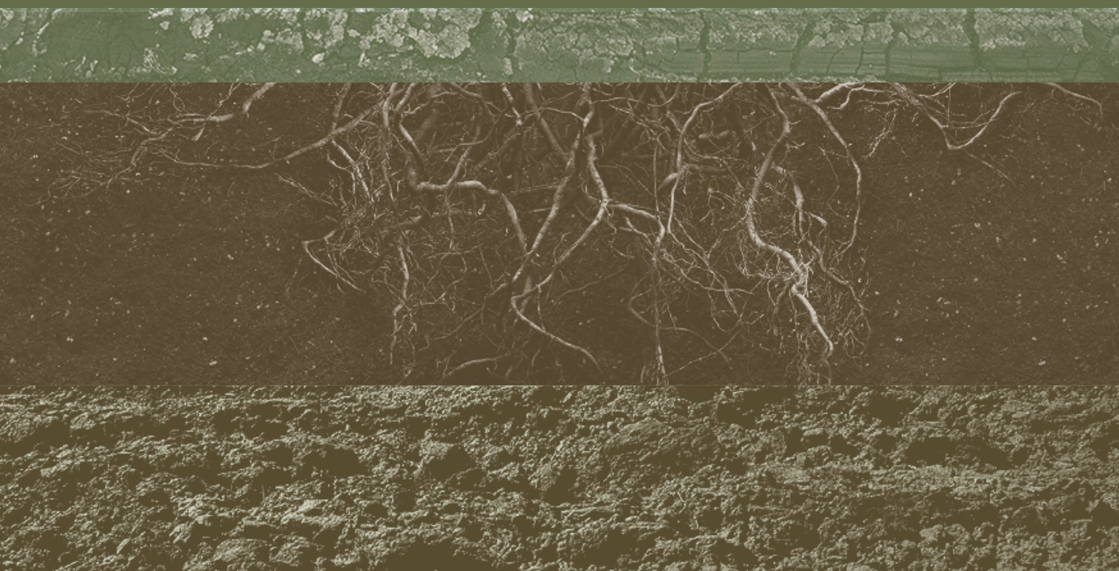
SOIL
HEALTH GUIDE

SOIL CARBON EDITION



Acknowledgment of Country

The North Central Catchment Management Authority (CMA) acknowledges Aboriginal Traditional Owners within the catchment area, their rich culture and their spiritual connection to Country. We also recognise and acknowledge the contribution and interests of Aboriginal people and organisations in the management of land and natural resources.

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INTRODUCTION

Healthy soils are fundamental to rural living and food production. Australian soils are among some of the oldest and most weathered in the world. They generally contain low levels of organic matter and if not carefully managed can erode and degrade easily under traditional European farming practices therefore it is imperative to look after the soil that we have.

For farmers or rural property owners soil is their most valuable asset. It provides structural support, water and nutrients for plant growth. Understanding soil types, applying the appropriate management practices and monitoring soil quality are all important steps in protecting and enhancing soil health.

Maintaining healthy soils is essential for farmers and land managers in north central Victoria to support productive agricultural industries, contribute to food security and deliver soil related ecosystem services (e.g. clean water and air). Its important to know how healthy our soil is and what things we can do to create a robust soil that can withstand impacts, such as agriculture, without the loss of fertility, structure and biological activity. A healthy soil is defined as a state of a soil meeting its range of ecosystem functions as appropriate to the environment. Healthy soils are essential for healthy plant growth, human nutrition, drinking water filtration and a landscape that is more resilient to the impacts of drought or flood (Soils For Life, 2015).

AIM

This Soil Health Guide is an easy-to-read, practical guide to understanding soil types in north central and broader Victoria.

The guide provides information to help identify possible soil health issues using nine simple visual tests conducted in the paddock. The tests are cheap and easy, and can be undertaken using home-made equipment such as wire quadrants.

Observations and results can be used to determine management actions to improve soil health and assess differences in soil health between paddocks, farms, management practices and/or growing seasons. Together with the soil organic carbon information and the Soil Health Score Card (see inside back cover), the guide aims to complement laboratory test results, providing real-time information on a soils physical, chemical and biological characteristics.

In addition to the feature on Soil Organic Matter (SOM) and Soil Organic Carbon (SOC) information, this edition of the Soil Health Guide incorporates the interaction of SOM and SOC with each of the nine soil health factors.

HOW TO USE THE SOIL HEALTH GUIDE

1. Read all the information first

Before heading out into the paddock it is important to read all the information and organise the equipment.

2. When to test

The Soil Health Guide contains a series of tests which should be carried out at least once a year during the main growing season (e.g. late winter or early spring). Avoid taking samples during very dry or wet conditions, extreme heat or cold temperatures and after fertiliser or lime applications (wait at least three to four weeks after applications before testing). To compare results between years or across paddocks, carry out the tests at similar times of year, under similar conditions and in the same location(s).

3. Prepare your equipment

Prior to testing collect and/or make the equipment (refer to equipment list).

TIP: Set up Test 9 first, as this will take 30 minutes and can be assessed at the end.

4. Select test sites

Firstly, select the paddock(s) for assessment – it could be the farm's best and worst soils, or paddocks under different management. For example, perennial versus annual pastures, or rotational versus continuous grazing. It is important to select a test site that is representative of the paddock. Try to avoid stock camps, headlands, watering points or any other sites of unusual traffic. Refer to sampling procedure. (Adapted from the Soil Structure Assessment Kit – Shelley McGuinness, Centre for Land Protection Research, 1991).

5. Decide how many cards you need

The score card has provisions to record three results for each of the nine tests. More cards will be required for additional testing.

TIP: Conduct tests in undisturbed areas of the paddock and along the fence line to compare results.

6. Carry out the tests

The Soil Health Guide lists 9 tests. The Soil Health Score Card offers space to record paddock information (e.g. rainfall, pasture type, site location/map, grazing frequency and so on) and up to three sets of test results. The more tests conducted within a site/paddock, the better the understanding of soil health, as results will be more representative. Once confident with the tests, it will take approximately 30 minutes to carry out all 9 tests.

TIP: Record the date on the score card before filing to compare results over-time.

7. Review the test procedure

Review the selected sites to ensure results are indicative of the area tested.

TIP: It's also important to regularly review testing procedures to make sure procedures are consistent between sites over-time.

8. Review the results and follow up on low scores

Line up the test sheets for the areas/paddocks or compare and identify any differences or similarities across the 9 tests.

TIP: If neighbours or members of the local Landcare or farming group are also carrying out the tests, get together as a group to compare results and discuss possible causes and management options.

9. Make a note to repeat the tests after one year.

By carrying out the tests regularly throughout the season and across multiple years, it will help identify soil health conditions and the implications of different management practices on soil health.

Note: To complement this guide, ongoing soil extension support is recommended.

EQUIPMENT

A plastic tub is recommended to hold equipment

- Shovel
- Tape measure
- GPS or farm map
- Home-made wire quadrant
- Hand magnifying lens
- 0.5 Litre water bottle
- Large plastic tub
- Large garbage bag or tarp
- Home-made penetrometer
- Soil pH kit (available from gardening supply stores)
- 1 litre bottle of rain or distilled water
- Shallow dish or transparent cup

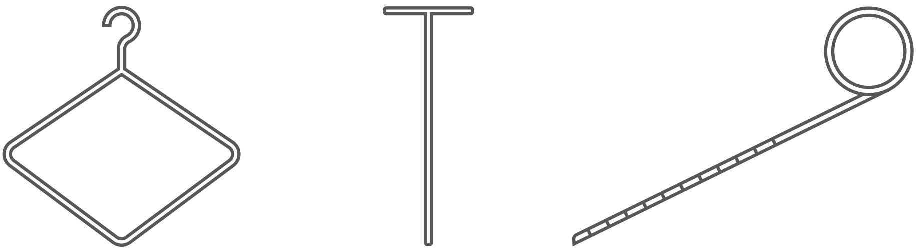
Home-made equipment

A quadrant is used to show a known area when placed on the ground.

Wire quadrant

Make a 30 cm x 30 cm quadrant (square) out of sturdy cardboard or wire. Alternatively a wire coat hanger can be used, which measures 24 cm by 24 cm when opened out to form a square.

Figure 1: Home-made wire quadrant, steel-rod penetrometer and wire penetrometer



Penetrometer

A penetrometer is a device to test compaction in the soil. The depth to which the average person can push the penetrometer into the soil is usually a good indication of compaction (Shelley, 1991).

A scientific penetrometer with a gauge can be purchased or a home-made one can be constructed using a piece of wire or steel.

Option 1 - For the wire method, take a 500mm length of 3.15mm/10 gauge high tensile wire. Curve 120mm of the length into a handle, the remaining length forms the penetrometer.

Option 2 - Alternatively a home-made penetrometer can be simply constructed using two pieces of steel rod. Weld a 1100mm length of 10mm steel rod at right angles to a 400mm length of 20mm steel rod. The tip of the shaft can then be sharpened into a point. If a hollow piece of rod is used, a hardened tip will need to be welded to the end.

Modest effort is required when using a penetrometer. If you hit a rock or tree root, choose another spot. The easier it is to penetrate the soil, the better the deep root development and water infiltration.

Using a penetrometer in the field to test compaction.

Photo: North Central CMA

DIGGING THE HOLE

TIP: *Dig a hole large enough to have a clear view of one face (Shelley, 1991)*

Equipment: Shovel, tape measure and GPS or map to record the location of the hole(s).

Instructions: Locate the site for the hole(s). If a farm is made up of different soil types consider completing the tests for each soil type. Record the GPS location or mark on a map the location of where the tests were completed so tests can be undertaken at the same location again in the future. (Victorian State Government, 2001)

Dig a hole 50-60 cm deep (or until rock is hit) by 50-60 cm wide. A hole of this measurement allows visibility of soil that is most important to plant roots. Try and remove the first 20 cm of soil as a solid cube in preparation for the soil structure test. (Victorian State Government, 2001)

Photo: Poprotskiy Alexey, Shutterstock.com

SAMPLING PROCEDURE

Taken from: https://agriculture.vic.gov.au/farm-management/soil/erosion/monitoring-groundcover-and-soil-degradation

When monitoring it is important to make sure that the areas being assessed are representative of the entire area. If a soil sample is a different colour from the other sample it should be discarded. The best way to achieve this is to walk along an imaginary transect line, diagonally across the paddock from post to post, Figure 2 or take 10 steps in one direction then randomly turn and take 10 steps in the other direction, Figure 3. Points. (Victorian State Government, 2001)

The larger the area the more tests are required. Take a quick walk over the general area to understand how variable the paddock is and how many tests should be undertaken. (Victorian State Government, 2001)

Draw a transect roughly on the Soil Health Card and note approximately where the tests were undertaken, remember to mark on the drawing where north or the top of the paddock is as a reference point.

TIP: If available, consider (not necessary) using a GPS (Global Positioning System) to record test site

Figure 2: Transect

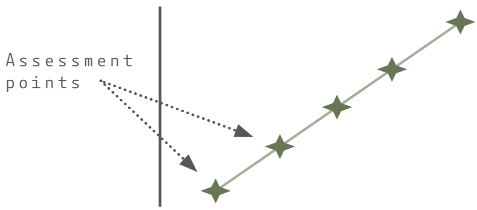
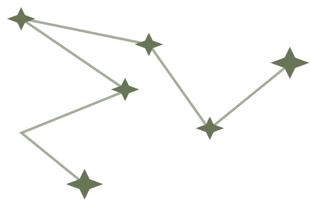


Figure 3: Zig zag - random



SOIL CARBON

The following information has been adapted from the Soil Carbon Snapshot. This is a joint publication from Agriculture Victoria and Fertiliser Australia and has been used with permission. For the full document visit https://agriculture.vic.gov.au/__data/assets/pdf_file/0006/857607/Soil-Carbon-Snapshot-updated-May-2022.pdf

Why is soil carbon important?

Carbon is essential to life on earth, with every living organism needing carbon to sustain life whether for physical structure, or as an energy source, or both. Carbon is quite mobile and cycles through the earth's atmosphere, oceans, biosphere and geosphere.

The total amount of carbon on earth is fixed, we cannot create more and we cannot remove carbon from the earth's system. Carbon can be found as a gas, and in solid and liquid forms, the total amount of carbon on earth always remains the same.

There is growing appreciation for the critical role played by the existing store of carbon in our agricultural soils. There has been considerable discussion relating to the possibility of increasing soil carbon levels for potential farmer income via future carbon credit markets. However, of greater importance is the story in regard to the valuable role played by existing soil carbon stores that offer great benefit to both agricultural productivity and the wider environment.

Soil carbon and organic matter play a number of beneficial roles and biological functions (GRDC Krull et al. 2006) in agricultural soils and supports productivity.

Maintaining or building reserves of soil carbon offers many benefits. As a result, farmer interest in practices and approaches that enhance the fertility, productivity and resilience of their soil assets is growing.

Soil Carbon and the climate

Soil is the largest reservoir of carbon in the terrestrial biosphere and a slight variation in this pool could lead to substantial changes in the atmospheric carbon dioxide concentration, thus impacting significantly on the global climate (Chan et al. 2008); (Luo et al. 2010). With global soils containing more carbon than is found in the atmosphere and biomass combined, soil carbon stocks are a significant carbon sink. Over the coming decades there is likely to be an increasing focus on maintaining global soil carbon stocks and exploring pathways for enhancing soil carbon stores.

In an agricultural system, carbon is cycled through the atmosphere, through plants and animals, and through the soil. The production of food affects the amount of carbon in the soil as harvesting plant and animal products removes carbon from the agricultural system. Increasing organic matter in soil increases the amount of carbon in soil, and wide range of soil health benefits result.

What is soil carbon?

Soil carbon is represented as Soil Organic Carbon (SOC) or Total Organic Carbon (TOC). While there is also inorganic carbon (minerals) found in some soils, it's the organic forms which are usually the largest proportion and the key driver of soil biology and function.

Soil organic carbon is a key component of the broader Soil Organic Matter (SOM) pool, which includes all of the organic components of the soil such as plant and animal tissue in various states of decomposition. Leaf litter and undecomposed materials on the soil surface are not considered to be soil organic matter until they start to decompose.

Soil organic matter contains important elements such as carbon, hydrogen, oxygen, calcium, nitrogen, phosphorus, sulphur and other elements found in living organisms. There is often some confusion between SOM and SOC. It is important to understand that on average soil organic carbon is only 58% of the soil organic matter component.

Several types of organic carbon (fractions) can be identified in soils, each with different biological, physical and chemical properties which have different roles in soil function, health, fertility and productivity. GRDC, Van Rees et al (2014) and GRDC, Farrell et al (2021) provide the following simple explanation of the key soil carbon fractions:

As a quick rule of thumb:

Soil carbon (SOC) is on average 58% of soil organic matter (SOM).

This is the same as saying SOM=SOC multiplied by 1.72.

For example:

2% SOC is the equivalent to 3.44% SOM (2% multiplied by 1.72).

4% SOM is the equivalent to 2.32% SOC (4% divided by 1.72).

1. **Particulate Organic Carbon (POC)** – is the least stable and shortest lived, usually lasting only weeks or months before the carbon is decomposed further and either released as CO2 or becomes part of the humus fraction. (Particle size is 0.05 to 2mm). Often referred to as the 'labile carbon' fraction.
2. **Humus Organic Carbon (HOC)** – relatively stable and lasts for years or decades. Usually decomposed material found as large organic molecules attached to soil particles (size <0.05mm).
3. **Resistant Organic Carbon (ROC)** – very stable and may last for hundreds of years. Contains inert material, mostly charcoal, and levels change very little over time.

How much carbon is in Australian soils

The CSIRO's Australian Soil Carbon Mapping Project (Rossel et al 2014) provides national scale representation of soil organic carbon (SOC) stocks. The average amount of organic carbon in the top 30 cm of Australian soil was estimated to be 29.7 tonnes per hectare and the total stock for the continent at 25.0 gigatonnes (Gt= 1000 million tonnes) with a 95 per cent confidence of being within the range of 19.0 to 31.8 Gt. The total SOC stock in agricultural regions of Australia is 12.7 Gt with 95 per cent confidence of being within the range of 9.9 to 15.9 Gt.

The largest SOC stores per hectare occur in the cool, temperate zones, which have the highest average rainfall Rossell et al (2014). The amount of organic carbon in Australian agricultural soils varies significantly, from peat soils under pasture where the organic carbon content can be greater than 10%, to heavily cultivated soils, where the levels are typically less than 1%, Robertson et al (2016).

Building soil carbon in soils

The most significant benefit of soil organic matter for crop yields comes via increases in mineralised nitrogen.

Soil organic matter contains a sink of bound up nutrients which are released into the soil as microorganisms mineralise or break down the organic matter for their own metabolism.

GRDC *'Managing Soil Organic Matter - a Practical Guide' (2013)* suggests that as a general rule, for every tonne of carbon in soil organic matter about 100 kg of nitrogen, 15 kg of phosphorus and 15 kg of sulphur becomes available to plants as the organic matter is broken down.

While soil organic matter can function as a significant source of nutrients for farm production, it is important to also consider the reverse of this process, as increasing or building stores of soil carbon will also require nutrients to be locked away and bound up along with the sequestered carbon.

The nutrient types and amounts provided by the breaking down of organic matter will depend on the type of matter which is mineralised and its ratio of carbon and other nutrients, especially nitrogen. While nutrients are released in this process, much of the carbon in organic matter is converted by microbes back into carbon dioxide.

The various pools of soil carbon have differing rates of breakdown and thus nutrient release. The particulate organic carbon breaks down the fastest. The humus organic carbon takes years to decades to break down and is usually a larger but slower source of nutrients for plants.

The proportion of carbon relative to nitrogen is known as the Carbon: Nitrogen or C:N ratio. Plant residues can have substantial variations in the proportion of carbon to nitrogen. Microbes require sufficient nitrogen relative to carbon to decompose organic matter and release nutrients, thus the C:N ratio of the soil organic matter, plus it's overall quantity, can provide indications of soil fertility and quality.

Building soil carbon stores is not easily achieved. As mentioned in the C:N discussion, soil microbes need organic matter as their food source, and when conditions are suitable for microbial activity (e.g. warm & moist soils) much of the labile or particulate organic carbon is decomposed and released as carbon dioxide.

Kirkby et al. (2011) '*Stable soil organic matter: A comparison of C:N:P:S ratios in Australia'* explain that the more stable portion of soil organic material known as humus (HOC) has a constant C:N:P:S ratio, which means that the relative proportions of each of these elements can limit the formation of carbon sequestered in the humus fraction.

Thus, carbon sequestration can be limited by the supply of nutrients. *Kirkby et al. (2011)* estimated that each new tonne of soil carbon being created in the stable humus fraction would require or lock up 80kg nitrogen, 20kg phosphorus and 14kg sulphur. *Kirkby et al. (2011)* estimated that at 2011 fertiliser prices this equated to a nutrient cost of $248 to build one new tonne of soil carbon in the humus portion. This has obvious ramifications for land managers when considering soil sequestration objectives, as the potential costs of any locked up nutrients could far outweigh potential income from carbon trading schemes. Irrespective of carbon trading aspirations, it is important to consider the implications for nutrients and crop production before embarking on soil carbon sequestration strategies.

The amount of carbon in soil can be thought of as a leaking bucket that constantly needs topping up. The size of the bucket represents the total amount of carbon the soil could potentially hold. Factors such as clay content, soil depth and soil density will affect the size of the bucket. For example, the size of the soil carbon bucket will be smaller for sand than it is for clay soil. Management practices can't influence the size of the bucket.

10 KEY CONSIDERATIONS FOR SOIL CARBON CHANGES

1. Accurate longer term measurement and monitoring is essential to determine changes to soil carbon levels. Factors such as soil carbon testing methods and accuracy, the age of trials (particularly if less than 5 years old), plus rainfall and seasonal variability are all factors which must be carefully considered before conclusions are made.

2. Increasing carbon input rates, or decreasing carbon loss rates can improve soil carbon levels and have other benefits including improved soil nutrient uptake, (where nutrients are available), water holding capacity and overall productivity.

3. While soil organic carbon can function as a source of nutrients for farm production, it is also important to consider the reverse of this process, as increasing soil carbon levels will require nutrients to be locked away and bound up with the sequestered carbon.

4. Soil carbon occurs in a number of different fractions, each having different properties, vulnerabilities and rates of decomposition. The Particulate Organic Carbon or labile fraction can be easily lost and decomposed in the soil and subsequently released back into the atmosphere as carbon dioxide.

5. The capacity for soils to sequester carbon is finite and there are specific maximum achievable equilibrium levels of soil organic matter for most farming systems due to climatic and primary productivity limits to plant dry matter production and decomposition rates.

6. For carbon accounting purposes, genuine carbon sequestration must result in an additional net transfer of carbon from the atmosphere to land, not just movement of a carbon source from one site to another.

7. Changes in land management which lead to increased carbon in soil must be continued indefinitely if farmers wish to maintain the increased stock of SOC. For many farmers, committing to long term land use may be undesirable if it reduces their ability to adjust land management to meet changing market or profitability drivers over the longer term.

8. Some management practices may only be reducing losses of soil carbon and not actually sequestering additional atmospheric carbon into the soil. Many soils are still responding to initial cultivation of the native soil and experiencing soil carbon decline.

9. Increasing soil carbon may potentially lead to perverse impacts as a consequence of the links between soil carbon, nitrous oxide and methane cycles. For example, changing from annual crops to permanent pastures may temporarily increase soil carbon, but may also lead to an overall increase in total net emissions via increased ruminant livestock production. Soil carbon needs to be considered in a wider systems context.

10. Climate change and changing patterns of seasonal variability will affect the ability of soils to maintain or sequester carbon. For some regions this may make the task of maintaining or improving soil carbon levels even more challenging over coming decades.

Management practice options and evidence for building soil carbon

Improving SOC levels can be achieved by either increasing organic carbon inputs or decreasing organic carbon losses. The CSIRO *Sanderman et al. (2010)* undertook a worldwide review of peer-reviewed studies of traditional management practices used to sequester soil carbon and concluded that:

'Within an existing agricultural system, the greatest theoretical potential for [soil carbon] sequestration will likely come from:

- Large additions of organic materials (manure, green waste)
- Maximising pasture phases in mixed cropping systems, and
- Shifting from annual to perennial species in permanent pastures.

Perhaps the greatest gains can be expected from more radical management shifts such as conversion from cropping to permanent pasture and retirement and restoration of degraded land' *Sanderman et al. (2010).*

While in theory it is possible to increase soil carbon, in practice there are often limitations or specific levels of soil organic matter that can be achieved for any farming system in a particular geographic region and soil type Powlson et al. (2011).

Lam et al. (2013) assessed the feasibility of increasing soil carbon stocks by improved management practices (conservation tillage, residue retention, use of pasture and nitrogen fertiliser application). Their results indicate that the potential of these improved practices to store carbon is limited to the surface (0-10 cm of soil) and diminishes with time. They also noted that low sequestration levels means that emerging carbon markets may not be financially attractive to farmers in many situations.

Whilst most studies conclude that management options that increase SOC usually increase overall farm productivity and sustainability, Chan et al. (2008); Sanderman et al. (2010); Meyer et al (2015), most of these studies have also noted management strategies aimed at increasing soil carbon may also lead to some potentially negative impacts. Issues such as soil carbon and nitrogen cycling, plus the wider carbon emissions lifecycle impacts of changes to farming systems still require significant research Sanderman et al. (2010).

For example, changing from annual crops to permanent pastures may increase soil carbon, but it may also lead to an overall increase in total emissions when the additional ruminant livestock production (methane emissions) is also taken into account Meyer et al (2016).

Table 1: Land Management practice options and evidence

Practice option	Research evidence
Stubble retention (compared with stubble burning or removal)	Most studies show limited to no effect on Soil C but good evidence in a few situations.
Elimination or reduction of the length of time of bare fallow phases in crop rotations (can include using cover crops).	Reducing fallows - Very strong evidence for reducing carbon loss. Cover crops mitigate losses in some situations.
Minimum tillage and direct drilling (compared with multiple-pass conventional cultivation)	Most studies show limited effect though some evidence in a few situations.
Increasing productivity through fertiliser application (compared with zero fertiliser or other nutrient applications)	Good evidence in some situations but not in others. Key is to have balanced inputs (due to stoichiometry).
Increasing productivity through irrigation	Yield and efficiency increases do not necessarily translate to increased C return to soil. Good evidence in some situations but not in others.
Grazing management	Strong evidence that over- grazing reduces soil C via erosion losses. Evidence for other grazing practices (stocking intensity, duration, rotational / set stocking etc.) is equivocal or non- existent.
Conventional to organic farming system	Insufficient data available.
Restoration of degraded land	Good evidence.

Benefits for carbon sequestration	Negative impacts / risk
Greater C return to the soil is likely to reduce C losses and may increase SOC stocks. Reducing C losses can result by reducing exposure to erosion.	Any increases are small and emerge over long-term (10+ years). Many situations where C increase measured in top 5-10 cm, but this can be negated by a decrease in C at greater depth.
Added potential to reduce C losses through reduced erosion. Carbon losses continue during fallow without any new carbon inputs, and cover crops can mitigate this.	None documented.
Reduces erosion and destruction of soil structure thus slowing decomposition rates of C. Can maintain or prevent decline of soil C.	Reduced tillage has shown little SOC benefit. Any increases are small and emerge over long-term (10+ years). Surface residues decompose with only minor contribution to SOC pool. Some situations where C increase measured in top 5-10 cm, but this can be negated by a decrease in deeper soil.
Good evidence where starting soil nutrient levels are deficient. Evidence re: N and P, but likely to hold for other nutrients too.	Adding more N fertiliser leads to increased root growth leading to more SOC, however potential trade-off between increased soil C and increased decomposition emissions. Evidence that applying fertiliser, in excess of plant requirements, has either no effect or a negative effect on soil C. Likely to depend on original nutrient status. Increasing N use needs to be balanced against GHG emissions associated with manufacture and use of fertilizer.
Increased biomass production can increase C inputs but this is often balanced against increased C decomposition.	Potential trade-off between increased C return to soil and increased decomposition rates.
Strong evidence that over-grazing reduces soil C via erosion losses.	Long term non-replicated trials at Hamilton (VIC), show no change in SOC for two plus decades under a range of grazing management systems. Any soil C change as a result of change in grazing pressure takes many years to be detectable.
Further research required.	Variable outcomes depending on the specific organic system (ie.manuring, composts, cover crops). Increased cultivation can reduce soil C. Compost use may only be C transfer and not actual C sequestration.
Greater plant and groundcover will increase C return to soil.	Low soil C starting conditions can be improved over time but can also be undermined if degrading processes return (eg livestock removal replaced by increased feral grazing etc)

Table 2: Crop and pasture based practice options and evidence

Practice option	Research evidence
Conversion of cropping to permanent pasture	Very strong evidence in most situations.
Inclusion of pasture phases in rotation with crops (compared to continuous cropping with no pasture phases	Good evidence in many situations, but not in all. Depends on the system.
Inclusion of pulses (leguminous crops) with cereal & oilseed cropping rotations (compared with continuous cropping without leguminous crops).	Evidence but only in very few situations.
Shift from annual to perennial pasture species.	Evidence equivocal, little data available.
Native grassland pasture systems versus introduced (sown) pastures	Insufficient data available.

	Benefits for carbon sequestration	Negative impacts / risk
	Long lived Pasture systems generally return more C to soils than annual crops. Current research suggests that where there is low SOC (with high potential for SOC improvement), then the net effect of the conversion on GHG emissions may be positive initially, but after about 20 years it would reach equilibrium. Increased soil C gain is greater where cropping was long-term or starting levels are low.	The added emissions (CH_4 & N_2O) from ruminant livestock grazing pastures needs to be considered, and may neutralise or detract from any soil carbon benefit. Benefit will likely depend greatly upon the specifics of the switch. Switch from cropping to pasture, without any decrease in market demands for crops, will lead to other land being put into cropping, merely transferring SOC losses to another farm.
	Pastures generally return more C to the soil than annual crops, but also depends on dry matter inputs from the pasture. Legume based pasture phase can be effective where N is limiting.	Potential of increased CH_4 and N_2O from livestock production systems need to be accounted for from conversion of cropping to grazing land. A non-legume pasture phase may increase need for N fertiliser which could result in additional emissions.
	Potentially effective where N is deficient.	Most studies show limited effect on SOC.
	Perennial plants can utilise water throughout the whole year, with increased below ground allocation but few studies to date. Current research suggests that where there is low SOC (with high potential for SOC improvement), then the net effect may be positive initially, but after a few decades it would reach equilibrium.	Few studies to date.
	Native pastures usually (but not always) have higher SOC than introduced pastures, simply because they remain relatively undisturbed. Improved pastures have may not have regained the original SOC prior to clearing and disturbance. It is possible that some introduced pasture sites can show improved SOC via improved nutrition.	The potential to increase SOC of undisturbed native pastures may be limited as it has likely reached equilibrium.

Table 3: Soil amelioration practice options and evidence

Practice option	Research evidence
Sub-soil amelioration of imported organic material (composts, manures etc)	Evidence in some situations.
Top-soil application of imported organic material (compost, manure etc)	Evidence in some situations.
Stabilised C in Biochar application to soil	Evidence in some situations. Can vary depending on biochar source, characteristics and the C life cycle. Point of 'sequestration' is at the biochar pyrolysis plant.
Other soil intervention strategies (eg clay spreading, delving, ripping)	Insufficient data available.

	Benefits for carbon sequestration	Negative impacts / risk
	Depends on amount and type of material applied. Likely that the practice has the potential to increase soil carbon at depth.	The increased soil C may not constitute actual C sequestration, but might only be C transfer, depending upon the alternative fate of the organic material being used or brought in. Requires C lifecycle analysis.
	Depends on amount and type of material applied.	The increased soil C may not constitute actual C sequestration, but might only be C transfer, depending upon the alternative fate of the organic material being used or brought in. Requires C lifecycle analysis.
	C in plant material is converted to a highly stable form of C as biochar, however the point of 'sequestration' is at the biochar plant (pyrolysis). Benefits of adding biochar to soils will vary depending on biochar source, type and soil limiting factors.	Validation of GHG mitigation benefits of biochar, requires a full life-cycle assessment across the whole system – ie. biomass source and procurement, biochar production system, and its application. Evidence for reduced N O is mainly because the biochar changes the soil C:N ratio and thus immobilises soil N. However, more N may need to be added to the system to become productive again. Point of 'sequestration' is at the biochar pyrolyser. Land application is technically carbon transfer and not actual sequestration.
	While can improve site biomass and productivity, soil carbon benefits less clear.	Variable outcomes depending on the specifics of the intervention. In situations where site production is increased, it may only lead to increased soil C turnover.

CARBON FARMING AND SOIL CARBON

As carbon markets emerge there are schemes which can offer to pay farmers for building new soil carbon sequestration stores on their farms. As the market expands it is first worth farmers considering their long-term goals for their property and which options will suit their situation best.

Farm businesses may have a variety of options with regards to how they may choose to utilize any carbon or emissions gains that occur on their farms, including:

- Using to balance against their own farm emissions
- Selling carbon to other entities via carbon markets
- Using towards certification programs for low emissions or carbon neutral produce (eg low emissions milk, meat or grain).

Farmer participation in carbon markets projects is voluntary. It is always best to seek advice, as carbon sequestration is a new type of product that in many ways is different to the traditional income sources farmers receive when selling food and fibre.

This section provides some links to programs and information on the emerging carbon market and policies in Australia.

The Emissions Reduction Fund

The Australian Government's Emissions Reduction Fund (ERF) is a scheme that aims to provide incentives for a range of organisations and individuals to adopt new practices and technologies to reduce their emissions.

The ERF provides opportunities for farmers and land managers to participate in emissions reduction projects via a range of "approved methodologies". Administered by the Australian Government's Clean Energy Regulator there are a number of methodologies for carbon project development for the land, agriculture and vegetation management sectors, including for soil carbon.25

Over the past decade there have been a range of carbon trading pilots which have provided income opportunities for a number of farmers, and which also offer some insights for landowners when considering longer term contracts or obligations specific for carbon sequestration projects on their properties.

Eckard et al. (2022) provides further insights into the practicalities of attempting to increase soil carbon along with some longer-term risks to be considered by farmers.

Some further useful 'Questions to ask before a farmer sells their carbon' are outlined by Agriculture Victoria which suggests considering:

- Understanding longer term obligations, and what happens if carbon stores are released (drought or bushfires) or if farmers wish to terminate their involvement at a later date
- Income from sequestration will not continue indefinitely (there is a natural limit to how much carbon can be stored per hectare), so it should not be considered an ongoing revenue stream for the long-term. This may have intergenerational implications for farms
- Appreciating the costs required to take carbon from the paddock to the marketplace, which will involve costs for measurement, auditing, accounting and brokerage
- Economies of scale and making sure the quantity of carbon is sufficient to cover all project development and management costs
- Longer term implications regarding flexibility for farmers to alter or change land use as might be required due to changing circumstances (changing market conditions or new technology opportunities)
- Assessing the implications of long-term contracts and the possible future obligations for other parties such as banks, lessees or potential future property buyers
- Implications of fluctuations and changes to carbon prices and policies over the longer term. 'Sequestration' means stored for safekeeping, so when a farm creates a new tonne of stored carbon, they may get paid but will then be required to maintain and keep it there for 25-100 years depending on the contract.

Carbon markets and rules are still developing, and participants are advised to always seek independent expert advice for their own personal situation.

As new developments arise (research, technologies, policies) in the emerging carbon farming area it is important to stay in touch with the latest information.

The Australian Government Department of Agriculture Water and the Environment (DAWE) provides further information on the carbon and emissions initiatives that have been developed across Australia.

This includes the National Soil Strategy which sets out how Australia will value, manage and improve its soil for the next 20 years.

The National Soil Strategy prioritises soil health, empowers soil innovation and stewardship, and strengthens soil knowledge and capability. These priorities have been identified through research and practical examples, government policies and programs, and by consulting with governments, industry, researchers, farmers and other land managers across Australia.

TEST

1

GROUNDCOVER

BIOLOGICAL

Why do we need to know about groundcover?

- Groundcover includes litter and both living and dead plant material. The amount of groundcover is influenced by grazing management, crop management and species selection.
- By understanding and maintaining groundcover to at least 70% coverage, soils become less susceptible to degradation caused by erosion from wind and water.
- A healthy soil contains a broad diversity of microbial types and plants depend on these beneficial soil organisms to help them obtain nutrients and water from the soil (Victorian Government of Primary Industries, 2005).

- Active production of groundcover promotes the potential increase of soil organic matter (SOM) and soil organic carbon (SOC) into the system. The more plant biomass that is grown, the more SOC is input into the system.
- Approximately 1/3 of what is grown above ground is reflected in root biomass below the ground with SOM cycling continuously between living, decomposing and stable fractions in the soil.

Equipment:

Wire quadrant

Test (the best time to assess is prior to the autumn break for grazing enterprises and post harvest for cropping enterprises in time for planning fertiliser needs for the coming/active growing season):

1. Randomly place the wire quadrant using the sampling patterns on page 9, including 20-30 replicates.
2. Estimate the proportion of groundcover inside each quadrant (includes both living and dead plant material and litter). (Victorian Government of Primary Industries, 2005)

Interpretation of results: Estimating groundcover levels in pasture

20% Groundcover

40% Groundcover

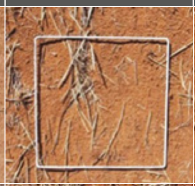
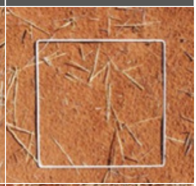
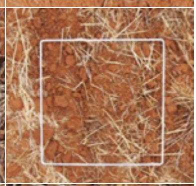
50% Groundcover

80% Groundcover

90% Groundcover

100% Groundcover

Table 1: Estimating groundcover levels in a cropping situation

Coverage	Standing Stubble	Rolled Stubble	Chained Stubble	Cultivated Stubble
20%				
50%				
80%				

Pasture photos: Greg Lodge, NSW DPI – 20% and 40% cover photographs. Primary Industries South Australia, 1996, Pasture Pics: easy estimation of pasture dry matter levels, Appila / Bundaleer Pasture Group, Appila, SA - 50, 80 and 100% photographs; Cropping photos: Mallee Sustainable Farming Inc., 2013, Improving Soil Health and Reducing Wind Erosion project of the ~~Murray~~ Catchment Management Authority.

TEST

2 EVIDENCE OF SOIL BIOLOGICAL ACTIVITY

Why a diversity of soil organisms is important?

- A healthy and functioning soil ecosystem contains a wide diversity of soil organisms.
- These organisms range from tiny bacteria, viruses, protozoa and fungi to large soil animals like centipedes, earthworms, spiders, earwigs, springtails and termites.
- Each organisms plays an important role in cycling carbon, nitrogen, sulphur, phosphorus and all other nutrients (NSW DPI, 2002) and can be allocated to one of three main roles, an ecosystem engineer (eg ants and earthworms), a litter transformer (eg microarthropods) or a micro-food web processor (eg microbes, bacteria and fungi).
- Earthworms have an additional role to play as they tunnel through the soil creating mixing and new pathways for nutrients, water and roots to move. They are good indicators of the soil health and structure. The more organic matter the greater the potential number of earthworms and macropores.

- Increasing plant growth increases Soil Organic Matter (SOM) and soil organic carbon (SOC) available to biological organisms to use as a feed source. SOM that is consumed is respired into carbon dioxide, used for growth or turned into by-products that adhere to soil particles or are used by plants or other organisms.
- Soil biological organisms mineralise and immobilise N, P and S through the decomposition of organic matter (Duxbury, Smith and Doran, 1989).

Equipment:

Wire quadrant, hand magnifying lens, shovel

Test (as you measure groundcover, also assess the range of soil animals on the surface of the soil):

When considering soil biology and what tests you might use you need to consider first: What is the need of the test and what results am I after? – Is it for decision support where you might be weighing up between management options, or reassurance?. Second - What is the question being posed? -What is specific impact/effect of interest? Finally when choosing a test, consider what informed decisions you can make with the results, and be aware of the limitations of tests.

To holistically assess soil health in the field it is the variety of different soil organisms that is important, not the numbers of individual soil organisms (NSW DPI, 2002). However there is a suite of biological tests/indicators that have been developed to measure/and or monitor the soil. Many of these are listed here: https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_biology_measure

Move away from the hole and take a shovelful of topsoil, approximately 20 cm square and 10 cm deep.

Carefully sift through the plant litter and soil and note how many different earthworms, ants, beetles, spiders, millipedes, etc you see. Fungi may also be present as a network (often white) of hyphae structure in the soil.

Earthworms are ecosystem engineers and tend to be concentrated in the root zone therefore it may be necessary to pull apart the root mass to locate them.

Photos: Agriculture Victoria, DEDJTR

TEST

3 SOIL COLOUR

Why do we need to know about soil colour?

- Over very long periods of time rocks are broken down to provide minerals to the soil and sometimes these rocks give colour to the soil. Usually the colour of the soil results from compounds reacting with available oxygen such as iron.
- Soil colour is related to chemical properties, aeration or drainage, and organic matter. (Baxter. N and Williamson. J (1963)
- Soil colour is an important characteristic of the soil as it can provide an indication of the soil's drainage characteristics.
- Soil colour may also help determine the different layers (horizons) of the soil, such as topsoil and subsoil (Shepherd, T.G. 2000).

- Humus, the final stage of organic matter breakdown is dark brown or black.
- Sodium content influences the depth of colour of organic matter and therefore the soil. Sodium causes the organic matter (humus) to disperse more readily and spread over the soil particles, making the soil look darker (blacker).

Equipment:

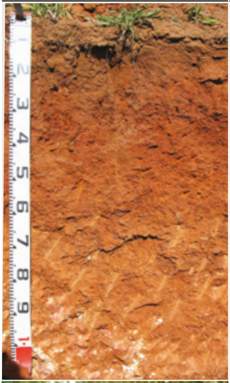
Tape measure

Test (the best time to assess is prior to the autumn break):

Once the hole is dug (refer to page 9), assess the colour of the soil using the colour chart below. Record the colour as one of the following colour:

- Red
- Yellow
- Black
- Brown
- Grey
- Pale

Table 2: Soil Colour Chart and Characteristics

Soil	Soil colour class	Interpretation
	**Red** Red sodosol: Howard Hep-burn (Source: Richard Mc-Ewan, Agriculture Victoria, DEDJTR)	Suggests the presence of un-hydrated iron oxides that indicates good drainage and aeration. Generally water can drain quite quickly through the profile of red soil and oxygen can therefore be stored in the macropores.
	**Yellow** Yellow duplex soil (Source http://vro.agriculture.vic.gov.au/dpi/vro/nthcenregn.nsf/pages/NC_soils)	Suggests inadequate drainage. The yellow colour indicates the soil remains saturated and is therefore starved of oxygen for several weeks after rainfall. Yellow soils may also have a perched water table.
	**Black** Black Vertosol near Cardinia (Source http://vro.agriculture.vic.gov.au)	Indicate high organic matter content or high clay content. Black soils can have variable drainage characteristics ranging from moderately well drained to poorly drained.

Soil	Soil colour class	Interpretation
	**Brown** http://vro/agriculture.vic.gov	Suggests reasonable drainage. The brown colour often (but not always) indicates high amounts of organic matter.
	**Grey** http://vro.agriculture.vic.gov.au/dpi/vro/nthcenregn.nsf/pages/NC_soils	Soils with grey subsoils are poorly drained, generally remain wet, and are starved of oxygen for many months, usually all winter. Subsoils of this colour often have a perched water table.
	**Pale** www.geo.msu.edu/soilpro-files Pale or light-coloured soils (particularly topsoils) are an indication that soil has been strongly leached of nutrients (iron oxides, aluminium and organic matter) which have been moved by water to a lower layer.	They are commonly referred to as a ‘bleached’ layer as they usually occur when there is a problem soil layer below, which stops water moving through the subsoil (e.g. clayey subsoil). The saturated soil results in no oxygen which changes the chemistry of the soil. This change allows the chemicals that give the soil it’s colour to become soluble and leach out of the soil layer.

TEST

4

SOIL PH

CHEMICAL

Soil pH:

- Soil pH (potential Hydrogen) is the measure of the acidity or alkalinity of the soil and is influenced by the soil parent material, past climatic events, annual rainfall and management practice. Generally, the higher the annual rainfall, the more likely the topsoil will be naturally acidic.
- Acidification of the soil is a slow natural process and part of normal weathering and linked strongly to temperature and rainfall, however some farming activities can cause an increase in the rate of acidification of the soil. Nitrate leaching increases acidification as nitrate binds to alkaline cations in the soil when it leaches out. Fertiliser choice, the selection of plant species that are more tolerant to extremes of pH, deep rooted species, summer crops or perennial systems can all help reduce nitrate leaching.
- Most sedimentary and granitic soils are naturally acidic. In contrast, lower rainfall zones tend to have more neutral topsoils and alkaline subsoils.
- Soil that is too acidic can be treated with lime. Keep in mind, though, that pH should only be changed to enhance introduced pasture and crop species. Native grasslands are perfectly adapted to the natural pH of the soil and do not require treatment.

- Soil organic matter (SOM) increases the ability of the soil to buffer changes in pH.
- Soil microbial activity is reduced in strongly acidic or alkaline conditions which in turn reduces the SOM breakdown in these soils.
- In strongly acidic soils microbes direct more of the carbon consumed into respiration activities instead of efficiently using the carbon for energy and growth, resulting in these soils having an increased release of carbon dioxide. The application of lime to raise the pH of acidic soils also may results in a net release in carbon dioxide.

How is soil pH measured?

The water component of soil is where pH is measured; where dissolved chemicals cause the soil to be acidic or alkaline.

The pH of a soil will change over time that is influenced by factors including parent material, weathering and current agricultural practices. pH levels will fluctuate through the year and affect how plants grow.

The pH scale is logarithmic. Meaning a one-fold decrease in a pH value signifies a tenfold increase in acidity eg (pH 6 is 10 times more acidic than a soil at pH 7 and a pH 5 is 100 times more acidic than a soil at pH 7)

The acidity or alkalinity of soil is measured by the pH scale. Less than seven is acidic, greater than seven is alkaline and seven is neutral. Most crop plants prefer a pH close to neutral. When pH becomes too high or too low, this can influence the availability of nutrients resulting in toxicities or deficiencies.

Figure 4: Plant growth and pH (CaCL2) scale

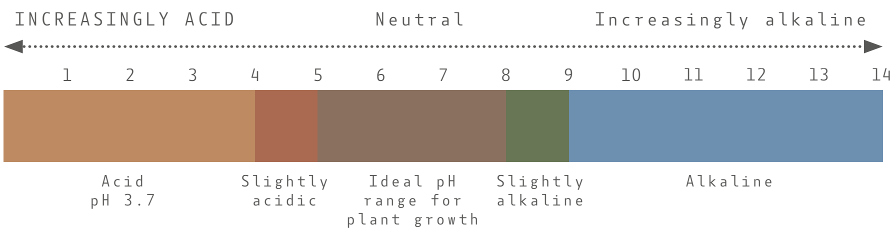


Diagram: NSW Agriculture Acid Soil ACTION

Low pH - beneficial elements such as molybdenum (MO), phosphorus (P), magnesium (Mg) and calcium (Ca) become less available to plants

High pH (greater than 7.5) – calcium can tie-up phosphorus making it less available to plants

pH can also influence the toxicity of elements (e.g. aluminium in acid soils), decrease plant production and water use and impact soil biological functions (e.g. reduced nitrogen fixation).

Note: pH values measured using a soil pH kit are similar to those measured in water. Laboratories may provide pH results in calcium chloride ($CaCl_2$) and/or water. pH values in water are typically 0.5 to 1 values higher than in $CaCl_2$. Take note when comparing results.

Equipment:

Soil pH kit

Test:

1. Take two small samples of soil from the side of the hole, one from 10 cm and one from 20 cm depth.
2. Test each sample for pH following the instructions included in the kit.

Color chart is used to read soil pH values.

Photo: North Central CMA

TEST

5

TEXTURE

PHYSICAL

Why is soil texture important?

- Soil texture, the feel, is a measure of sand, silt and clay proportions in soil. It is an indicator of capability rather than soil health. Clay particles are the smallest, have a flat surface and have a negative charge (which allow them to bind to water and other nutrients). Sand particles are the largest, often course and very resistant to weathering. Silt particles are sized in-between clay and sand.
- Soil texture influences other soil properties such as water holding capacity, porosity, permeability and the soils behaviour in water.
- The sand fraction allows the soil to drain and the silt improves the water holding capacity of the soil
- The clay fraction is perhaps the most important as it enables the soil to hold water and nutrients. Silt and sand however hold little water and nutrients in comparison (McGuiness, 1991).
- The change (or lack of) texture down the soil profile is important in understanding how water, plant roots and nutrients will move and be retained in the soil. Soil typically increases with clay moving down the profile (due to the small and mobile particle size of clay).
- Ideally this change is gradual, however often this is not the case with an abrupt change from a lighter soil (such as a loam) in the top soil and a clay in the subsoil, reducing water, root and nutrient penetration at depth. Some soils will also have no change in texture down the profile.

- The clay content of a soil has a significant role in determining the ability of the soil to retain Soil Organic Matter (SOM) and build soil organic carbon (SOC) as the clay particles and SOM bind together (with the assistance of soil microbiology). The clay protects the SOM from being exposed and broken down by soil microbiological organisms.

- Sandy soils are limited in their capacity to increase significant amounts SOC as the course texture of the sand particles exposes the SOM to breakdown by soil biological organisms. However SOM build up can be achieved through good management (reduced tillage and increased ground cover preservation) or the addition of SOM through amendments.
- SOC accumulation in the humic and particulate form is important for clay soils, aiding in improving soil structure. SOC accumulation in the resistant or humus form in sandy soils is important in increasing the cation exchange capacity of the soil as well as the particulate form in increasing plant available water. SOC in the particulate form is however turned over most quickly so its permanence is questionable in sandy soils.

Equipment:

Water bottle

Test (repeat for subsoil once this has been identified in test 6):

1. Soil texture can be estimated by feel. Take a small handful of soil from the top 10cm of soil, at the side of the hole. Remove any gravel, stone or organic matter.
2. Add water drop-by-drop and knead to break down aggregates. The soil has reached the proper consistency when it is plastic and mouldable like moist putty.

Soil texture should be measured separately for the topsoil and subsoil. Follow the flow chart below to determine the soil texture for each soil layer. (Source: NSW Agriculture, 2002)

Figure 5: Flow chart for determining soil texture

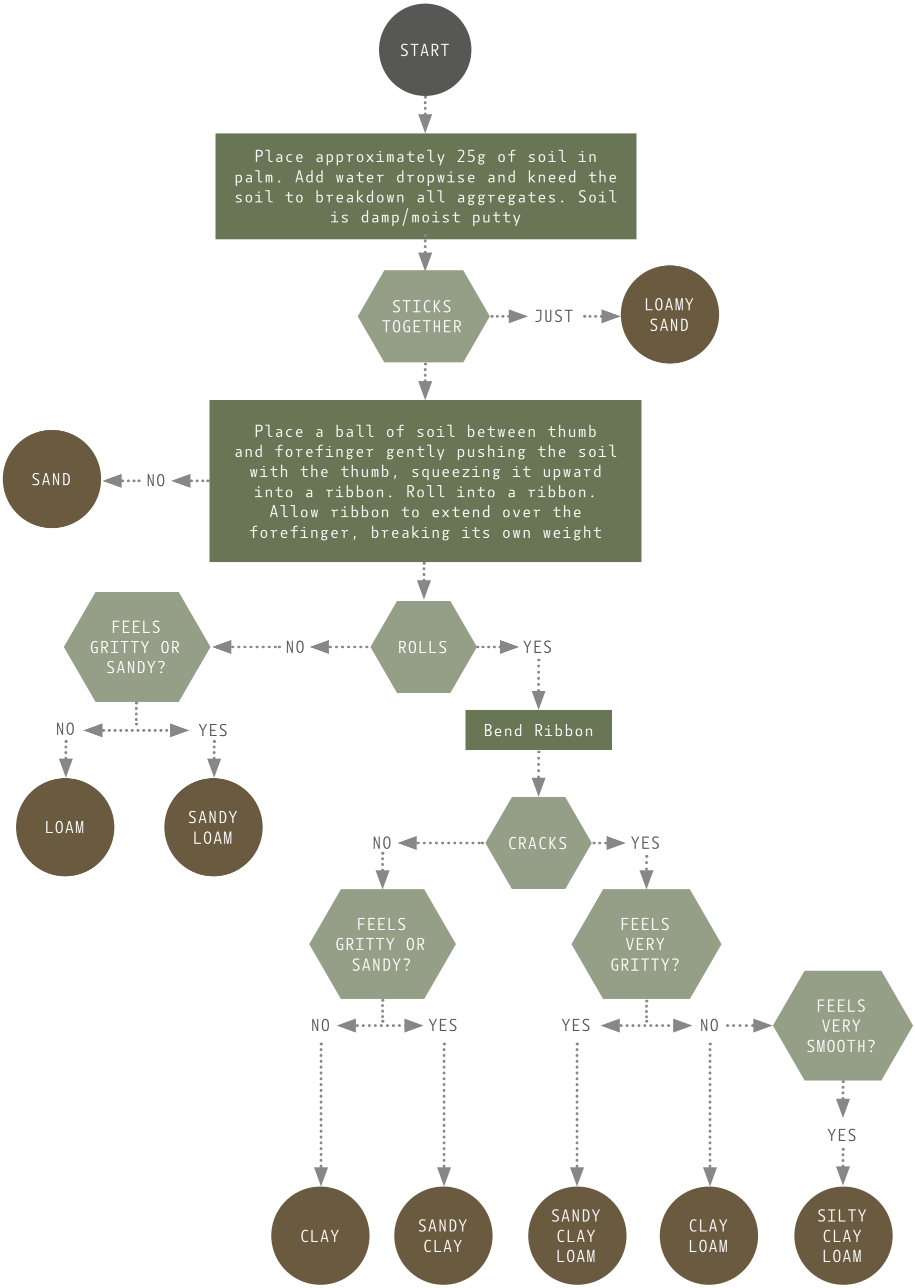


Diagram: S.J. Thien, J. Agric. Ed. 8:54-55, 1979

TEST

6

TOP SOIL

PHYSICAL

What is topsoil?

- Topsoil is the most organic-rich layer in the soil and the main zone for water and nutrient uptake by plants and thus should be protected.
- The soil beneath the topsoil is known as the subsoil and is often identified by a change of colour as described in Test 4 and texture change as described in Test 5. However there is not always a difference in these, and other indicators are used.

- As the top soil is the most organic rich layer, the layer with the most biologically activity, it is also the layer where soil organic carbon is more prevalent. Increasing Soil Organic Matter (SOM) in the top soil will also eventually increase the SOM deeper in the soil profile as soil cation exchange capacity will improve, moving carbon down the profile.
- Where SOM is present at the soil surface and relatively fresh, particulate organic matter intercepts the energy of raindrops and protects physical soil surfaces from damage and erosion.

Equipment:

Tape measure

Test:

Dig a hole (refer to instructions) and, depending on the type of soil, use one of three methods to determine topsoil:

Method 1 – Obvious difference in colour and texture

- Obvious difference in colour and texture between the topsoil and subsoil. The topsoil is typically darker in colour (often brown) and of a lighter texture, while the subsoils are a brighter colour and has a heavier texture (i.e. higher clay content).

- A variation of the above can occur when there is a 'pale layer' above the subsoil layer. This pale layer has a similar texture to the layer above, is lower in organic matter levels but is still referred to as the topsoil. For a further explanation on 'pale layer', please refer to the colour chart (refer to test 3). The subsoil begins when both texture and colour changes.
- Once the boundary between the topsoil and subsoil layers is identified, measure the depth of the topsoil layer.

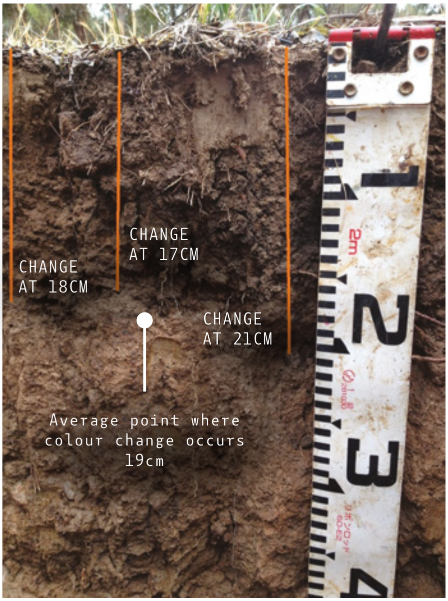
Method 2 – Changes in structure down the profile

- The depth at which it becomes harder to dig usually indicates a change in soil layer. Measure the depth at which these changes occur.

Method 3 – Similar colour, texture and structure

- Look at where most of the plant roots have accumulated; this is a good indicator of the topsoil layer. Measure the depth at which plant root mass declines, this is where the subsoil starts.
- Sometimes where the changes occur the boundaries are uneven so record the average boundary depth

TIP: Take a photograph of the soil profile. This will become a good future reference point.



Measuring the depth at which these changes occur.

Photos - Left: Agriculture Victoria, DEDJTR; Right: North Central CMA

TEST

7

SOIL STRUCTURE

PHYSICAL

What is soil structure?

- Soil structure is the arrangement of soil particles in the soil. The spaces between the aggregates/particles allow for adequate aeration and good drainage, as plants need air and water near their roots to grow well.
- Soil requires pores and channels large enough to be readily seen by the eye – e.g. worm burrows or old root channels. These pores are called macropores and allow the ready movement of air, water and roots through the soil and are therefore very important for drainage.
- Pores within the aggregates/particles are called micropores and are important for water storage.

- Soil structure is improved and strengthened as decomposition products from Soil Organic Matter (SOM) adhere to physical soil particles and build aggregation.
- Humus (which has a large surface area) is usually the largest proportion of SOM comprising 45 to 75 per cent. Typically it adheres to soil minerals, and thus plays an important role in structuring soil. However the resistant SOM portion also plays a role in improving soil structure.
- Tillage of the soil not only breaks up soil aggregates and reduces soil structure but also breaks up the SOM into accessible and attractive particle sizes for the soil biological organisms to consume the SOM and reduce soil organic carbon levels.

Equipment:

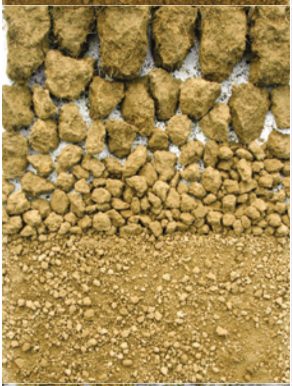
Plastic tub and large garbage bag

Test:

1. Take the 20 cm cube of soil that was removed when digging the hole
2. Drop it into the plastic tub from a height of one metre.
3. If large clods of soil break away from the cube after the first drop, drop them again one to two times. If a clod shatters after the first or second drop, don't drop it again. Don't drop any piece of soil more than three times. If your soil has a sandy loam texture (refer to test 5), don't drop the soil more than once and reduce the height to 0.5 metres above the plastic tub.
4. Transfer the soil from the plastic tub to the large garbage bag spread out on the ground.
5. Applying only gentle pressure, attempt to split any large clods by hand along any exposed cracks. If the clod can't be easily parted do not apply further pressure, as it is unlikely the cracks are continuous and transferring air and water.
6. Sort the soil pieces on the plastic bag from small to large, with the height of the soil roughly the same over the whole surface area of the bag. This provides a measure of soil aggregate size distribution.
7. Take a photo of the soil for future reference and comparisons.

Results:

Table 3: Interpreting soil structure results

Visual appearance	Assessment score	Interpretation
	Poor soil structure.	• Soil dominated by large soil clods. • Very few fine soil aggregates. • Soil clods are very firm and/or angular in shape. • Soil clods have very few pores. Note: some 'poor' soils can have no structure at all, like a sand because of the absence of clods.
	Fair soil structure.	• Soil contains roughly equal proportions of large soil clods and fine aggregates. • Soil clods are very firm and/or angular in shape. • Soil clods have very few pores. • Comparisons.
	Good soil structure.	• Soil is dominated by fine soil aggregates. • There is only a small amount of large soil clods. • Soil aggregates are generally rounded and often quite porous.

Photos: Shepherd, G. (2000)

TEST

8 SOIL COMPACTION LAYERS

Why should I worry about it?

- Soil compaction layers (sometimes called hard pans or plough pans), are layers of very dense, hard soil within the topsoil layer, having lost adequate macropores and structure.
- Compacted layers can slow down or even stop plant root growth and water infiltration.
- Compacted layers are often caused by heavy equipment travelling across the soil surface (especially when it is moist) and from the types of cultivating equipment cutting at the same depth year after year. Stock can also cause compaction of soils.

- In compacted soils, plant roots have reduced access to nutrients and water and don't grow to their potential, reducing Soil Organic Matter (SOM) inputs back into the soil
- Compacted soils are less able to take up additions of new SOM and over time decline in SOM and soil organic carbon (SOC). However as microbes have reduced access to SOC in compacted soils, soil testing can reveal higher levels of SOC (however this SOC is not of use to the plants).
- Measuring bulk density is very important if seeking to understand changes in soil organic carbon over time. For soil organic carbon changes to be accurately measured, the percentage of soil organic carbon in a particular soil layer (0-10cm or 0-30 cm) also needs to be adjusted for bulk density changes that may have occurred over that same period of time. For example, if a soil becomes more compacted over time (without any true change to soil organic carbon), when retested it will have a higher bulk density which could falsely indicate an increase in carbon sequestration: when in fact all that has happened in this instance is that the existing carbon stores have been squashed into less volume of soil.

Equipment:

Penetrometer and tape measure

Test:

1. Choose sites a few metres from the dug hole.
2. Using only moderate pressure, push the penetrometer into the soil. Feel for any differences in the strength required to push the penetrometer into the soil and note the depth at which this occurs. If a rock or tree root is hit move to another site. Repeat a few times to get a feel for the soil.

Compaction layers are usually found 5—10 cm below the soil surface. The subsoil is denser than the topsoil and could be mistaken for a compaction layer. Compare the depth to the compaction layer with the topsoil layer determined in Test 6.

Result: There is no evidence of compaction if the top of the subsoil is reached.

Note: Perform the test where there is stock or wheel tracks and under plants to note differences in soil strength.

Roots can tell us a lot about what conditions they are experiencing. Digging up a few plants can also reveal if there are any compaction issues (such as roots growing down, then growing sideways around compaction)

Table 4: Assessing and interpreting compaction using a penetrometer

Penetrometer	Assessment score	Interpretation
Home-made penetrometer will not penetrate the soil.	Poor 	• Soil is generally hard and/or hard at surface. • Usually an indication that the soil surface has been compacted by machinery traffic, livestock or overworking, especially if wet at the time. • Low soil organic matter levels.
Home-made penetrometer penetrates with difficulty to less than 15 cm.	Fair	• A dense layer of soil is present in the topsoil. • Root growth is stunted and roots tend to grow horizontally above the compacted layer. • Often caused by heavy machinery traffic, especially when it's wet. Can also be caused by the types of cultivating equipment cutting at the same depth each year.
Home-made penetrometer easily penetrates the soil to 15 cm deep.	Good 	• No compaction layer before reaching the top of the subsoil. • Plant roots grow freely through the soil profile. • Water infiltrates the soil easily.

Table: NSW Agriculture, 2002

TEST

9

SOIL STABILITY

(SLAKING AND DISPERSION)

Why is it important? Indicators

- How stable a soil is when it becomes inundated with water is important. Soil aggregates can either be stable, fall apart (slake) or completely disintegrate (dispersion)
- Slaking occurs when weak soil aggregates break down into smaller fragments as a result of rapid wetting (clays swell). This results in the blocking of macropores, which in turn reduces the movement of water and air into and through the soil.
- Dispersion is a chemical process whereby clay particles separate from soil aggregates when the soil is wet. Clay particles carry a negative electrical charge and repel each other. Dispersive soils are usually sodic, structurally unstable, and require special consideration for development. This is controlled by exchangeable cations, soil texture, clay type, organic matter and the salinity of the soil. Its imporant not to till dispersive soils which can further impact their stability.

- Soil Organic Matter (SOM) reduces slaking of the soil by binding mineral particles of the soil together and slowing the rate of wetting
- SOM reduces dispersion of the soil by reducing the disintegration of the soil aggregates into smaller particles.
- The impacts of dispersive soils, such as surface crusting, reduced seedling emergence, reduced aeration, increased run-off and erosion risk, all reduce plant growth which reduces microbial activity and SOM and soil organic carbon build up.

Figure 6: Flow chart of slaking and dispersion

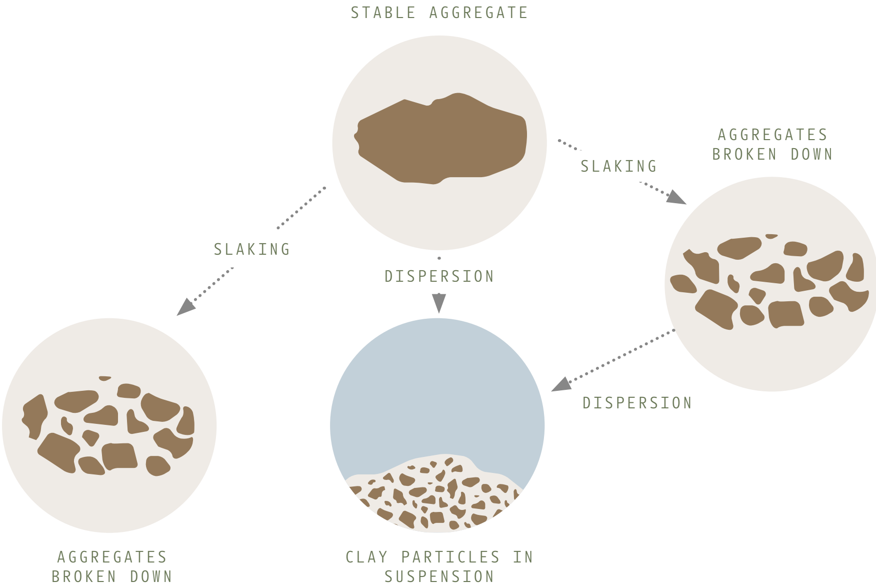


Diagram: Agriculture Victoria, DEDJTR

Equipment:

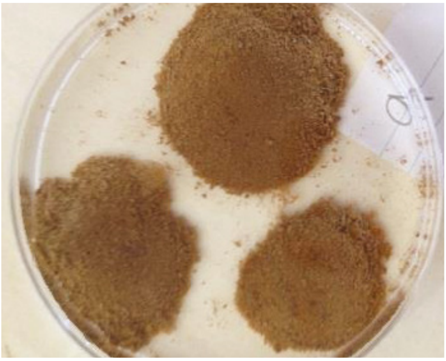
Bottle of rain or distilled water, shallow dish or transparent cup

Test:

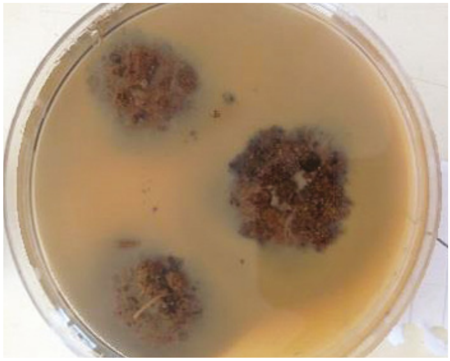
1. Place two samples (about the size of a marble), one from the top soil and one from below, in a shallow dish or transparent cup of distilled water or clean rainwater without shaking or stirring the samples (do not use mains or bore water as they contain chemicals which may prevent slaking).
2. Slaking clay will slump and fall apart in the water forming a small blob of mud however the water will remain clear.
3. Dispersion will result in a milky layer forming around the soil crumb after 30 mins.

Note any differences between the top and sub soils. If dispersion is evident in the sub soil, it has implications for management as it is best not to pull up this soil to the top.

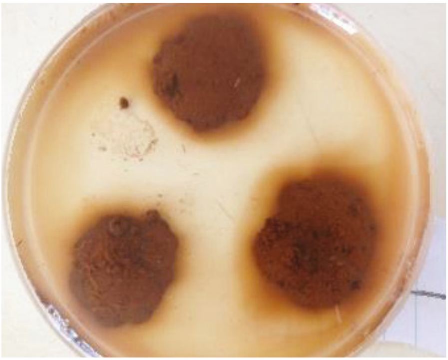
What to look for?



Slaking



Complete dispersion



Incomplete dispersion

No dispersion or slaking

Photos: Agriculture Victoria, DEDJTR

SOIL HEALTH SCORE CARD

Test	Poor Score = 1	Fair Score = 2
1. Groundcover	Less than 50% groundcover (plants dead or alive; stubble)	50% to 70% groundcover (plants dead or alive; stubble)
2. Evidence of soil biological actiivity	Fewer than two types of soil organisms	Two to five types of soil organisms
3. Soil colour (predominant colour of the top 20 cm)	Grey	Light (Yellow/ Red/Brown)
4. Soil pH (water) (use most extreme pH value from top and/or sub soil)	pH 5.0 or lower; greater than pH 8.5	pH 5.0 - 6.0; pH 7.5 - 8.5
5. Soil texture (take the soil texture from the top and sub soil)	Soil texture abruptly changes from the top soil (e.g. sandy loam) to the subsoil (e.g. clay)	Soil texture is the same throughout the profile
6. Top soil depth	Top soil less than 10 cm deep	Topsoil greater than 10 cm deep overlaying a pale layer
7. Soil structure	Poor soil structure. Soil is dominated by large soil clods that are hard or crusty,few cracks/holes, no pores visible.	Fair soil structure. Some visible crumbly structure. Few pores visible. Soil contains roughly equal proportions of large soil clods and fine aggregates.
8. Soil compaction	Soil is hard; penetrometer will not penetrate the soil	Penetrometer penetrates with difficulty to less than 15 cm
9. Soil stability (Slaking & Dispersion)	Unstable structure; aggregates break down and disperse; milkiness of water	Evidence of slaking; aggregates break down; no milkiness of water

Name:	Date:	Site location: *(Map transect location on following page)*		
Good Score = 3	**Weighting**	**Site 1**	**Site 2**	**Site 3**
		(score x weighting)		
More than 70% groundcover (plants dead or alive; stubble)	x3			
More than five types of soil organisms	x2			
Dark (Red/ Brown/Black)	x1			
pH 6 to pH 7.5	x2			
Soil texture gradually becomes heavier down the profile	x1			
Topsoil greater than 10 cm deep	x1			
Good soil structure. Crumbly top soil. Soil forms and is dominated by stable fine aggregates.	x3			
Penetrometer easily penetrates beyond 15 cm	x2			
Maintains structure; aggregates remain intact. No swelling of clay particles	x2			

Transect location

Refer to sampling procedure on page 9.

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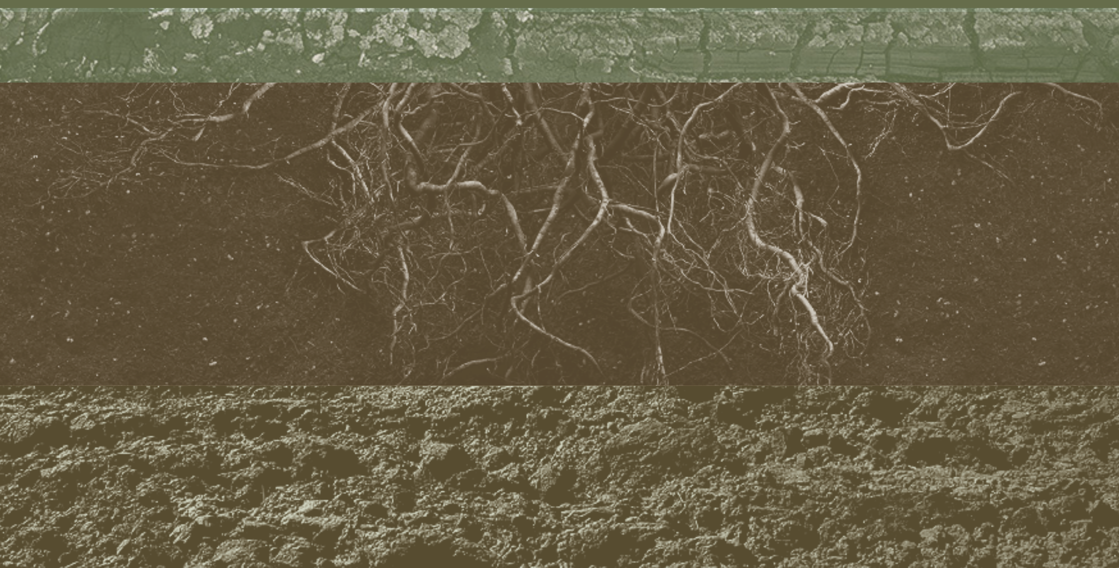

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