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Assessing Soil Health for Tree Fruit and Vine Crops

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What is soil health?

The objective of this presentation is to present information on the types of measurements of soil biological properties that might be useful as bio-indicators of soil health. First, however, it is necessary to discuss what soil health means. Scientists, farmers and land managers have long known that there is more to the productive capacity of soil than what can be predicted from knowledge of parent material, texture, chemical properties and available levels of macro and micronutrients. It was also widely understood that soil biology was the missing element from earlier research to understand the productive capacity of soil, and that it would be beneficial to begin thinking of the soil as an ecosystem in which productive capacity arises from the interaction of biological interactions and processes with soil physical and chemical properties. Consequently, the concept of soil ecosystem health arose in the 1990's, and the following "textbook" definition has come to be the most widely accepted definition of soil health: "*The continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health*" (Doran and Safley 1997).

Most growers of perennial fruit crops have an intuitive sense of soil health because they are well aware of the declines in soil productivity that often occur with long-term cultivation to a particular crop, particularly when management practices do not include regular use of cover crops or applications of manures or composts. This decline in productivity is often observed despite careful nutrient-fertilizer management, so growers are also often aware that there is more to the decline in productivity than reduced availability of N, P and K. Through the years, this syndrome has been given various names such as "soil sickness" or "tired soil". "Healthy soil" is conceptually the alternative to sick soil or tired soil. In the case of perennial fruit crops, particularly tree-fruits, the well-recognized "replant disease syndrome" is a particular manifestation of poor soil health. Indeed, some researchers have begun using the term soil health synonymously with the replant disease syndrome (Manici et al., 2013).

The factors contributing to poor soil health include deleterious changes in soil biology which are ultimately the result of excessive tillage, pesticide use and inadequate or inappropriate inputs of organic matter to sustain diverse and active soil food webs. These deleterious changes in soil biology can include (1) the loss of beneficial root-microbe interactions or processes such as mycorrhizal symbioses, N fixing symbioses, or cycling of nutrients within the soil biomass; (2)

the development of root pathogen complexes; or (3) some combination of decline in beneficial interactions and increased prevalence of pathogenic interactions.

In addition to the biological interactions and processes that directly affect nutrient availability or plant health, soil health is also a function of important soil physical and chemical properties that are mediated by soil biological activity. Perhaps the most important of these biologically-mediated physical properties is soil structure. The formation of stable soil aggregates makes soil more granular and porous, which improves the distribution and retention of water and air, and reduces resistance to root growth. These are the soil properties that are collectively known as "tilth". Soil bacteria exude extracellular polysaccharide slimes that function as glues, binding clay and silt particles together into aggregates. Fungal hyphae further reinforce such aggregates and tie micro-aggregates together into macro-aggregates. Arbuscular mycorrhizal fungi have a particularly important influence on soil aggregate formation as they also exude a glycoprotein (sugar-protein) called glomalin that is a particularly effective and ubiquitous glue for aggregate formation. Aggregates are also formed as soil passes through the earthworm gut where particles are coated with mucilage (slime). The worm castings are in-turn hotspots for subsequent microbial activity, and they appear to have specific root growth stimulating effects (Tomati et al. 1988). Finally, the soil macrofauna, which includes beetles and various grubs in addition to earthworms, form macropores as they burrow through soil, which further improve porosity and drainage. The relationships between organic matter inputs, soil biological activity and changes in soil properties, processes and interactions are represented in Figure 1.

One of the difficulties in identifying general indicators of soil health is that the relative importance of these many different factors contributing to soil health varies among production systems and scenarios. For example, past research suggests that for orchards planted on coarse-textured and therefore "unstructured" soils, the buildup of root pathogens, particularly root-lesion nematodes, often has a stronger influence on orchard replant success than sub-optimal soil structure or limited nutrient availability (Mazzola and Manici, 2012).

Indicators of soil health

It is not possible to manage for improved soil health without being able to assess it. The ultimate measures of improved soil health are increased soil organic matter, improved root growth and sustained production of quality fruit with minimal inputs. These responses can be slow to change, however, and it is desirable to have some other parameters that are *indicative* of overall soil health but change more rapidly than total soil organic matter and productivity. "Indicators" are parameters that are relatively easy to measure and are associated with improved overall soil health, but are also more sensitive to change than total soil organic matter and actual crop productivity. Because soil biology is central to soil health, it seems logical that measurements of soil biological properties, i.e. "bio-indicators" may be the most appropriate parameters to use for monitoring change in soil health.

A multitude of biological properties have been proposed to be indicative of overall soil health (Table 1). This list can be broken down into measurements of (1) organic matter fractions and biomass, (2) biological activity, and (3) measurements of biological diversity, community structure or measurements of specific organisms or even genes that are associated with a specific interactions (e.g. N-fixing bacteria, mycorrhizae) or process (e.g. nitrification). Important criteria in the choice of good bio-indicators include ease or cost of measurement, reproducibility, how prone the parameter is to extreme spatial and temporal variation, and how well it reflects the complex attribute of overall soil health.

Most potential bio-indicators exist on a continuum from general to specific that generally corresponds to a continuum from easy to difficult and inexpensive to expensive (Figure 2). Parameters on the general end of the spectrum, such as microbial biomass or active carbon (the small fraction of total organic matter that fuels microbial activity), are not always indicative of specific root-microbe interactions such as suppression of specific plant pathogens that may be particularly important for certain production systems or scenarios. For example, while increased gross microbial biomass and measurements of gross microbial activity have been associated with suppression of some soil-borne fungi, there does not appear to be a direct relationship between increased gross microbial biomass or activity and the suppression of root-lesion nematodes. Consequently, it would not be wise to make assumptions about the potential for replant stress (a manifestation of soil health) on the basis of a measurement of microbial biomass. On the other hand, microbial biomass is a good indicator of biologically-mediated improvements in soil structure and the cycling of nutrients because nearly all organisms in the soil contribute to aggregate formation, and nutrients cycle into and out of the biomass as a whole, not just specific species or groups. As well, increased organic matter inputs that drive increased microbial biomass also foster increased populations of earthworms. Just as the general indicators may not always represent the full spectrum of factors contributing to soil health (which will vary among production systems and scenarios), the more specific indicators may represent a specific process or interaction well, but not the more general processes such as aggregate formation.

In my opinion, the more general indicators, such as labile organic matter (which is the fraction of organic matter that drives microbial activity), microbial biomass and mineralizable nitrogen (a measure of the amount of nitrogen in the microbial biomass) are the most useful general indicators. This is because (1) they are relatively easy to measure in a standardized way which makes it easier to compare results from different labs; (2) they are relatively inexpensive and do not require particularly specialized personnel or equipment; and (3) they are generally not as prone to wild temporal (e.g. date-to-date) and spatial variation as some other indicators. The suite of general indicator measurements offered in the Cornell Soil Health Assessment package (http://soilhealth.cals.cornell.edu/) covers labile organic matter, microbial biomass and mineralizable nitrogen. As indicated above, however, these general indicators are limited in that they are not always indicative of specific interactions or processes that may be more or less important in different production systems and scenarios. Depending on their scenario, growers, consultants and land managers may wish to supplement measurements of these general indicators with more specific analyses specific to their situation in order to get a more complete picture of the factors contributing most to soil health-productivity in their situation. In the specific example of the orchard soil health, i.e. apple replant syndrome, measurement of the general soil health indicators listed above should be complemented with a specific replant assay and/or a nematode analysis.

References

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Figure 1. Diagram of relationships between organic matter inputs, the decomposer food web (soil biomass) and its influence on components of soil health.

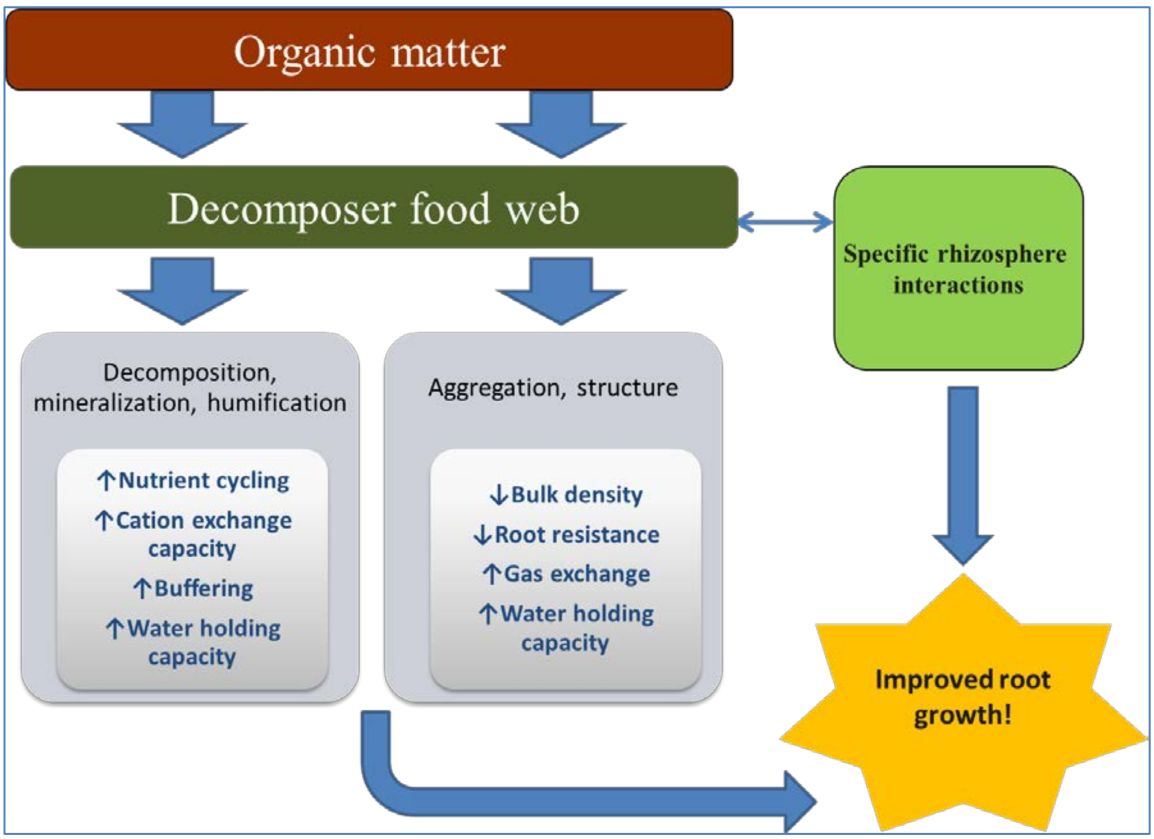

Table 1. Abbreviated list of biological measurements that have been proposed for use as bio-indicators of soil health.

Organic Matter and Biomass	**Biological Activity**	**Diversity-Community Structure**
Total soil organic matter	Respiration (e.g. Solvita®)	Nematode community structure indices
Active fraction organic matter (e.g. particulate organic matter, permanganate-oxidizable carbon)	N mineralization	Earthworm counts
Fulvic acid/Humic acid ratios	Enzymes (e.g. FDA, dehydrogenase, phosphatase)	
Polysaccharides, glomalin	Community level physiological profiles (e.g. BioLog EcoPlate ®)	Phospholipid fatty acid profiles
Microbial biomass		DNA-PCR based approaches for overall diversity (e.g. deep sequencing/ metagenomics/ pyrosequencing)
B:F biomass ratio		DNA-PCR diagnostic arrays for specific organism groups (e.g. pathogens)
		DNA-PCR based arrays for specific groups of genes (e.g. nitrification, denitrification)

Figure 2. Schematic of some general differences between general and specific bio-indicators.