TECHNICAL NOTE 721 April 2019 • ELEC

Soil Biodiversity and Soil Health

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Summary

- **Soil biodiversity is the variety of living organisms within a soil.**
- **A healthy soil will contain a large number and variety of organisms (i.e. have a high biodiversity) which will interact to provide a wide variety of ecosystem services.**
- **Increasing biodiversity will increase the resilience of the soil to environmental challenges.**
- **It is important that the biological, physical and chemical aspects of the soil are in balance to encourage soil biodiversity.**
- **Good soil health means sustainable agricultural output.**
- **There are a number of steps you can take to measure and improve soil biodiversity and soil health.**

Introduction

Biodiversity is a word that has acquired extra connotations through common use. It is actually a short form of 'biological diversity' and is simply the number and proportion of different species present. That in itself is not particularly useful to know as your soil could have great biodiversity, but if the species present are harmful or not efficient then your soil will not function well. The potential biodiversity in soil is spectacular. It is estimated that in excess of a quarter of all species on Earth exist in soils (Table 1).

Table 1 - Estimated diversity and abundance of soil organisms per square metre

Taxon (organism group)	Biodiversity (maximum number of different species per square metre of soil)	Abundance per square metre of soil (approximate maximum number of individual organisms)
Prokaryotes (bacteria)	9,000	200 trillion
All Fungi	200	1 million
Mycorrhizal Fungi	20	800,000
Protists	1,200	10 million
Nematodes	100	9 million
Enchytraeids (potworms)	15	300,000
Collembola (springtails)	20	50,000
Mites (Oribatida)	150	100,000
Isopoda (woodlouse)	100	10
Diplopoda (millipedes)	2,500	100
Earthworms (Oligochaeta)	15	300

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There are potentially more than 13,000 different species per hectare in your field (mainly bacteria) with a total weight of some 5 tonnes ha^{-1} in an arable field. A more useful description of this biodiversity is how balanced the species are within the soil food web. There is a natural hierarchy of organisms based on 'who eats who' (Figure 1) with a tendency for the biodiversity and abundance of organisms to decrease at higher trophic levels (so, few species and low numbers of predaceous mites, more species and moderate numbers of bacteriophagous nematodes, many species and huge numbers of bacteria). Therefore, as in Table 1, there are far more bacteria and fungi, which are the primary decomposers of organic matter in soil, than predatory organisms which feed on the animals that consume the bacteria and fungi.

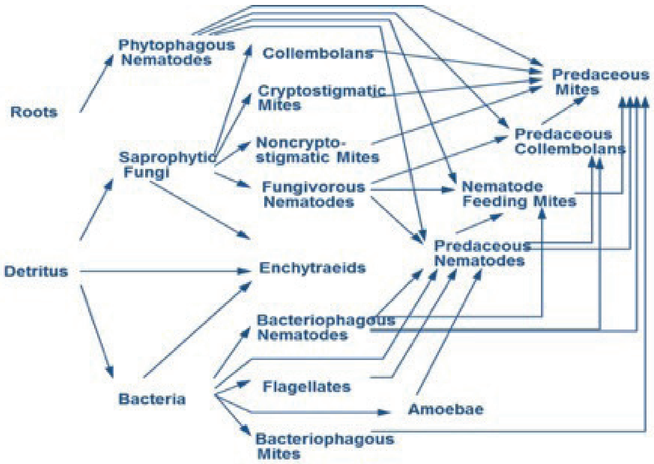


Figure 1. Diagrammatic representation of the soil food web. The arrows reflect the flow of carbon and nutrients through the soil.

Detritus (organic matter such as dead roots, ploughed in stubble, added manure) is the main source of food and energy and is decomposed primarily by bacteria and fungi, who are then consumed by small animals and so on through the food web. Although earthworms operate at a larger scale they create soil conditions that encourage a healthy food web.
This food web organisation is important in the delivery of what are known as ecosystem services. Soil organisms will:

- control plant pests and diseases (natural enemies and predators will keep pathogen populations in check);
- decompose organic matter (this makes nutrients available for plant growth);
- improve soil structure (generation of pores by earthworms, incorporation of organic matter to deeper layers, enmeshing and binding of soil particles by fungi, gluing particles together by bacterial polysaccharides);
- improve plant growth and nutrition (mycorrhizal fungi are more efficient at accessing soil P than roots, growth-promoting-rhizobacteria access micro-nutrients);
- sequester carbon (important in maintaining soil organic matter levels and mitigating climate change);
- detoxify contaminants (microbial activity can breakdown toxic chemicals and reduce organic contamination leaching to water courses).

The biodiversity in the food web represents just the biological aspects of the soil. There are also physical and chemical aspects, and to have soil in 'good heart' you need the balance of biology (biodiversity), physics and chemistry (Figure 2).

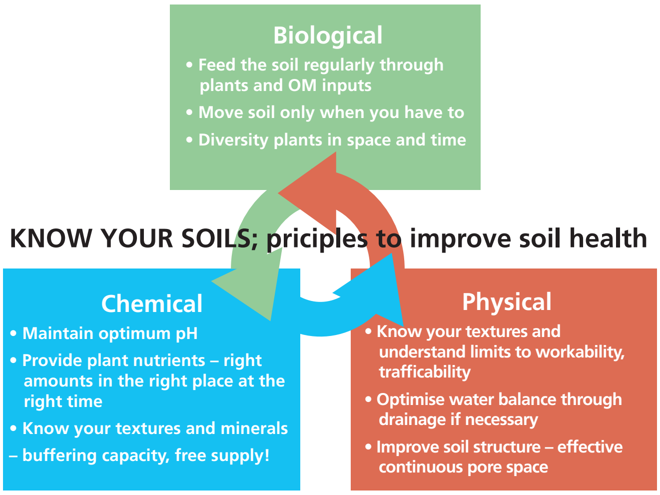


Figure 2. The interaction between physical, chemical and biological components of the soil is key to maintaining soil health and encouraging soil biodiversity.

Measuring soil health might seem a daunting prospect, with 13,000 different species to measure in addition to the physics and chemistry, but there are a small number of key indicators that can be measured in addition to your routine nutrient analyses to give you a measure of soil health. These indicators can be used to provide a soil health scorecard which integrates the physical, chemical and biological aspects to give a snapshot overview of soil health, akin to an MOT or end of school report.

Soil health indicators

Physical health

Soil texture is the physical composition of the soil: the percentage of sand, silt and clay. Soil texture is a stable property so it is not possible to change your soil texture, but it is useful to know soil textures across your farm as it can vary greatly and will influence how best to manage them. Soil structure is the size, shape and hardness of the crumbs and lumps that make up the soil. A well-structured soil allows plant roots to grow freely, water to move through the soil profile and gases to exchange with the atmosphere. Problems with soil structure such as compaction, poaching and capping can prevent plants from rooting properly and accessing nutrients, which in turn can reduce productivity. These problems also lead to increased soil erosion and promote the production of the potent greenhouse gas nitrous oxide (N_2O). Soil structure can be assessed using a test called the Visual Evaluation of Soil Structure (VESS). It is worthwhile digging a spade of soil in your fields to familiarise yourself with soil structure, and it can highlight problems such as compaction (Figure 3). Further information on assessing soil structure and the VESS guide can be found at https://www.fas.scot/publication/a-guide-to-the-visual-evaluation-of-soil-structure-vess/

Figure 3. Sampling a block of soil for the VESS test.

Chemical health

Soil chemistry covers those elements and compounds that are directly beneficial for plant growth, such as major nutrients (e.g. nitrogen, phosphorus, potassium, sulphur), micro-nutrients (e.g. boron, selenium) and growth promoters (i.e. plant hormones). In addition it includes the general chemical environment resulting from pH and cation exchange capacity (CEC) that indirectly influence chemical availability and those agrochemicals such as herbicides and pesticides that may end up in the soil.

Having your soil pH within the optimal range for the particular soil and crop type is probably the single most important factor to get right to maintain soil health and crop productivity. CEC is a technical measure of the soils ability to release nutrients into solution that is used in some soil tests.

Routine testing for soil chemistry will give a rapid assessment of soil nutrient status and how much should be added to the field to optimise plant growth. The same samples are usually also analysed for pH, which technically is a measure of the concentration of hydrogen ions in the soil with more hydrogen ions giving a lower pH or a more acid soil. Plant roots can only access nutrients that are dissolved and present in the soil water (i.e. are available) and the availability of many nutrients depends on an interaction between soil texture (clay soils have more exchange sites where nutrients can be chemically bound to the clay particles than sandy soils) and the pH (hydrogen ions can swap places with other chemicals making them more available). A problem arises if there are too many hydrogen ions present (the soil has too low a pH) because the hydrogen ions swap with ions such as aluminium that are toxic to plants. At the opposite end of the scale too high a pH, reflecting low concentrations of hydrogen ions in alkaline soils, limits the availability of some nutrients and so also reduces plant growth (Figure 4).

Agrochemicals, such as pesticide residues, are generally unwanted in soil. Additionally, they are at risk of being washed into watercourses and may have unforeseen side-effects on soil organisms. Agrochemicals are tested for their environmental safety before release, but because of the complexity of interactions in the soil it is hard to predict all the possible outcomes. Also, agrochemicals accumulating in soil means that they are not where they need to control pests, diseases and weeds.

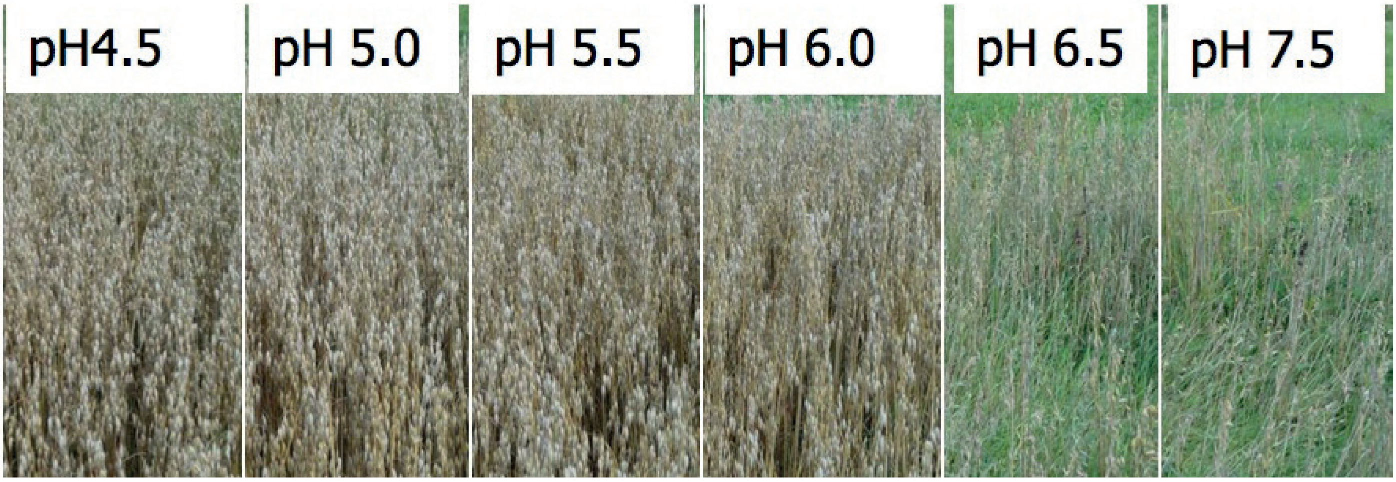


Figure 4. Oats, growing in the controlled pH plots at SRUC Craibstone, can tolerate acid soils but growth is severely limited in alkaline soils.

Biological health

Biological health is concerned about the health of the food web (Figure 1), which includes the effects of earthworms as their activity creates conditions in which the food web thrives. Earthworms are a useful indicator of soil biological health, and are easy to count in the soil block when carrying out a VESS assessment of soil structure. There are readily available keys and guides to identify the species of earthworms in your soil if you are interested to learn more (https://www.opalexplorenature.org/earthwormguide), but a simple count is a good way to start and is sufficient to give an indication of soil health. A healthy arable soil would normally have 5-10 earthworms in a 20 x 20cm square of soil dug to spade depth. Earthworms have been shown to have a positive effect on crop yield.

Other soil animals along with the bacteria and fungi, that are the most abundant organisms in soil, are too small to readily count and identify, and are typically analysed in a laboratory. Besides the organisms present in the soil, their activity or what they do is also a vital component of soil health. They are responsible for innumerable functions in soil, converting complex organic molecules into simple inorganic nutrients that plants can absorb, controlling pests and diseases, stimulating root growth, and many others. Most of their activities are too complex to measure easily and quickly, but measures of general activity (either respiration or potentially mineralisable nitrogen) are included in many soil health tests.

In addition to soil organisms, soil organic matter is an essential part of good soil biological health and can be defined as all living or once-living materials in the soil, such as roots, incorporated stubbles and straw, and added manures, slurries and composts. Soil organic matter increases soil stability, drainage, fertility and encourages biodiversity. Many organisms living in the soil feed on soil organic matter and fresh plant residues can boost soil biodiversity. Soil organic matter can be tested in a laboratory using a well-mixed representative sample taken from multiple points across a field as part of a routine nutrient/pH test. It is useful to take samples over several years to monitor changes in soil organic matter content, however it is important that samples are taken at a similar time of year and place in the rotation.

Measuring soil health rather than soil biodiversity

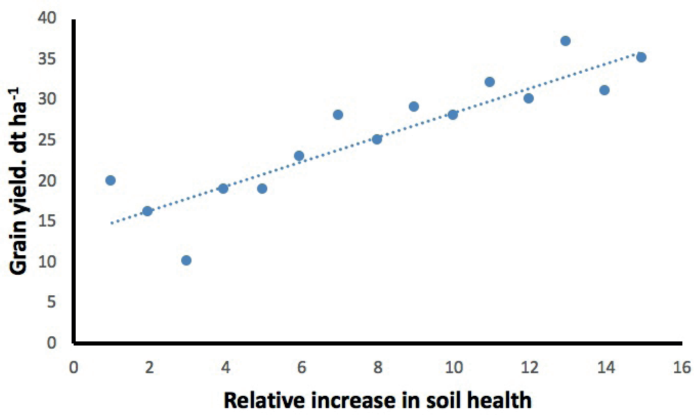
There are some simple measurements that you can take yourself and help keep your own log of soil health. These include spade tests such as the VESS and earthworms, already mentioned. More information about 'do-it-yourself' tests can be found at https://ahdb.org.uk/greatsoils. There are apps now available for your smart phone or tablet to help you document soil health yourself, such as https://soils.sectormentor.com/ or https://www.bgs.ac.uk/mysoil/. Soil health tests are also provided by commercial analytical laboratories, such as NRM (http://www.nrm.uk.com/services.php?service=soil-health) and FERA (https://www.fera.co.uk/crop-health/soil-health), as well as agronomy consultants such as SAC Consulting (https://www.sruc.ac.uk/soiltest)and Hutchinsons (https://healthysoils.co.uk/). The SAC Consulting soil health test has the ability to benchmark soil health against expected values for your particular soil type and crop system.

This lets you see how healthy your soil is compared to how healthy it potentially could be. All the tests, whether commercial or 'do-it-yourself' allow benchmarking over time, which is important for finding out whether current management practices are sustainable and/or whether any recent management changes are having the desired effect on soil health.

Improving soil biodiversity and soil health

There is growing evidence that increased inputs of organic matter and reduced tillage act together to promote increased biological activity and that resilience to extreme events may be improved as a result. Recent studies show statistically significant correlations between improved soil health and increased crop yield (Figure 5).

Figure 5. Redrawn from Mueller et al (2018) Yield of small grain cereals in relation to soil health from a series of trials at 50 locations across Eastern and Central Europe.



There are a number of steps you can take to improve or maintain both soil biodiversity and soil health (Figure 6).

These fall into three categories that are not mutually exclusive, so a combination of all three will have additive effects:

1. *Reducing tillage.* Conventional inversion tillage is generally detrimental to soil biology. It is disruptive to earthworm channels, breaks fungal hyphae, re-organises the distribution of organic matter in the soil and reduces soil biodiversity. Tillage tends to shift the food web towards a bacterial dominated system that encourages rapid turnover of nutrients and decomposition (when a slower fungal dominated system is widely held to provide more continuous and sustainable release of nutrients). Inversion tillage does have its uses though, it is good for weed control and can alleviate compaction, albeit with a cost in fuel and time. Reducing the intensity of tillage, with techniques such as minimum tillage, strip tillage and no-till or zero tillage, encourages soil biodiversity and soil health.

2. *Increasing soil organic matter, or feeding the soil.* Inputs of organic matter to soil, whether as added material (manures, digestates, straw, slurry, crop residues) or from living plants (a growing annual crop, green manure, cover crop, grass ley, perennial crop) positively affect all three components of soil health: the physics, the biology and the chemistry. It is not only the quantity of organic matter added that is important, the quality is crucial as well. Material that is rich in nitrogen (has a low C:N ratio), such as green crop residues and cattle slurry, also tends to have the carbon present in chemical forms that are relatively easy for the microorganisms to break down, such as cellulose, proteins and amino acids. This will favour rapidly growing organisms from the bacterial-energy channel in the soil food web and will give a rapid boost to nutrient availability. Material rich in carbon (has a high C:N ratio), such as straw and brown crop residues, tends to have that carbon present in strong, structural forms such as lignin and ligno-cellulose complexes. This makes it harder to decompose and favours the fungal energy channel in the food web. This material will have more of an effect on soil physical structure and providing a long-term resource for soil biodiversity. Crop rotations also fall into the category of increasing soil organic matter. A diverse crop rotation will provide a diverse input of different forms of organic matter, albeit over a number of seasons.

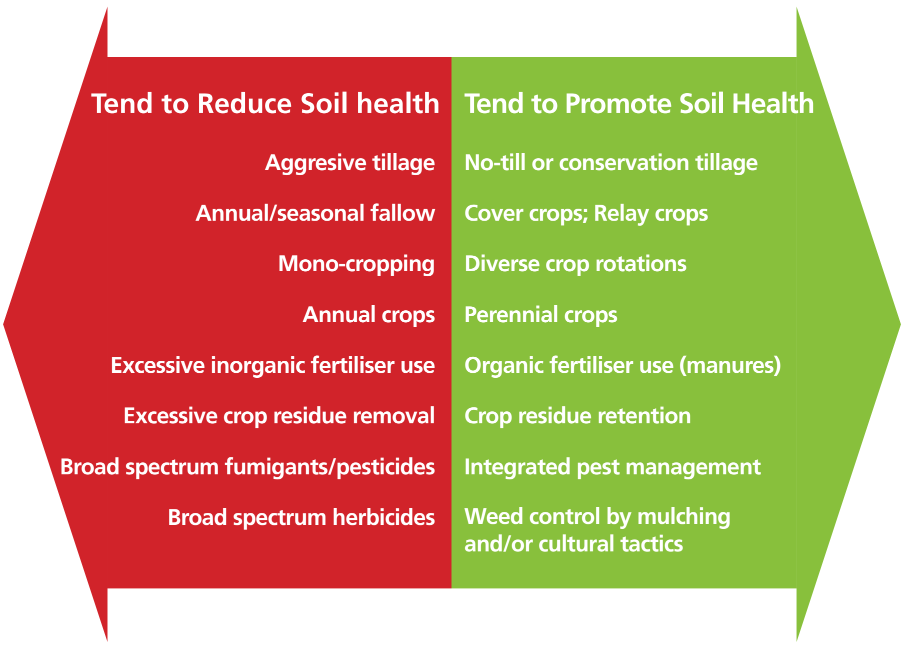


Figure 6. Management practices that reduce or improve soil health.

Thus, the soil is not just getting continual inputs of the same resource (i.e. continuous cereal stubble) but a more complex mixture of different crop residues even more so if there are livestock in the rotation. A more diverse food supply translates into increased soil biodiversity and soil health.

3. *Integrated pest and weed management.* Integrated pest and weed management is the optimal mix of biological, chemical, physical and cultural control techniques. By using a combination of measures you can often get greater control before pests reach a critical level, and reduces the reliance on pesticides to treat the issue after it has occurred. Biological techniques include plant resistance/tolerance, variety choice, natural enemies and elicitors. Chemical control in the form of pesticides and seed treatments is commonly used in conventional agriculture. Physical control techniques include crop residue management, rogueing and ploughing weeds. Cultural techniques include crop rotation, pest identification and monitoring, record keeping, action thresholds and nutrient and water management. In order for integrated pest and weed management to be a success it is essential to understand the biology of the pest/disease/weed you are trying to control. You can then assess the risk and select suitable combinations of control measures to tackle your specific set of issues. It is worthwhile to keep monitoring the problem, evaluating control measures and keeping records to create a whole farm plan for pest control.

Reference

Mueller, L., Eulenstein, F., McKenzie, B.M., Schindler, U. and Mirschel, W. (2018). Tillage depth and crop yields: re-evaluation of late holocene soil tillage trials in Eastern and Central Europe. Vol. 4. Optimising Agricultural Landscapes. In: Novel methods and results of landscape research in Europe, Central Asia and Siberia (in five volumes). Publishing House FSBSI, Pyranishnikov Institute of Agrochemistry, Moscow. pp312-319.

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Production of this SRUC Technical Note was funded by the Scottish Government as part of its Farm Advisory Service.