer. Decades of anecdotal evidence from farmers is now supported by studies that show extended (3+ years) crop rotations, especially those than include cover crops, are the cornerstone to agricultural soil health. A recent meta-analysis of 122 agriculture research studies found that extended rotations increase soil health indicators like total soil carbon by 3.6% (up to 8.5% with cover crops), total soil N by 5.3% (up to 12.8% with cover crops) and microbial biomass by an average 21%![2] Other studies show that the abundance of fungi also increases.[3,4] The reason for this connection is also becoming clear: crop rotations provide a range of plant inputs to feed microbes a plentiful and balanced diet.[5]

Perennial plant cover and grazing feed microbes year-round

Perennial plants and pastures with mixtures of grasses, forbs and legumes are microbes' dream come true. Microbial biomass, including the amount of fungi, is high in well-managed pastures. This is because microbe-root associations and fungal networks in the soil are not broken at harvest; fed year-round, microbes actively produce enzymes to process organic material. Even more, grazing (but not overgrazing!) stimulates root sloughing. Sloughed roots are a perfect source of food

Basic ingredients for soil health

Here are the key factors to think about when farming to feed microbes:

Diversity. Diversity begets diversity, such that plant (and animal) diversity aboveground can increase belowground microbial diversity, abundance and activity. Diverse microbial communities are more resistant to shifts in climate, like drought, and have a better chance of thriving in extreme or novel environmental conditions.[5,13]

Year-round food. Our animals need food year–round and so do our microbes! Given food, some microbes remain active all year. Active microbes decompose organic material, which forms humus and stabilizes aggregates.

Balanced diet. Microbes need a balance carbon sources and nutrients in order to multiply and actively produce the enzymes that decompose organic material.

Fungi. Fungi need carbon and interaction with roots to thrive. Fungal-dominated communities are associated with enhancement of SOM and aggregation and increased nitrogen retention in soils.[9,14]

There is no single recipe for soil health; the greatest benefit is usually seen when multiple soil health-promoting practices are used.

because they contain a balance of easy and less accessible sugars and nutrients.[6,7]

The importance of perennials to microbes is also why cover crops are so beneficial – farmers use annual plants to mimic year-round interactions between plants and microbes.

Carbon-containing fertilizers provide a balanced diet for microbes

A balanced diet for microbes is key to whether fertilizer application enhances or depletes soil health. While fertilizers are applied to soils to feed crops, they also feed microbes. Organic fertilizers, such as manure and compost, contain nutrients (N, P, K and etc.) balanced with carbon. Amending soil with carbon-containing fertilizers helps grow large and active microbial communities and, in turn, leads to the formation of humus and stability of aggregates.[8]

In contrast, inorganic fertilizers, such as anhydrous ammonia and urea, are "unbalanced" because they have no carbon complement. Amending soil solely with inorganic fertilizers fosters a predominance of "addicted" bacteria reliant on inorganic sources of nutrients. This type of community is detrimental to soil health because the community is smaller and less active; microbes rapidly consume nutrients and then lay dormant waiting for the next volley of inorganic inputs.[9]

No-till and no-spray minimize disturbance to microbes

Less soil habitat disturbance lets microbes can better enhance soil health. Tillage disrupts soil structure and fungal networks, and over-stimulates microbes to quickly burn through food sources. No-tillage systems generally have greater SOM, greater microbial biomass and higher ratios of fungi to bacteria. The specific effect of tillage, however, depends on residue removal rates and placement and soil moisture.[10] Spraying chemicals can also interfere with microbial life. For example, glyphosate, a chelator, binds essential minerals in the soil thereby making them unavailable for microbial use and interfering with important symbiotic relationships like nitrogen fixation and mycorrhizal root colonization.[11,12]

Measuring soil health

The health of soil depends on a number of factors so there is no one-way to measure it. Typically, soil health is estimated from a few or many different measurements.

Total soil carbon is a way to estimate soil organic matter.

Aggregate stability measures the resistance of soil aggregates to disruption from outside forces such as water.

Microbial biomass measures the amount of carbon (and nitrogen) stored in microbial cells.

Phospholipid fatty acid (PLFA) analysis measures the ratio of fungi to bacteria.

Mineralization assays measure microbial activity.

Enzyme assays specifically measure activity associated microbial digestion/decomposition.

Combination tests, such as the Haney test, measures soil health as a sum of tests about the soil, microbial community and microbial activity.

Within farms and between farms, soils are different. This heterogeneity makes it hard to interpret soil health indicators from a single measurement. To get a reliable picture of soil health it is best to take multiple measurements.

Depending on your specific question, multiple measurements might be best taken (1) over time – like after you change management practices or crop rotation, (2) within a single farm – to compare current practices or rotations, or (3) across farms – to compare a new practice on your farm to other practices in the same general area.

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References

[1]Doran, J. W., and M. R. Zeiss. 2000. Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology,15:3–11.
[2]McDaniel, M. D., et al. 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? a meta-analysis. Ecological Applications, 24:560–570.
[3]Gonzalez-Chavez, M.D.C.A., et al. 2010. Soil microbial community, C, N, and P responses to long term tillage and crop rotation. Soil Tillage Research,106: 285–293.
[4]Suzuki, C., et al. 2012. A DGGE analysis shows that crop rotation systems influence the bacterial and fungal communities in soils. Soil Science and Plant Nutrition, 58, 288–296.
[5]Tiemann, L. K., et al. 2015. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. Ecology Letters, 18:761–771.
[6]de Vries FT, et al. 2007 Fungal biomass in pastures increases with age and reduced N input. Soil Biology and Biochemistry, 39:1620–1630.
[7]Hargreaves, S.K. and K.S. Hofmockel. 2014. Physiological shifts in the microbial community drive changes in enzyme activity in a perennial agroecosystem. Biogeochemistry, 117:67-79.
[8]Kallenbach, C., and A. S. Grandy. 2011. Controls over soil microbial biomass responses to carbon amendments in agricultural systems: A meta-analysis. Agriculture, Ecosystems & Environment, 144:241–252.
[9]Ramirez, K. S., et al. 2012. Consistent effects of nitrogen amendments on soil microbial communities and processes across biomes. Global Change Biology, 18:1918–1927.
[10]Six, J., et al. 2006. Bacterial and Fungal Contributions to Carbon Sequestration in Agroecosystems. Soil Science Society of America Journal, 70:555.
[11]Zobiole, L.H.S., et al. 2010. Effect of glyphosate on symbiotic N_2 fixation and nickel concentration in glyphosate-resistant soybeans. Applied Soil Ecology, 44:176-180.
[12]Druille, M., et al. 2013. Glyphosate reduces spore viability and root colonization of arbuscular mycorrhizal fungi. Applied Soil Ecology, 64:99-103.
[13]Griffiths, B.S., et al. 2000. Ecosystem response of pasture soil communities to fumigation-induced microbial diversity reductions: an examination of the biodiversity–ecosystem function-relationship. Oikos, 90, 279–294.
[14]de Vries, F. T., and R. D. Bardgett. 2012. Plant–microbial linkages and ecosystem nitrogen retention: lessons for sustainable agriculture. Frontiers in Ecology and the Environment, 10:425–432.