Soil health: Assessing and monitoring using soil biology

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Emily Warrender

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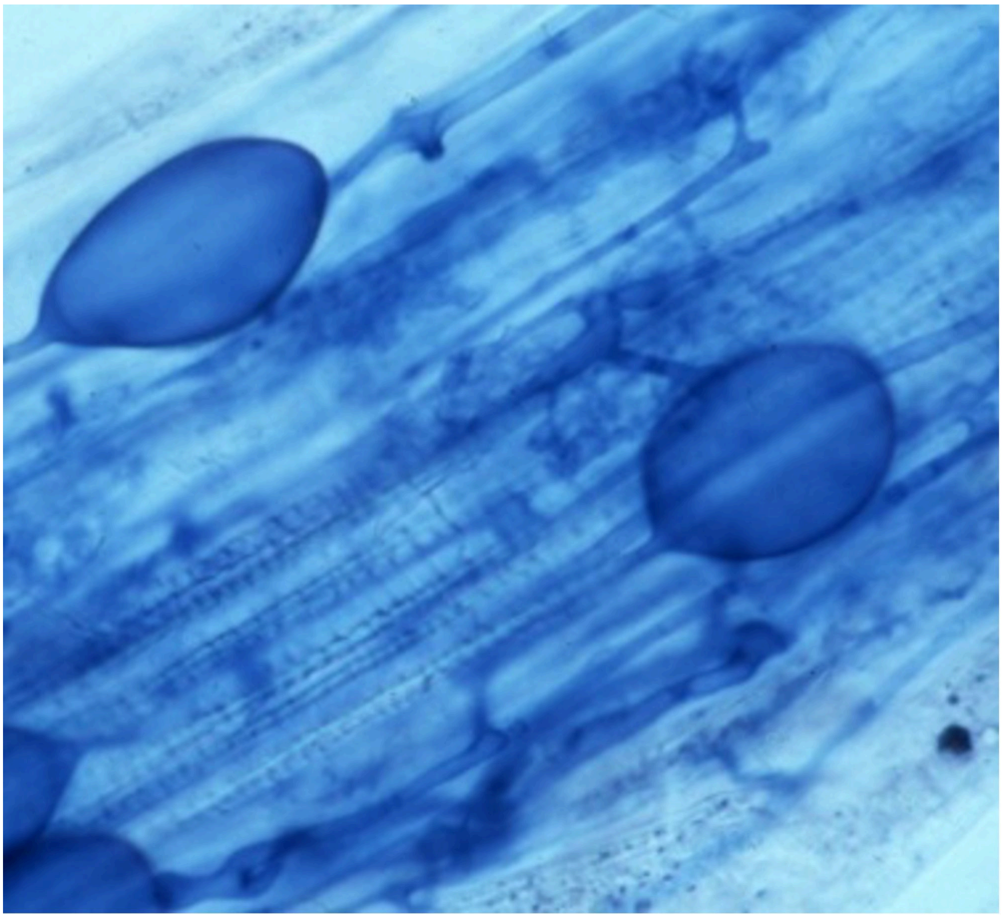
Soil Fungi - image: © UWA Institute of Agriculture Perth, Western Australia

Lynette Abbott from The University of Western Australia, focuses again on soil health, this time by assessing and monitoring using soil biological indicators

There is considerable interest in monitoring and quantifying soil biology as an indicator of soil health. [1] However, this is a complex task because of (i) the extreme diversity of soil organisms [2], (ii) the wide range of processes they participate in within soil, (iii) their heterogeneous distribution within the soil profile, (iv) their heterogeneous distribution within the soil matrix, and (v) because their abundance and activity can be very responsive to their surroundings.

Mushrooms – image: © UWA Institute of Agriculture Perth, Western Australia,

While it is possible to quantify soil organisms, their presence in soil does not necessarily correspond with their activity at any point in time. Different soils naturally have different communities of soil organisms that carry out similar functions. Some soils have different quantities of soil organisms due to their inherent structure [3] – for example, sandy soils may have lower levels of soil organisms than more clayey soils. Therefore, quantification of soil organisms as indicators of soil health is not black and white, or a simple matter of one-off measurement.



Arbuscular mycorrhizal fungi in roots – image: © UWA Institute of Agriculture
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Understanding soil locally is important for interpreting soil biology measurements in the context of soil health indicators. Many different components of soil biology can be measured, but some values are time-dependent or soil-type dependent. Therefore, understanding local soil communities is essential. Many measurements require complex equipment and are expensive, while some are simpler and can be carried out on-farm.

Root nodules containing rhizobia (bacteria)
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Relationships between soil biology measurements and soil health (4) may be site-specific. While this constraint may seem unnecessarily complicated, there are reasons for this. Local knowledge, combined with monitoring a few soil biology assays, can provide a good indication of how land management practices influence soil conditions in one paddock compared to another. Some practices increase 'soil health' while others decrease 'soil health'. These fluctuations are normal and provide important information about ongoing soil and land management decisions.

A. Soil biology quantified as specific organisms	
Bacteria	Bacteria are the most diverse group of soil organisms. Many bacteria cannot be isolated and grown in laboratory conditions. They are microscopic and include communities involved in organic matter breakdown (heterotrophs), symbiotic nitrogen-fixing bacteria (e.g. rhizobia), bacteria involved in nitrification (autotrophs), and bacteria that cause root disease (e.g. some potato rots). Bacteria can be identified and quantified using DNA-based tools.
Fungi	Soil fungi are very diverse. Many cannot be isolated and grown in laboratory conditions. Most form microscopic hyphae, some form visible structures (e.g. mushrooms), some form symbiotic associations with plant roots (e.g. arbuscular mycorrhizal fungi [5]; ectomycorrhizal fungi; orchid symbionts), and some cause root disease (e.g. wheat root diseases). Specific kinds of fungi can be identified and quantified using DNA-based tools or microscopy.
Soil microfauna	Soil microfauna include protozoa and nematodes. These microscopic organisms live in soil pores within water films. Nematodes have different life habits, including free-living members of the soil community, some cause root disease (e.g. galls), and others prevent plant disease. Nematode communities make wide-ranging contributions to soil health and can be identified and quantified using DNA-based tools or microscopy.
Soil mesofauna	Mites and springtails are the dominant soil arthropods, with important roles in nutrient cycling during the degradation of organic matter. Other mesofauna in soil include enchytraeids (potworms). Some soil mesofauna can be identified and quantified using various forms of Baermann funnels and microscopy.
Soil macrofauna	The larger soil faunal communities are dominated by earthworms [6], termites and ants. Burrowing activities improve soil structure, and form pathways for root growth and water infiltration. They contribute to nutrient cycling. Earthworms, spiders and larger insects can be identified and quantified after sieving soil.
Plant pathogens	Various kinds of bacteria, fungi and nematodes can cause root disease. They can be assessed using DNA tests (for identification), bioassays (to assess disease-causing potential), and root scores (to quantify disease level).

B. Soil biology quantified as groups of soil organisms	
Microbial biomass	Microbial biomass includes the total amount of soil organic matter in living cells of soil organisms. It is assessed as the amount of carbon, nitrogen, phosphorus or sulphur in living soil organisms using laboratory tests.
Fingerprinting diversity of soil bacteria by sequencing DNA	Bacterial DNA can be sequenced to identify the relative abundance of different phyla, families, genera and species, as well as indices of bacterial community richness.
Fingerprinting diversity of soil fungi by sequencing DNA	Fungal DNA can be sequenced to identify the relative abundance of different phyla, families, genera and species, as well as fungal community richness indices.
Fingerprinting microbial genes involved in carbon cycling	Microbial DNA can be sequenced to identify the abundance of genes involved in carbon cycling by breaking carbon bonds in molecules such as lignin, chitin, cellulose, hemicellulose and starch derived from plants.
Fingerprinting microbial genes involved in nitrogen cycling	Microbial DNA can be sequenced from soil communities to quantify genes involved in transformations of different forms of nitrogen, including ammonification, nitrification, denitrification and nitrogen fixation.
Quantifying arbuscular mycorrhizal (AM) fungi [5] in roots and soil	The length and proportion of roots colonised by AM fungi can be assessed after staining the fungi and scoring them under a dissecting microscope. DNA tools are also available to quantify AM fungi in roots and in soil.
Fatty acid signatures of groups of fungi and bacteria	Distinctive signatures of fatty acid molecules can be matched to certain soil fungi and bacteria, enabling quantification of key organisms in soil microbial communities.
Fungal/bacterial ratios	There is an interest in assessing the proportion of fungi to bacteria as a means of monitoring the impacts of land management on soil health.

The soil monitoring plan

Armed with a basic understanding of how management practices influence soil organisms, **a monitoring plan** can be developed. There are many different organisms in soil. They cannot all be monitored; therefore, a selection can form the basis of monitoring that considers changes in season, rotations, land management, fertiliser use and grazing practices, etc.

Soil Mites – image: © UWA Institute of Agriculture Perth, Western Australia,

The **monitoring plan** for particular organisms, groups of organisms or biological processes, will include standard sampling times (based on likely seasonal effects), how sampling is done (based on depth in the soil profile and likely variability across the site), and how often samples are collected (based on an understanding the life cycles of soil organisms and rates of biological processes). Monitoring in a consistent manner, using the same methodology, is important so that variability is minimised.

Earthworm- – image: © UWA Institute of Agriculture Perth, Western Australia,

Soil organisms are extremely diverse and vary greatly in size and abundance within the soil. Therefore, specific methodologies are required for different kinds of soil organisms. Examples in the tables include A. soil biology quantified as specific groups or individuals, B. soil biology quantified as groups of soil organisms, C. soil biology quantified as soil biological fractions, and D. soil biology quantified as processes carried out by soil organisms.

C. Soil biology quantified as soil biological fractions	
Soil carbon, soil carbon fractions	Quantification of soil carbon relative to soil type and land management can be used to monitor impacts of land use on soil health. Changes in the relative proportions of different fractions of soil carbon can be used to track changes in soil health conditions.
Potentially mineralisable soil nitrogen	Mineralisable soil nitrogen is the nitrogen in soil organic matter that is accessible for degradation by soil organisms and indicates its potential availability to plants.

D. Soil biology quantified as processes carried out by soil organisms	
Soil respiration	A measure of carbon dioxide release during the breakdown of organic matter in soil.
Greenhouse gas production	A measure of the release of methane and nitrous oxides during nutrient cycling.
Ammonification	A measure of NH_4^+ release during organic matter breakdown.
Nitrification	A measure of the release of NO_3^- during nitrification.
Denitrification	A measure of the release of nitrous oxides from soil.
Enzyme activity	A measure of the functioning of genes for specific enzymes.
Soil aggregation	The degree of stability of soil aggregates can be measured, and this involves the activities of some soil bacteria and fungi.
Water repellence	The rate of water infiltration in soil can be assessed to indicate water repellence, sometimes caused by certain fungi.

After quantifying selected measures of soil biology, the next step in the **monitoring plan** is to interpret the data in the context of their value as indicators of soil health. The most important consideration is the rate of change of the measurements of soil biology monitored in relation to land management practices. This requires an understanding of local factors, including soil type and weather.

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Primary Contributor

Lynette Abbott
The University of Western Australia
ORCID: 0000-0001-8586-7858

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