GREATSOILS

Biological tests for soil health

Figure 1. Earthworms are a good indicator of soil health, however, few are found in intensively cultivated soils

Soil biology and soil health

Soil is a living material teeming with a diversity of creatures as rich and varied as any tropical rainforest. It's estimated that soil hosts a quarter of our planet's biodiversity (FAO, 2015). Communities of microscopic bacteria, fungi, protozoa and nematodes inhabit the spaces in a healthy soil, forming an underground food web (AHDB, 2016).

The diversity of these organisms is essential in transforming organic and inorganic compounds (including unwanted chemicals such as pesticide residues) into carbon dioxide (CO_2), humus and plant nutrients (such as ammonium and phosphate ions). In addition, the gums and polysaccharides produced by soil organisms during the decomposition of organic matter (plant residues, organic manures, etc) contribute to the formation of stable soil aggregates which are important for good soil structure. There are also mutually beneficial associations between plant roots and soil bacteria (for example, nitrogen fixation by legumes) and soil fungi (phosphate-scavenging mycorrhizas). And finally, there are opportunistic members of the soil population that exploit plants purely for their own means, ie plant pathogens.

Each group of soil microorganisms has its pathogenic members (bacteria, fungi, nematodes) that are normally kept in check by the vast majority of non-pathogenic soil organisms. Maintaining a healthy, diverse and active soil population is key to preventing invasion and dominance by undesirable pathogens. Organic amendments can help with this by creating a greater diversity of physical spaces and conditions within the soil, thereby supporting a more diverse and more stable soil ecosystem.

Action points

Earthworm counts and soil respiration offer two simple methods for assessing soil biological health.

When assessing earthworm numbers:

- **Take more than one soil sample from within each field - 10 samples are recommended for earthworm counts**
- **Include samples from uncultivated field margins as a benchmark against which to compare**
- **Avoid taking samples when the soil is very dry (soil should have been wet for a few days prior to sampling). Spring and autumn are the best times to carry out earthworm assessments**

When assessing soil respiration:

- **Get a representative soil sample from the field area being tested using standard soil sampling methods**
- **Keep soil samples cool and out of direct sunlight**
- **Dispatch samples to arrive next day at the laboratory, otherwise store in a refrigerator and dispatch within 24 hours**
- **Commercial labs offer the carbon dioxide (CO_2) burst test (soil is dried and re-wetted to measure burst of biological activity) and the Soil Food Web test**
- **DIY basal soil respiration tests kits are available where soil is tested in its natural state. Soil should be moist but not waterlogged, and at a temperature of between 18-24^{0}C, when carrying out the basal soil respiration test**

Soil biological activity varies with environmental conditions (daily and seasonal changes in weather, soil temperature and soil moisture, etc). Any observed changes in soil biological measurements should only be considered significant when they are obvious and lasting.

Biological testing for soil health

Whereas soil chemical tests such as the standard pH, phosphorus (P), potassium (K) and magnesium (Mg) analysis have been tried and tested over decades, and systems established for interpreting test results in relation to management interventions, methods for biological testing for soil health are still in their infancy (Wood and Litterick, 2017).

Possible measurements include assessment of earthworm populations in the field by digging holes and counting the numbers, commercially available services for measurement of soil respiration (CO_2 production) and measurement of groups of soil organisms under the microscope. Although techniques based on molecular biology, eg DNA fingerprinting, are now being used to estimate the structure of soil microbial communities, the approach does not yet provide general information that can form the basis of soil management decisions. However, DNA-based monitoring of soil-borne pathogens can be used to predict risk of disease development, enabling more informed selection of crop varieties.

Soil respiration as an indicator of soil health

On a holistic level, soil is a living system which consumes oxygen and produces CO_2. This has been known for many years. Following early interest in soil respiration as an indicator of sustainable soil fertility, the focus shifted to assessing the potential side-effects of the then newly-developed pesticides on the soil population (Johnen, 1977). It is important to recognise the fact that soil biological processes vary with environmental conditions (daily and seasonal changes in weather, soil temperature, soil moisture, etc). Therefore, an effect of applying pesticides was considered of long-term ecological significance only when a process such as CO_2 production changed by more than 50 per cent and the change persisted for at least 30 days (Wood, 1989). This is a useful yardstick when interpreting the significance of any biological measurement of soil health. However, it should be borne in mind that management to improve soil biological activity is a gradual process that takes place over several years. So, to confirm benefits from soil health management, any changes observed in soil biological measurements should be obvious and lasting.

Recent progress has been made in the use of respiration as a tool to measure soil biological activity, both in the laboratory and in the field. Field measurements can be made of respiration under natural conditions (basal soil respiration). The method has been further refined in the laboratory to measure the flush of CO_2 from a soil sample that has been dried and re-wetted. This is associated with a flush in mineralisation of nitrogen and phosphorus (Haney et al, 2008). This means that the CO_2 burst test can be made on soil samples sent to the lab for standard chemical analysis.

Furthermore, the burst of CO_2 from soil following drying and re-wetting provides an estimate of the soil microbial biomass and this has been shown to be a more sensitive predictor of changes in soil organic matter than the direct determination of organic matter (Powlson et al, 1987). Soil respiration measurements can show differences between soil management treatments (inorganic fertiliser, compost, incorporated cover crop) and results can be grouped into categories and linked to management interventions.

One laboratory in the UK is now using soil respiration measurements as part of a soil health analytical package. Each individual analysis result is allocated a score and a weighted average is used to calculate a Soil Health Index for a soil (Table 1). This method was trialled by growers as part of the GREATsoils Project. The Frontier Soil Life Report also offers an integrated assessment of standard soil chemistry with soil physical properties (bulk density, compaction) as well as soil biology using the CO_2 burst test.

Measuring groups of soil microorganism in soil

Another way of assessing soil biology is to carry out a detailed census of all the major groups of microorganisms in a soil sample using a combination of extraction techniques, staining and microscopy. In addition to providing fundamental ecological knowledge on the types of organisms involved in important soil functions (eg nutrient cycling) and the ways in which these organisms interact (a soil-food-web), the information has prompted the introduction of soil analysis services to quantify selected key functional groups of organisms.

These groups of organisms (bacteria, fungi, various types of protozoa and nematodes) clearly play important roles in the functioning of soil, but, to date, there is a lack of understanding of all the factors that control the complex biological communities found in soil at different spatial and temporal scales. Without this information, the significance of changes in absolute numbers of key functional groups or ratios of numbers (eg bacteria:fungi) is unclear and we have no substantial scientific basis for recommending appropriate management interventions (Wood and Litterick, 2017).

The main factor to influence the ratio of bacteria to fungi is soil pH. Measurements have shown an acid forest soil to have a ratio of bacteria to fungal biomass (g/m^2) of 4:45, whereas the equivalent value for a neutral-pH grassland soil was 61:1 (Wood, 1989).

Alongside well-established techniques for measuring the abundance, diversity and activity of soil microorganisms, techniques based on molecular biology, DNA fingerprinting is also being used to estimate the structure of microbial communities (Philippot et al, 2012). However, the apparent microbial diversity measured using any nucleic acid analysis procedure is highly dependent on the method used to extract DNA from soil. Although this approach shows much promise in terms of improving the understanding of soil biology, it does not yet provide information that can form the basis of soil management decisions. It does however provide an approach to assessing the presence of specific plant pathogens, eg *Fusarium* and *Didymella* spp., the causative agents of stem footrot disease in peas.

Table 1. Example soil analysis results for a soil in Warwickshire, used to grow vegetables and salads

pH	P Index (mg/L)	K Index (mg/L)	Mg Index (mg/L)
6.5	4 (48)	2- (134)	3 (104)
Organic matter (%)	**CO_2 burst (mg C/kg)**	**Texture**	**Soil Health Index (1-5)**
2.5	35	Sandy loam	3

Therefore, whilst there are well-established laboratory methods for soil chemical analysis, and a range of laboratory and field methods for measuring soil physical properties, new methods are now emerging for soil biological analysis. Some of the tools have started to provide David Aglen with the measurements and reassurance that the innovations he is introducing to his mechanically-intensive vegetable production system are having a positive impact on the health of his fragile soil.

Case study – Balbirnie Home Farms

David Aglen is Farms Manager at Balbirnie Home Farms, a 1200ha mixed farming enterprise in rural Fife, 35 miles north of Edinburgh. His soil is a moderately varying sandy loam with a sandy subsoil. This allows a varied rotation which includes carrots, potatoes, cabbages and cauliflower, as well as combinable crops, grass and forage crops for the cattle enterprise.

David said: "Nurturing the fragile structure of these soils whilst growing mechanically-intensive crops is becoming a major driver of the rotation. An absolute minimum level of cultivation is used for the establishment of the combinable crops along with vegetable and root crops only being grown one year in four across the 900ha of cropped land."

One of David's recent innovations has been to grow an over-winter cover crop of stubble turnips or vetch after harvesting winter barley in August and before sowing spring oats in April. In many cases, the cover crops are grazed off by the farm's livestock prior to ground preparation for the next crop. The aim of such innovations is to reduce soil erosion, save money, reduce the carbon footprint and increase biodiversity.

"This has been a steep learning curve to date. We seem to have a fairly limited choice of cover crop species, so far, that will establish successfully in late August and September in Central Scotland," David said.

David has been interested in testing the soil at Balbirnie Home Farms to measure the effect of organic amendments, such as compost and straw, on soil health. One of the aims was to include assessments of soil biology, but he was unsure how to go about it. David consulted with soil health expert Dr Audrey Litterick of Earthcare Technical Ltd, and both agreed to monitor earthworm counts and to test for life by measuring soil respiration (Figure 2).

Balbirnie Estates earthworm counts 2016

Balbirnie Estates East Moss Field and East Field were sown with carrots in the first week of May 2016. In both April and September, at four locations within each field and at two locations in the field margins.

Figure 2. The Solvita® soil health test measures the carbon dioxide evolved from respiration of soil organisms

There were good numbers of earthworms in the uncultivated field margins in April, but fewer (and a higher proportion of juveniles) in the cultivated areas of the fields. Earthworms are very sensitive to soil disturbance and the species *Lumbricus terrestris* can burrow down to 2.5m and therefore go out of range of the soil sampled.

In East Moss in April, the worm counts in the four samples varied from one to 14. There were fewer worms counted in the top 30cm of soil in September compared to April, probably due to the dry soil conditions at the time of sampling (no worms were found in the cultivated field areas, Table 2).

When assessing earthworm numbers, it is important to take more than one sample from within each field. 10 samples per field are recommended in the AHDB factsheet 'How to Count Earthworms' (AHDB, 2018a). It is important to take samples from uncultivated field margins as a benchmark against which to compare and avoid taking samples when the soil is very dry. Soil should have been wet for a few days prior to sampling.

Table 2. Balbirnie Estates – seasonal differences in earthworm counts in cultivated vs uncultivated fields

Earthworm counts	East Field (8ha)		East Moss (6ha)	
	April	September	April	September
Cultivated area	6	0	7	0
Uncultivated field margins	14	2	27	3

Table 3. Respiration measurements for the different treatments at Balbirnie

Soil respiration	Compost no straw	Compost straw	No Compost no straw	No Compost straw
CO2 production (mg CO2/g/h)	62	76	60	76
Interpretation	Good biological activity	Very good biological activity	Good biological activity	Very good biological activity

Soil respiration testing at Balbirnie

In April 2017, after the carrot crop had been harvested, East Moss field was divided roughly into four. Each quarter of the field had a different treatment, the Eastern-half had straw applied at approximately 50t/ha and the Northern-half had compost applied at 20t/ha. Paper crumble was also applied to the entire field at 20t/ha. The organic materials were cultivated in and the field was sown with spring barley in May.

20 samples of soil were taken from each of the four treatment areas in May 2017, bulked and subsampled for analysis. Respiration of the fresh soil was measured using the Solvita® field test method. A sample of approximately 90g soil was placed in a sealed jar with a CO_2 indicator. After 24 hours, the amount of CO_2 produced was measured using a digital colour reader. During transport from the field to the test room, the soils were stored in a polystyrene cool box containing cool packs. The tests were set up the same day on which samples were taken.

The addition of straw to this field (soil organic matter content 4.1%) caused an obvious increase in soil respiration compared to soil which did not receive straw (Table 3), indicating an improvement in the soil health. Compost had no effect after a single application, but can have beneficial effects on soil respiration when applied over several years (AHDB, 2018b). Soil respiration readings were shown to be a good indicator for measuring the impact of reduced cultivation on soil health (Pankhurst et al, 1995).

Commercial labs offer a CO_2 burst test (soil is dried and re-wetted to measure burst of biological activity). DIY basal soil respiration tests kits are available where soil is tested in its natural state. Samples should be stored in a cool, dry place. For the DIY test, soil should be moist but not waterlogged and at a comfortable room temperature of between 18 and 24°C.

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Further information

In addition, a range of resources to help you with soil health assessment and soil management, are available on the AHDB Great Soils website **horticulture.ahdb.org.uk/great-soils.**

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