A Health Check for our Agricultural Soils

Soils are essential for food production, with 95% of food grown in association with soil. By 2050, it is estimated that agricultural production must increase globally by 60%, just to meet food demand (FAO 2015). With global population growth and increasing competition for land and water resources, there is a need to increase the health and productivity of soils that are available for agriculture. In the past, increasing food production has led to a decline in soil health with an estimated two thirds of Australian agricultural soils deemed to have one or more physical, chemical or biological limitation affecting soil health. However, we have learnt from the past and have a better understanding of sustainable soil management for improved productivity. Understanding your soils, their key limitations, and the feasibility of overcoming these limitations will determine if you can improve soil health and productivity to create a more profitable farm.

"Agriculture will only survive in the long term if soils are managed in ways that not only repair historical damage but also improve their physical, chemical and biological properties." [1]

What is Soil Health

Soil health is the ability of the soil to function as a living ecosystem in relation to its natural capacity. A healthy soil sustains biological productivity, maintains environmental quality, promotes plant, animal and human health, and is resilient and profitable.

A healthy soil has many functions (Table 1). The specific definition of a healthy soil used in agriculture will be different from that of a healthy soil in a natural ecosystem. Even within agriculture, there will be different requirements for dryland wheat compared to pasture soil for a grazier and it needs to be understood that soil health is relative to the system of production and the inherent natural properties of the particular soil.

Table 1. Functions of a healthy soil

Productivity outcomes	Environmental outcomes
Physical support for plants	Filters and purifies water
Structure suitable for root growth	Detoxifies pollutants
Capacity for water infiltration	Home for a range of organisms
Supply of water and nutrients	Prevention of nutrient and sediment loss to waterways
Suppression of pests and diseases	Carbon sequestration

A healthy agricultural soil is often considered in regards to fertility however, physical and biological properties are also essential (Table 2). Biological processes have an integral role in creating a bridge between the chemical and physical components of soil health.

Table 2. Examples of features affecting soil health

Physical	Biological	Chemical
Mineralogy	Organic matter	pH
Texture	Macro fauna (e.g. worms, insects)	Salinity
Structure	Meso fauna (e.g. mites, spring tails)	Sodicity (Ionic balance)
Pore size	Micro fauna (e.g. nematodes, protozoans)	Total N
Compaction	Bacteria	Total P
Slaking	Fungi	Trace elements
Water infiltration	Archaea	Iron, Aluminium, Calcium
Water drainage	Diverse microbial community	

How do you measure soil health?

Due to the multifaceted nature of soils, there is no single approach for measuring soil health. Soil organic carbon is often used as an indicator of health, but results need to be interpreted in the context of the associated biological, chemical and physical properties. For example, in highly acidic soils (with pH_{Ca} below 4.5) there is reduced diversity and activity of soil organisms, which reduces the turnover of organic carbon. Therefore, the soil may have high organic carbon levels but is not favourable for healthy plant growth. It is critical to understand the soil being tested and identify any soil properties that could be limiting soil function.

It is difficult to set a universal soil health benchmark as mineralogy and texture largely determine the chemical, physical and biological properties of the soil. Climate and farming system strongly influence farm productivity.

It is more important to identify the most limiting soil constraints to productivity and adopt practices to overcome them.

Identified soil health constraints need to be monitored over time. It is advisable to also monitor the outcomes of improving soil health, productivity, increased water and nutrient use efficiency and reduced money spent on energy be it fuel, chemical or labour.

It is critical to understand that soil health issues are interrelated and difficult to test in isolation.

How can soil health be improved?

Aside from expensive soil modification activities, little can be done to change the mineralogy and texture of the soil. However, soil and crop management practices can have a huge effect on other soil properties. Practices that can impact soil health include tillage, fertiliser inputs, trafficking (livestock and machinery), crop rotations, residue management, amendments and pesticides.

Many agricultural soils have physical and chemical limitations (Table 3) and they must be rectified before biological processes can be improved. Identification of soil constraints that are affecting soil function and limiting productivity is the first step. Constraints then need to be assessed into those that can be overcome and those where it is impractical or uneconomic to address. For example, soils that have poorly drained clay with naturally toxic levels of boron and salinity within the root zone, or soils with very alkaline topsoils may not be able to have these constraints overcome due to economic reasons but changes to management practices may be able to improve soil function. However, soil constraints such as compaction or hard setting layers are able to be addressed.

Table 3. Common soil constraints

Physical	Chemical
Low organic matter	Low organic matter
Waterlogging / prolonged wetness	Acidity
Low water holding capacity	Alkalinity
Hard setting / surface sealing	Low nutrient retention
Compaction	Salinity
Water repellence	Sodicity (poor ionic balance)
Poor aggregate stability	High / low phosphorus fixation

Key practices to improve soil health include continuous inputs of organic matter, permanent plant and residue cover, diverse rotation sequence, balanced inputs of nutrients, minimum tillage, avoidance of compaction and erosion.

Changes to management practices can create a more favourable environment for microbes. For example, retaining crop stubble increases soil moisture and moderates high temperatures leading to greater plant productivity, nutrient availability and formation of soil aggregates. When a practice is changed it needs to be managed to 'best practice'. It is widely considered that permanent pasture leads to increases in organic matter compared to annual cropping. However if the practice results in over-grazing and baring soil this can lead to low organic matter inputs, susceptibility to erosion and is likely to be worse than the original cropping practice.

Change in practice needs to be carefully considered in relation to what is practical, economical and fits with the long-term goals of the enterprise as well as the capacity to implement the change well.

The importance of organic matter and carbon

Soil organic matter has a pivotal role in soil health and a large impact on soil properties. It is important for stabilising soil structure, creating aggregates of soil particles, increasing water infiltration and overall water holding capacity, storage and release of nutrients; improved cation exchange and buffering capacity and humus production. It has a critical role as a food source for soil organisms, increasing their diversity and activity so they can cycle the nutrients and compete with pests and pathogens.

Table 4. Role of organic matter in modifying soil properties and improving soil health. *Information extracted from 1*

Physical	Chemical	Biological
lower bulk density rapid infiltration of water better drainage improved water holding capacity better root growth better structural stability less erosion	source of nutrients continual release of nutrients improved cation exchange sorption and deactivation of contaminants	increased biological activity increased diversity improved suppression of soilborne pathogens

Soil organic matter is difficult to measure directly so laboratories measure soil organic carbon (OC). Soil OC makes up about 58% of the mass of soil organic matter. Microbes digest up to 90% of OC that enters the soil in organic residues and 1-5% is stored in living microbes. OC exists as four fractions, each with different turnover time in the soil. The actively decomposing fraction consists of dissolved and particulate fractions and has a turnover time of less than hours through to a few decades, the stable humus pool generally takes decades to centuries and the resistant fraction can take several thousand years and is relatively inert. As organic matter is decomposed and moves through the fractions it becomes more nutrient rich and more resistant to decomposition.

It is important to realise that OC may not increase in systems that are functioning at high capacity. In these soils, OC is constantly cycling through the living, actively decomposing and stable fractions providing many soil health benefits but not affording a carbon sequestration benefit. It is imperative to understand the distinction and be able to differentiate systems that have the capacity to increase organic carbon through remediation or change in management practice and those soils that are already near their full carbon storage potential.

Importance of getting roots deeper in the soil

Where OC is found in the soil strongly influences if it will be stored or decomposed. OC in the surface 10 cm is more likely to be decomposed and cycled by microbes due to a favourable environment with high inputs of organic matter through shoots and added residues. However, at depths greater than 10 cm it is more likely that OC will be stored in soil as there is much lower loss of OC to the atmosphere.

Plant roots play an important role in increasing OC at depth through increased root biomass, root exudates and sloughing of cells. The OC in the area surrounding the root (rhizosphere) is much higher compared to the bulk of the soil. The root exudates encourage microbes deeper into the soil and in doing so transforms OC through the fractions.

Roots contribute 2-6 times the OC to that of shoot residues. This is largely due to the physical inability of microbes to decompose roots that have grown into soil aggregates as well as higher lignin in roots making them harder to decompose. Root derived OC is more likely to persist in the active and humus fractions.

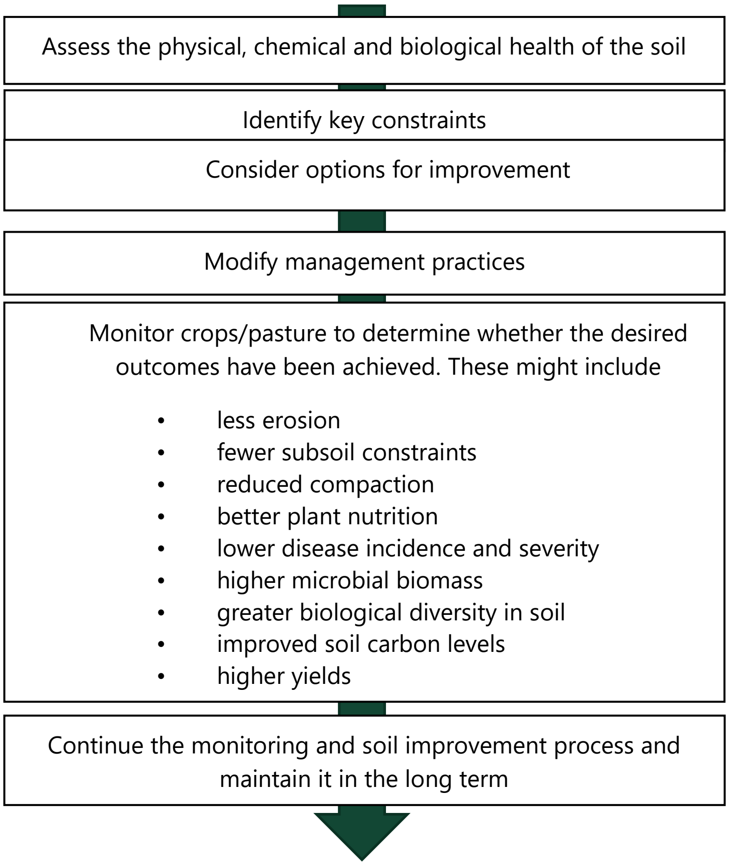

Figure 1. A pathway to improving soil health. ***Information extracted from (1)***

References and Further Reading

1. Stirling G, Hayden H, Pattison T and Stirling M (2016). Soil health, soil biology, soilborne diseases and sustainable agriculture: a guide. CSIRO Publishing, Clayton VIC.
2. Hoyle, F (2013). Managing soil organic matter: a practical guide. GRDC, Kingston ACT.

Preferred way to cite this information sheet

Department for Environment and Water (2021). A Health Check for our Agricultural Soils. https://data.environment.sa.gov.au/Land/Land-Resources/ (insert date web page accessed)

For more information

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Prepared by Amanda Schapel PIRSA, supported by Department for Environment and Water Sustainable Soils 2021.