DIY
SOIL HEALTH ASSESSMENTS

FEBRUARY 2023

Mahi Tahi
Working Together

NZKGI
NEW ZEALAND KIWIFRUIT GROWERS

MĀORI KIWIFRUIT
GROWERS INCORPORATED

A Water Strategy for the kiwifruit industry was developed in 2019 by NZKGI, Zespri, Māori Kiwifruit Growers Incorporated (MKGI), and growers. Together, we are committed to working collaboratively with the entire kiwifruit industry to protect water quality, use water efficiently, and build soil health on orchards.

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INTRODUCTION

The value of soil health

Soil is a foundation of an orchard's productivity and profitability. Healthy soil holds more plant nutrients, both as organic matter and sorbed onto the organic matter. Soils in poor health simply cannot sustainably support the same level of crop performance as healthy soils regardless of the amounts of fertiliser applied.

Healthy soils can absorb and store more water, making better use of rainfall and reducing the need for irrigation. By absorbing water more quickly, healthy soils reduce the risk of run off and erosion in high rainfall events. They can provide resistance to compaction from machinery and are less likely to rut from frequent machinery passes under wet conditions.

All of these benefits provide better conditions for strong root health, supporting vines to produce the high yields of high quality fruit, with reduced reliance on synthetic fertilisers.

Soils have a critical role in many of the global environmental challenges, such as climate change, nutrient pollution and biodiversity loss. They can be used to capture carbon in the form of organic matter, reducing atmospheric CO_2 thus helping mitigate climate change. Healthy soils are also less likely to lose nutrients or soil particles, so protecting waterways and helping to meet environmental regulations. Soils are the most diverse and important ecosystems on the planet and a healthy soil is the most biodiverse.

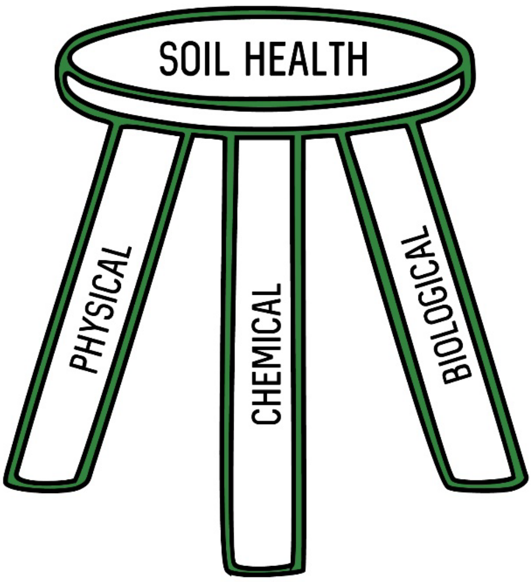
For Māori, soil has mana (importance) and mauri (a life force or energy), and people are strongly connected to soil through their whakapapa (ancestry). While there are many emerging definitions of what a healthy soil means for Māori, a set of core values and principles have been identified by Manaaki Whenua Landcare Research; further information on these is available from **www.landcareresearch.co.nz** including their **soil health factsheet**[1] which offers a basic overview.

This booklet explains how to monitor orchard soil health through a range of different DIY soil health tests. To date, few specific guidelines or target measures for soil health on New Zealand kiwifruit orchards have been established, so the tests and commentary offered here are interim and relatively generic, drawn from a broad range of New Zealand agricultural and horticultural situations.

Three legged stool of soil health

Soil health has been defined as "*the continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans*"[2]. Put simply, a healthy orchard soil is one that supports healthy vines and a healthy local ecosystem.

At a practical level, soil health is like a three legged stool; it requires a good balance of its physical, chemical and biological properties.



[1] **https://www.landcareresearch.co.nz/assets/Discover-Our-Research/Land/Soil-health-resilience/factsheet-soil-health.pdf**

[2] Doran JW, Zeiss MR, (2000). Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology 15(1): 3-11.

Physical soil health is about soil structure – whether it is well aggregated with a crumbly structure or if it is compacted and too dense with insufficient air spaces. Soil should be like a sponge – a whole lot of holes (pores) of different sizes. The holes are what allow air and water to percolate though the soil and help it hold more water. Soil oxygen and root penetration is improved with physical soil health. The key things that damage physical soil health are:

- Compaction from heavy machinery. A good sward also improves soil resistance to compaction.
- Tillage / cultivation, the more of it and the more intensive the more damage.
- A lack of living roots which drive soil biology that aids good soil structure – see section 2.2 below.

Chemical soil health is having the optimum levels of nutrients and pH for plant growth. It is not just the major nutrients like NPK, the micronutrients are equally as important. As all organisms are made up of roughly the same proportions of nutrients, optimum nutrient levels for plants will be optimum for all soil biology. A soil's chemical balance is harmed when nutrients are removed (in harvest, or from leaching or run-off) and not replaced. It can also be harmed if nutrients are above optimum as this can induce deficiencies in other nutrients which may stunt crop growth. Some nutrients at high levels are toxic to soil biology. For example, high copper or zinc levels suppress the soil bacteria which produce the simple sugars that are food for earthworms. A chemical imbalance can reduce soil heath and therefore crop performance.

Laboratory testing is the primary method for assessing chemical aspects of soil health and for kiwifruit orchards this is usually led or informed by a fertiliser advisor, so this aspect is not included in the suite of DIY tests described in this booklet. However, in discussing soil test results with your advisor, it's useful to consider:

- What trends can be seen over time and what be causing those?
- Is there a depletion of some macro or micro nutrients?
- Is there an accumulation of some elements such as copper or residues from herbicides and pesticides?

Biological soil health is having a large and diverse range of organisms in your soil, including a vegetative sward. Soil is the most complex ecosystem on the planet with organisms from the simplest, like bacteria, to the most complex such as mammals (Figure 1).

Just like a three legged stool all three forms of soil health support each other. If one or two are in poor condition then this will negatively impact the other(s).

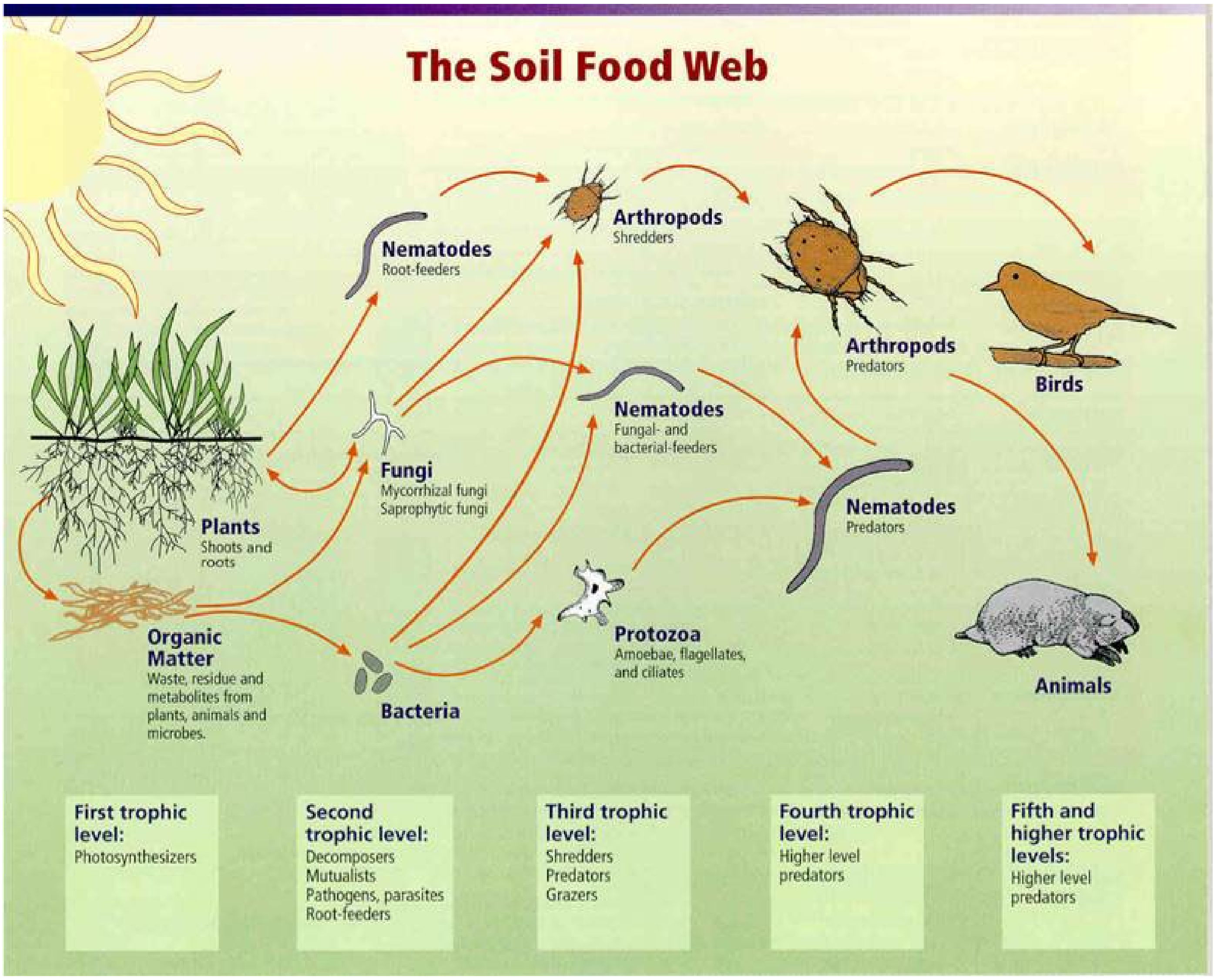


Figure 1. Relationships between soil food web, plants, organic matter, and birds and mammals. Image courtesy of USDA Natural Resources Conservation Service.

What drives soil health?

Scientific understanding of soil health has undergone a revolution in the last decade. At the heart of soil health is soil organic matter (SOM) as good SOM levels are a result of and reciprocally underpin soil health (Figure 2).

Figure 2 shows two SOM creation paths. On the left hand side is the path that creates particulate organic matter (POM) from plant and animal residues. This is where above ground residues are fragmented by larger soil organisms such as worms before being further decomposed by microbes such as fungi and bacteria. It was thought that the tougher organic material, like lignin (the main compound in wood), was turned into humus and that it could persist in the soil for centuries to millennia. It is now known that the POM is completely broken down much faster – a few years to a few decades, and most new above ground residues are completely decomposed in the first few years. POM is mostly carbon.

The right hand side of the diagram (Figure 2) shows how organic matter is created from plant root exudates. Depending on the plant species, 10 to 40 percent of the photosynthates plants make from sunlight can be turned into root exudates. These feed the helpful microbes that live in a thin layer of soil around the roots called the rhizosphere. Microbes return the favour by helping the plants access water and nutrients and help protect the plant against harmful organisms.

Plants can actually change the type of compounds they excrete to favour particular species of microbes when they need their particular help.

Different plant species also put out different kinds of exudates which feed different species of microbes. Some of the exudates are decomposed by the microbes turning them into organic matter. The microbes then put the organic matter inside soil particles, especially clay particles, protecting the organic matter from further decomposition. This organic matter inside the soil particles is called mineral associated organic matter (MAOM). This means that it is MAOM that now lasts from centuries to millennia. MAOM is also mostly carbon but is higher in nitrogen than POM so is the more important store of soil nitrogen which is nearly all in the form of organic matter.

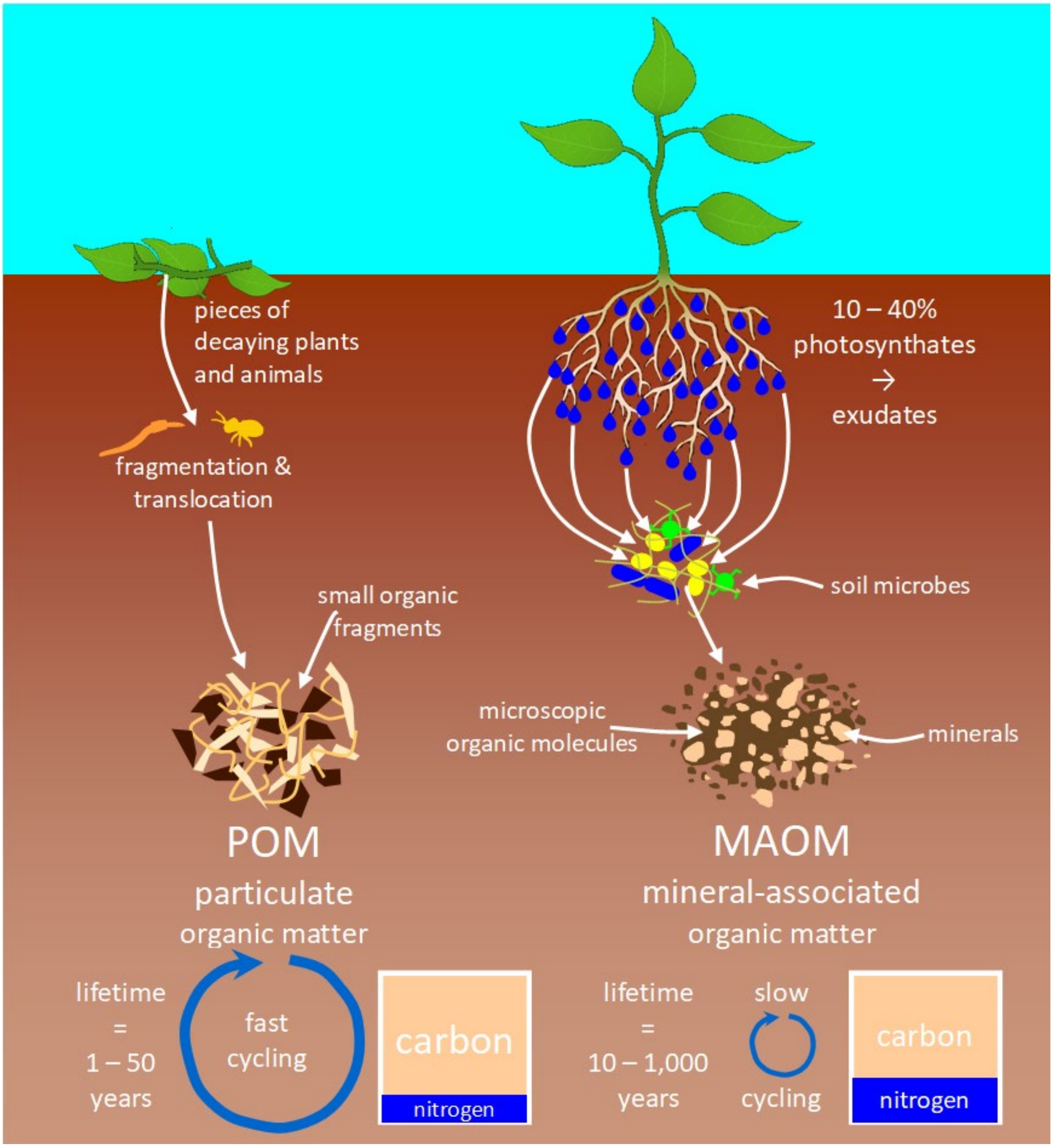


Figure 2. The two main soil organic matter (SOM) formation routes: particulate (POM) and mineral-associated organic matter (MAOM)[3].

[3] Cotrufo, M. F., Lavallee, J. M. & Sparks, D. L. (2022). Soil organic matter formation, persistence, and functioning: A synthesis of current understanding to inform its conservation and regeneration. In Advances in Agronomy (Vol. 172, pp. 1-66): Academic Press. doi:10.1016/bs.agron.2021.11.002 **https://www.sciencedirect.com/science/article/pii/S0065211321001048**

The soil health tests

The DIY soil health tests described in this booklet allow monitoring of mainly physical and biological aspects of soil health, see Figure 3 for an overview of what each test measures and when to do it. Laboratory testing is the primary method for assessing chemical aspects of soil health and for kiwifruit orchards this is usually led or informed by a fertiliser advisor, so this aspect is not included here.

Many of the tests described in this booklet require the soil to be sufficiently moist to be able to dig into them or for the test to work. Silt or clay soils can go very hard when dry so it is recommended to test them when they are moist.

It's also important to test in more than one location. New Zealand soils are quite variable; they are generally young, formed from various air borne volcanic ash showers or water borne mixed ash and weathered rock sediments. Sandy loams or sandy silt loams are common for Bay of Plenty kiwifruit orchards but these are often altered by contouring. One test site may not be representative of the whole orchard, so it is recommended to do a few assessments for each soil type within an orchard.

Soil properties	Test	What it assesses	When to do it	Page
Biological and physical	Spade	Quick diagnostic of multiple soil conditions	When soil moist	7
	Visual soil assessment (VSA)	Comprehensive score based measure of soil health	When soil moist	30
Biological	Decomposition tests	Biological activity	When soil moist	14
	Earthworm counts	Earthworms – indicator species of overall soil health	When soil moist (avoid summer)	16
	Hot water extractable carbon	Microbial biomass – good proxy for overall soil health	Any time	18
Physical	Soil texture	Proportion of clay, sand, silt	Any time	9
	Slake test	Aggregation	Any time	20
	Ring infiltration test	Infiltration, porosity, aggregation	Any time, best when soil moist	22
	Soil probes	Density, compaction, pans	When soil moist	27
	Penetrometers	Density, compaction, pans	When soil moist	28

Figure 3. Overview of soil tests described in this booklet, categorised by soil properties.

For many of the tests, comparing soil from different orchard areas can also be highly informative, for example by collecting and comparing samples from:

- the middle of the vine row, where there should be no machinery compaction,
- right under where the tractor wheels pass, which is likely to be really dense,
- in the centre between the tractor wheels – especially if there is permanent, healthy sward present, and
- areas that are not managed but that have permanent vegetation, such as adjacent bush or riparian areas (not weed-sprayed) or under some trees where there is no foot traffic. These locations give you a baseline for what your soil type looks like when unaffected by management.

These DIY tests are most useful for a quick analysis and/or comparing different parts of the orchard, but except for the more comprehensive Visual Soil Assessment (page 31), the results do not generally offer an absolute score that is easily comparable over time or different locations.

1. THE S.P.A.D.E TEST

When to do it: Anytime.

Where to do it: Anywhere you think there is a problem that needs a quick initial diagnosis.

What it tells you: Quick diagnostic of a range of soil health problems.

Equipment needed: A spade.

Time required: A few minutes.

The **S**oil **P**edology **A**ctive **D**iagnostic **E**valuator, better known as a spade is the most important soil diagnostic tool you have. Any spade will do, though a post hole or ditching spade with a longer blade allows you to dig deeper (Figure 4).

Figure 4. Standard spade left and post hole / ditching spade right.

A spade allows a quick assessment. It helps you to understand what good and bad soil conditions look like. Many of the other soil tests described in this booklet, e.g., VSA (p.31), also require a spade.

Dig a square hole about the width of the spade, to a minimum of the depth of the spade's blade, and ideally down into the top of the sub-soil. Either take a slice of soil out, or have a look at the sides of the hole you have dug, as well as looking at the main pile of excavated soil.

Key questions you need to be asking yourself are:

- How easily did the spade go into the soil? If it slides in with moderate foot pressure, that's great, if you had to jump on it, that's bad especially if the soil is moist throughout the profile.
- Did it start easy and then get hard, or other way around? This indicates compaction at different levels: hard to start with indicates surface compaction, easy to start and then hard indicates a soil pan.

- What does the topsoil structure look like? Is it:
    - A healthy dark colour (due to organic matter) or is it pale or bright orange (suggesting poor contouring)?
    - Are there signs of gleying (sticky, rusty mottling or grey tinged with blue or green) indicating seasonal drainage problems with low soil oxygen content. See example in Figure 5 below.
    - Is it well aggregated, i.e., have a nice crumb structure with lots of holes like a sponge?
    - Does it smell fresh and earthy like a forest floor (healthy), or sour or smelly, particularly the sulphur rotten egg smell (unhealthy)
    - Any earthworms to be seen? One or two is OK, three or more is great.
    - Any pests like grass grub?
    - All of these indicators provide a quick and simple assessment of soil health.

Figure 5. Blue/grey or orange mottling in the soil is an indication of poor drainage.

Further resources

- This is a very comprehensive spade test video from FiBL in Switzerland, in Swiss with subtitles **https://youtu.be/f-kigHj3vbw**
- This video from Iowa State University Extension and Outreach compares among soils in neighbouring paddocks with different cropping histories **https://youtu.be/VB7BAdP8uGs**

2. SOIL TEXTURE TESTS

When to do it: Anytime.

Where to do it: In each part of your orchard that you think may have a different soil type. Contouring activity, slope, aspect, ground cover variation, or varied vine response to the same water and/or nutrient management regime may be indicative of this.

What it tells you: Soil texture describes the relative proportions of sand, silt and clay in a soil. The texture of a soil can influence drainage, how much water and nutrients a soil can hold, how easily vines can access that water and nutrient content, and how easy it is for plant roots to grow.

Equipment needed:

- For the quick 'feel' test: a spade, your hands and a little water.
- For the jar test: a spade, jam jar or similar, dishwash liquid or powder, water, marker pen, ruler and calculator (masking tape is useful too).

Time required: A few minutes plus (for the jar test) settling time of one to three days.

2.1 Background

Soil texture is an important measure that can help with management decisions, as the relative particle size distribution gives soils properties that affect water-holding capacity, permeability and soil workability. Soil texture measurements are most beneficial when taken from different levels in the soil profile, as sub-soil texture has a big effect on drainage in particular. The water-holding capacity of a soil is almost wholly dependent on soil texture.

As shown in Table 1 over page, clays can store water but this water is not readily available to plants, whereas loams can also store water but it is more accessible to plants. Sands have a low water holding capacity due to their nature, low total available water and are very fast draining[4].

As an alternative to the DIY options offered below, soil texture can also be assessed through a laboratory test, on request to a service provider such as Hills Laboratories.

2.2 Sample collection

For both the feel and jar test, choose your sample site and dig down a few inches so you get mostly the mineral soil.

Spread the soil out and remove any pebbles and as much of the bits of roots and fluffy organic matter as you can. Also crush the lumps of soil and ideally sieve through a c. 2 mm sieve. These lumps are actually soil aggregates – a good thing in your soil but they need to be broken down to learn about your soil texture.

[4] From Hills Laboratories Technical Note - Soil Texture Measurement **https://www.hill-laboratories.com/assets/Uploads/52068v1-Technical-Note-Soil-Texture-Measurement.pdf**

Property	Textural class				
	Sands	Sandy loams	Loams	Clay loams	Clays
Total available water	Very low to low	Low to medium	High to medium	Medium to high	Medium to low
Rate of water movement	Very fast	Fast to medium	Medium	Medium to slow	Slow
Drainage rate	Very high	High	Medium	Medium to low	Low
Nutrient supply capacity	Low	Low to medium	Medium	Medium to high	High
Leaching of nutrients & herbicides	High	High to moderate	Moderate	Moderate to low	Low
Tendency to hard setting or surface sealing	Low	High	High to moderate	Medium	Medium to low
Rate of warming after wetting	Rapid	Rapid	Rapid to medium	Medium	Slow
Trafficability & workability after rain or irrigations	Soon	Intermediate	Intermediate	Intermediate	Long
Susceptibility to trafficking	Low*	Moderate	Moderate to high	Low	High

**Sands are naturally in a compacted state and are rarely further compacted by traffic.*

Table 1. Physical properties of soils in different texture classes: A Cass – CRC for Soil and Land management. Sourced from Hills Laboratories[4].

2.3 Jar test method

For easier marking and measurement, place a piece of masking tape down the side of your jar before you start.

Take a clean jar and fill it to one-third with your soil. Then add clean water to about two-thirds of the jar, plus a teaspoon of dishwashing liquid or dishwasher powder. Screw on the lid and shake well, and then let it stand for a day or two.

You will see different layers appearing because the different sizes of the grains settle at different speeds, mark the jar at the top of each layer as it appears or at the end of the settling period. The sand settles first (within about a minute), forming a layer on the bottom of the jar. Afterwards, silt-sized particles – if present – will accumulate on top of the sand (within two to three hours). Clay particles take a long time to settle in water due to their small size, so they will settle last and may take one to three days to do so. You may also see organic matter floating on the surface of the water.

Once the jar has fully settled, use the differences in structure and colour to differentiate the sedimented layers. On the bottom, where particles can clearly be seen - it is sand. The silt above it still has a bit of texture, and the clay on top will appear very dense.

Using a ruler, measure the different layers (the clay layer may be difficult to see, and very small) and note these down as below:

	Height of layer in jar (cm)
A: Sand	
B: Silt	
C: Clay	
A + B + C = D: Total	

You can then estimate the percentage of each sand, silt and clay layer as follows:

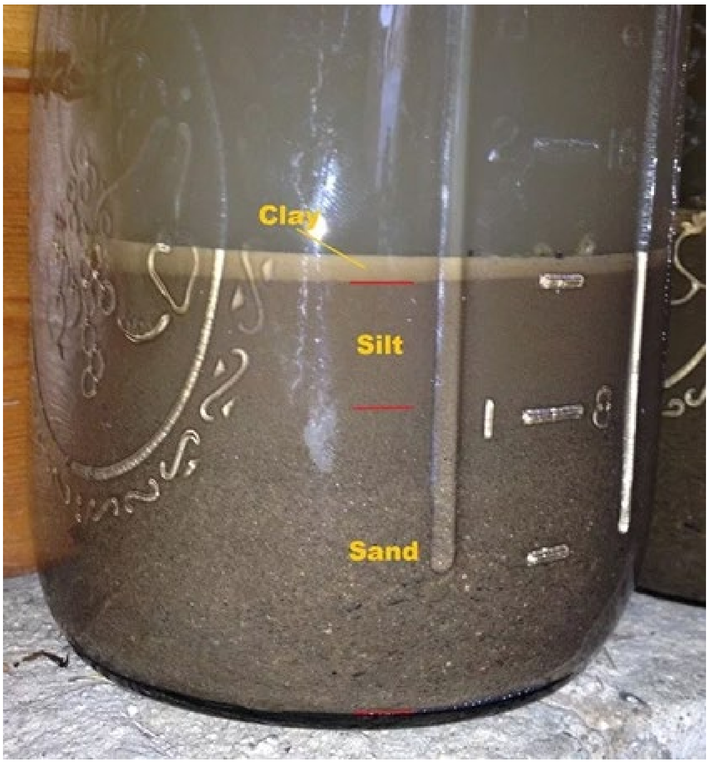
(A ÷ D) x 100 =_______ % SAND

(B ÷ D) x 100 =________ % SILT

(C ÷ D) x 100 =________ % CLAY

Now use the texture triangle (Figure 6, page 12) to work out your soil texture classification.

Track the lines with the percentages measured and find the spot on the triangle where all three lines intersect. The region where these lines intersect indicates the soil texture. The example shown represents a silt loam texture of 25% clay, 45% silt and 30% sand.



An example of a soil texture jar test. Source: permacultureflora.com

HOW TO READ THE TEXTURE DIAGRAM

The **clay percentages** are on the right side of the triangle. Lines corresponding to clay percentages extend from right to left (see red line).

The **sand percentage** is on the left side, with lines extending downward diagonally left to right (see blue line).

The **silt percentage** is on the bottom, with lines extending upward, diagonally left to right (see green line).

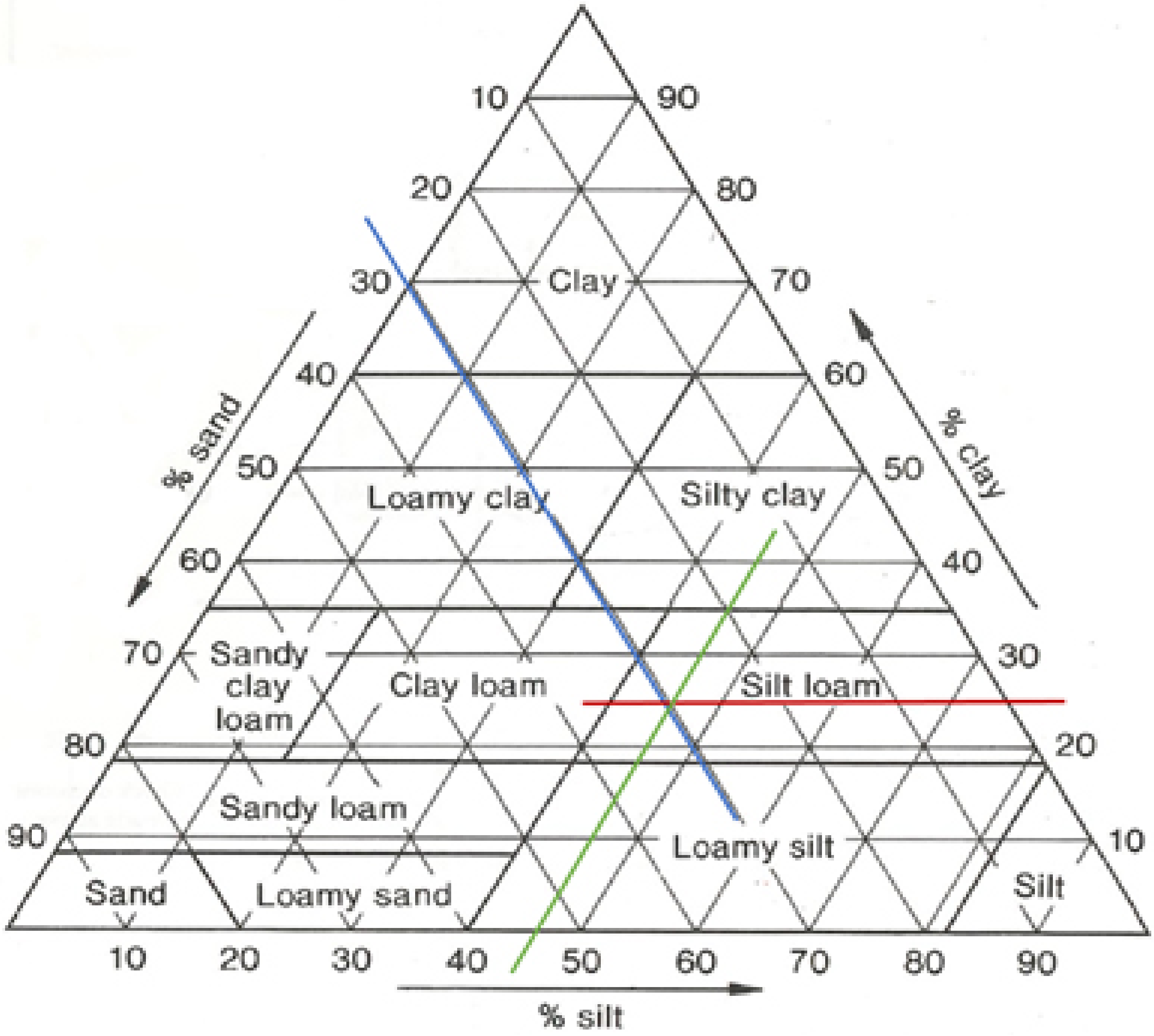


Figure 6. Soil texture triangle. Sourced from Manaaki Whenua Landcare Research.

2.4 Feel test method

Take about a tablespoon of soil in your hand and slowly wet it with some water until you can knead it but it isn't completely soaked. Then follow the flow chart (Figure 7, page 13) to categorise the soil texture based on how it feels.

2.5 Further references

- **https://soils.landcareresearch.co.nz/topics/understanding-soils/get-dirty/**

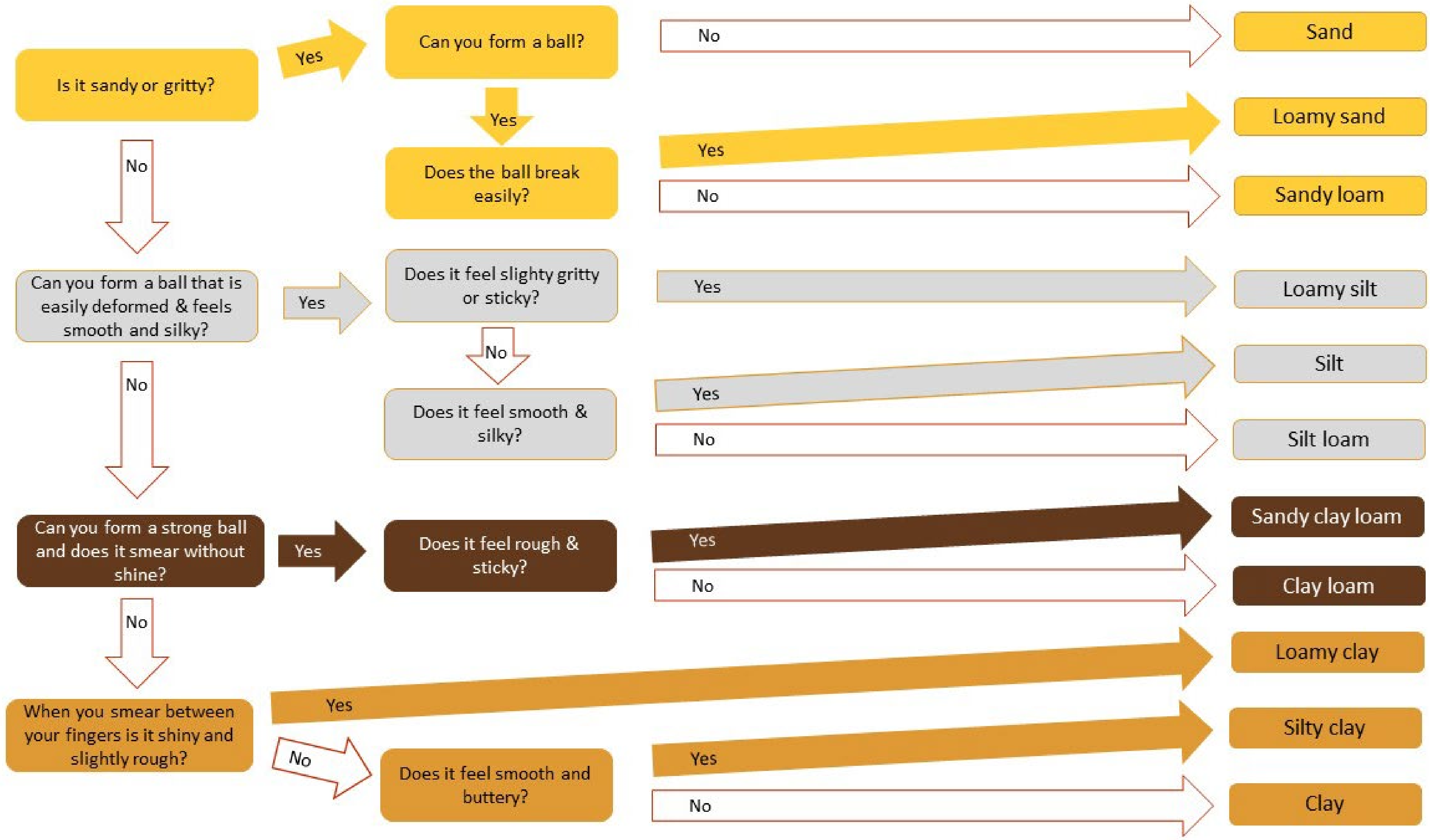


Figure 7 . Flow chart for determining soil texture by feel. Sourced from Manaaki Whenua Landcare Research.

3. DECOMPOSITION TEST – SOIL YOUR UNDIES

When to do it: When the soil is warm and moist – autumn is good.

Where to do it: In any part an orchard.

What it tells you: Level of soil biological activity.

Equipment needed: Either un-dyed thick cotton sheet like calico or white cotton underwear.

Time required: A couple of minutes per items buried, then up to two months waiting time.

3.1 Background

Decomposition tests measure the amount of biological activity in the soil by measuring how fast a piece of buried cotton rots away. Some Oregon farmers had the bright idea of using cotton underwear for the test and the great 'Don't soil your undies' challenge was born; this is now a global phenomenon with national competitions being held, including Otago University and Beef + Lamb running one https://beeflambnz.com/your-levies-at-work/soil-your-undies and Ballance Agri-Nutrients putting a twist on the idea with 'Don't Soil your Singlet' **https://bit.ly/3Pv8QUg**.

Any organic material will work, not just cotton, however, cotton is simple and cheap so it is the favoured option. Any piece of calico or a similar thick cotton fabric can be used.

The cotton provides food for soil organisms so the faster the cotton decomposes the more biological activity there is present in the soil. The difference in decomposition rates between soil types and locations can be phenomenal. Some undies have been dug up after two months and still look new, while others have only the rubber waist band and plastic stitching thread remaining

Soil temperature, moisture and available nitrogen also affect the rate of decomposition, so the test is a useful indicator of those also, but not an accurate measure.

This test works best in spring and particularly autumn, as the soil is more likely to be moist and warm at those times. If soil temperatures are below approximately 8°C it is too cold for soil microbes to function (called biologic zero). No decomposition will occur at this time, making mid-winter an unsuitable time for this test. If the ground is irrigated then summer is also a good time, but, if the soil is dry then it is not.

3.2 Test method

For greatest accuracy use unbleached and un-dyed cotton, such as calico, as the bleaching process can leave residues that are toxic to biology, and likewise some dyes are also toxic. Underpants therefore need to be white. Ideally, wash the cotton on a regular cotton cycle in a washing machine before use to remove any manufacturing contaminants. This will give the most consistent results.

Cut the fabric into pieces that are about the size of a spade blade, e.g. 20 x 15 cm. To get a numerical result, weigh each dry piece of fabric to 1 g accuracy.

In the field, make a vertical slit in the soil with a spade about 20 cm deep. Carefully insert the cotton piece into the slit. Folding the cotton over the bottom edge of the spade and using that to slide the cotton in the slot can help. Leave about 3 cm of cotton, or the waist band of your undies, sticking out above the soil surface to help find them again. Push the soil back so there is good contact with both sides of the cotton piece. Clearly mark where the pieces are they can be found again, then leave them for at least three weeks.

Three weeks is the minimum time in optimum conditions – moist warm soil that is biologically active. Allow up to eight weeks if conditions are less than optimum and the soil is not biologically active. If you're not sure how long to leave the cotton, put several pieces in the soil and then dig them up sequentially, e.g., every fortnight. Carefully retrieve the cotton by digging them up – don't try and pull them up as they are likely to rip.

Figure 8. Decomposition comparison. Fresh cotton undies (left), a pair buried for 24 days (centre) shows mild decomposition, while a pair buried for 51 days (right) shows holes due to decomposition.

3.3 Results assessment

If your soil is really biologically active there won't be any cotton left below the strip or waist band that was above the soil surface. Shorten the test duration next time.

For simple comparisons and a record, take a photo with details of the location. For a more accurate comparison where you had pre-weighed the fabric, carefully wash the soil off (hand wash is probably best as they may disintegrate in a machine), dry and re-weigh. The difference between the weight before and after the test can be used to calculate percent change ((final value – initial value) / initial value) × 100 = percent change, which can be used to compare among different sites and dates.

If you are comparing among different locations ensure all tests are started and evaluated at the same time.

3.4 Further resources

- Oswego Lake Watershed Council undertook a more detailed look at the effect of vegetation type and surface residues on decomposition. There are also good photos of undies with different levels of decomposition **https://www.oswegowatershed.org/soil-your-undies/**
- USDA Natural Resources Conservation Service – Oregon including video **https://www.nrcs.usda.gov/wps/portal/nrcs/detail/or/soils/health/?cid=NRCSEPRD1470410**
- A web search for 'don't soil your undies' will produce a very large number of results!

4. EARTHWORM COUNTS

When to do it: When the ground is moist and at the time every year. June to September is a good time.

Where to do it: Anywhere in the orchard.

What it tells you: Earthworms are an ‘indicator’ species. High numbers indicate healthy soils, while low or no worms indicates lower soil health.

Equipment needed: Spade, small container (e.g., click-clack box) wet on the inside.

Time required: About five minutes per hole.

Most earthworms found in New Zealand orchards and farms are exotic rather than native species. This means that worm species have a patchy distribution so it is possible that you won’t have any or not all types. There are three main types of earthworms:

- Epigeic (surface-dwelling worms) – these inhabit the surface layer without forming permanent burrows. They feed on dung, decaying roots & leaves and other organic residues.
- Endogeic (topsoil worms) – live in the top 20 – 30 cm of the soil (i.e., the topsoil as the name suggests!). They burrow through the soil, eating it and digesting the organic matter in the soil they eat.
- Anecic (deep-burrowing worms) – these have permanent vertical burrows up to three meters deep. They feed by coming to the surface to collect organic matter like dung and leaves and pull this down into their burrows where they eat it.

Earthworms are really important to soil ecology and health. They are often called ‘ecosystem engineers’ due to the pivotal role they play. They feed on the bacteria and fungi that are decomposing organic matter, releasing nutrients to roots, aerating the soil, and improving its structure and aggregate stability as they go.

Pink worm – deep burrower
Aporrectodea rosea

Grey worm – topsoil dweller
Aporrectodea caliginosa

Tiger worm – surface dweller
Eisenia fetida

Figure 9. Common worm types in New Zealand.

4.1. Test method

Dry soil conditions make digging difficult and many worms hibernate at depth when it's dry or very cold, so earthworm counts need to be done when the soil has been wet for some time and not frozen. It's also best to do worm counts at the same time each year as populations also vary a lot over the seasons, this makes late spring an ideal time. Epigenic worms can be attracted to compost, so be aware of the impact of compost applications, especially if banded, on earthworm activity. Earthworms prefer medium-heavy loam to loamy sand soils and don't favour heavy clay or dry sandy soils, so soil texture will also impact your counts.

If you are wanting accurate results to compare over time, use a similar approach as you would for collecting soil cores for your annual soil test: choose a representative area and dig several holes.

Gently dig up a standard spade spit of soil (~20 x 20 x 20 cm). Ideally place the soil on a sheet or board so you don't lose any worms, a small tarp works well. Then break the soil up and sort through it and count the worms. One 20 × 20 cm hole is 1/25th of a square meter, i.e., 25 holes would equal 1 m^2. Multiply the number of worms in each hole by 25 to get the number of worms per m^2.

4.2. Results assessment

Average or ideal worm numbers for New Zealand kiwifruit orchards have yet to be determined; kiwifruit orchards may have inherently lower numbers than other landuses.

- Ballance Agri-nutrients give an indicative value of >20 worms per spade square as a good target for agricultural soil health in New Zealand, noting that dry conditions may reduce this number.
- Winter counts by ARGOS in 2004 and 2006 to assess orchard system differences in New Zealand kiwifruit orchards recorded averages of 90 – 196 worms per m^2 (3 – 8 per spadeful) with the higher values recorded in organic orchards.

4.3. Further resources

- AgResearch's 'The great kiwi worm hunt' has lots of NZ specific info and great pictures of the different species **https://www.agresearch.co.nz/assets/downloads/2021-Great-Kiwi-Earthworm-Survey.pdf**
- FiBL in Europe have a comprehensive earthworm handbook **https://orgprints.org/id/eprint/30567/**
- The Foundation for Arable Research have details on worm counts in their 'Soil Quality on Southland Cropping Farms' booklet **https://www.far.org.nz/assets/files/blog/files//070f33ba-e94c-534b-a73f-6c6cc771b420.pdf**
- Ballance Agri-nutrients soil health resources **https://ballance.co.nz/soil-health**

5. MICROBIAL BIOMASS - HOT WATER EXTRACTABLE CARBON TEST

When to do it: Anytime – as part of your standard soil nutrient tests.

Where to do it: Take a representative sample from across the orchard.

What it tells you: How biologically active your soil is.

Equipment needed: Standard soil test corer.

Time required: About twenty minutes for a one hectare vineyard or orchard

The hot water extractable carbon test (HWEC) is an inexpensive laboratory test. It can be done as part of standard nutrient soil testing so just needs an extra tick on your annual soil test order form.

The test gives an indirect measurement of microbial biomass which is the living part of soil organic matter and the most important. It is the microbes in the soil, often called soil biology, that drives soil health. Unlike total soil organic matter which changes quite slowly in reaction to changes in management (e.g., using cover crops, living mulches under the vines), microbial biomass responds more quickly to management changes. Regular testing will also give you an early indication if soil health is changing for good or bad.

Directly measuring microbial biomass is difficult and expensive but measuring hot water soluble soil organic carbon compounds gives a good approximation of microbial biomass. The hot water extractable carbon test involves soaking a measured amount of soil in hot water for a specified time and then measuring the amount of carbon that is dissolved in the water.

HWEC results also strongly correlate with other soil health indicators such as mineralisable nitrogen (min-N), carbohydrates, and physical indicators such as aggregation. It is therefore also a good measure of overall soil health. As a lab test it's highly standardised and comparable across different soils, times etc.

Guideline or target values have not yet been established New Zealand kiwifruit orchards, however regular testing and recording of HWEC can be useful for detecting shifts over time in response to changes in orchard management practice, or due to climate change.

Hill Laboratories advice is that typical measurements for HWEC in New Zealand soils range from 500 -13,000 mg/kg. General interpretive ranges are shown in Table 2 below.

Level	Hot Water Extractable C (mg/kg)
Very low	<350
Low	350 – 1000
Medium	1000 – 3500
High	3500 – 7500
Very high	>7500

Table 2. General interpretive ranges for HWEC in New Zealand soils[5]

[5] From Hill Laboratories Technical Note - Laboratory Tests for Soil Carbon **https://www.hill-laboratories.com/assets/Documents/Technical-Notes/Agriculture/40922v3-Technical-Note-Laboratory-Tests-for-Soil-Carbon.pdf**

5.1. Further information

- **https://www.hill-laboratories.com/about-us/news/more-value-from-hot-water-soil-tests/**
- **https://www.hill-laboratories.com/assets/Documents/Technical-Notes/Agriculture/40922v3-Technical-Note-Laboratory-Tests-for-Soil-Carbon.pdf**

6. SLAKE TEST FOR AGGREGATE STABILITY

When to do it: Anytime but soil needs to be reasonably dry.

Where to do it: In field or in the shed.

What it tells you: How stable your soil aggregates are.

Equipment needed: Largish transparent jars with wide mouths, some 1 cm hole wire mesh, water to fill the jar, and soil clods that fit inside the jar mouth.

Time required: Minutes to a few hours.

6.1. Background

The slake test is really impactful as it quickly and visually shows you how stable your soil aggregates are i.e., how resistant they are to breaking apart. This is known in soil science as 'ag stab'!

When a chunk of topsoil is placed into water, the water is drawn into the soil and displaces air. If the large pores within the soil are stable, water can move into the soil without causing the aggregate to break apart ("slake").

Good aggregate stability is a great indicator of the overall health of your soil. It's also a quick and simple test – much less work than ring infiltrometers for example. However, it does not give any numerical results, so its best used for comparing among soils from different locations within an orchard.

Both soil type and organic matter have an impact on soil aggregation. Biological processes such as earthworm burrowing, fungal and bacterial activity, root growth and decomposition, all contribute to soil aggregation and the stability of macropores. Clay soils form strong aggregates, while sandy soils can only form weak aggregates. Soils with high organic matter form more stable aggregates that are resilient to erosion and slaking.

Start of test

After one hour

Figure 103. Slake test of unhealthy (left jar) and healthy soil (right jar) shown at start of slake test and after one hour.

6.2. Test method

Set up your test by finding a transparent glass or plastic jar for each soil sample you wish test. Wide-mouthed jars are best, an alternative is to cut the top off a clear plastic fizzy drink bottle. You'll also need some wire mesh with approximately 1 cm sized holes in it (can be square or round holes). Use the wire mesh to make a small basket in the mouth of each jar – deep enough to hold a clod of soil up to five centimetres in diameter.

Dig up some soil from the areas you want to test. Pick out a single clod of soil that's between three to five centimetres in size; the exact size doesn't matter, it just needs to fit into the wire basket in the jar. The soil needs to be relatively dry – moist soil does not work so well. If the soil is moist, air dry it first at ambient temperatures for several days.

To start the test, fill the jar with water so that when you put a clod of soil into the wire basket it will be immersed in the water. Pop a clod of dry soil into the wire basket and watch with wonder.

6.3. Results assessment

If you have healthy, well aggregated soil, virtually nothing will happen – a few pieces may fall off the clod, and the water will remain clear. If your soil is in really poor health or not yet well-aggregated, then the clod will disintegrate before your eyes into a murky soil soup as in Figure 10. The video links in the further resources section below also show this really well.

6.4. Further resources

- University of Wisconsin College of Agriculture and Life Sciences have a comprehensive video on both infiltration and slake tests – the latter starts at 2 minutes 22 seconds. **https://youtu.be/d1M7EFqqsMM**
- University of Wisconsin College of Agriculture and Life Sciences one page handout with links to additional videos **https://fyi.extension.wisc.edu/danecountyag/files/2020/02/Slake-test-handout.pdf**

7. RING INFILTRATION TEST

When to do it: Best when the soil is moist.

Where to do it: Anywhere – this is a good comparative test for different areas.

What it tells you: The infiltration rate of your soil (how fast water can get into your soil) which indicates how good your soil structure is.

Equipment needed: Infiltrometer rings (make your own), piece of wood, lump hammer or mallet, container of water, timing device (watch, phone), water measuring device (optional), glad wrap (optional).

Time required: Varies. A few minutes per ring to setup. Infiltration of the water can range from a few minutes to hours.

7.1. Background

Infiltration is the ability of water from rain and irrigation to enter your soil. This depends on your soil's texture, structure and aggregation. If it is well structured, like a bath sponge, then water can infiltrate quickly. Poor structure can result in the water hardly infiltrating and ponding occurs. There is also the related term 'porosity' that describes how well water can travel down through the soil profile. Infiltration and porosity are therefore related.

Infiltration rate is simply the depth of water that will soak into the soil in one hour. Table 3 gives the infiltration rates for different levels of soil structure. As discussed further below, this varies with soil texture.

Rate of water entry (mm/hr)	Description	Soil structure assessment
0-10	Slow	Very poor structure
10-20	Moderately slow	Poor structure
20-70	Moderate	Moderate structure
> 70	Rapid	Good structure

Table 3. Soil structural assessment based on water infiltration rate.

Infiltration rate also directly relates to rainfall or irrigation, both in amount and intensity. Twenty-five millimetres (mm) of rainfall, means a 25 mm depth of rain has fallen (or 25 litres onto every square metre of ground). The rate of rainfall, e.g., 25 mm in an hour directly relates to the ability of a soil to absorb that rate of water and whether all of it will infiltrate the soil or if some will run off across the surface.

Soil texture (type) also has a large impact on infiltration rates; sandy soils drain very freely, silts have medium infiltration, and clays have the lowest infiltration rates. If comparing infiltration among different soil types this needs to be taken into account. This is important when designing irrigation and water-based frost protection systems.

The ring infiltration test is also an accurate soil science research tool used to measure infiltration rate. It uses purposely designed rings and detailed procedures to ensure accurate and consistent results. The approach described here is a simplified version for grower use that still gives good quality numerical results that can be compared across time and location.

7.2. Equipment and test methods

A ring (short piece of pipe) is driven into the soil and filled with water. The time for the water to disappear from the above-ground portion of the pipe and infiltrate into the soil is recorded. Research grade rings are made of metal and are some 20 to 30 cm in diameter. For grower purposes, sturdy plastic is fine unless you have stony soil and / or plan to do a lot of testing, as the edge on a plastic ring will get damaged.

It is important that the wall of your chosen ring is not too thick, 3 mm is the ideal maximum, otherwise the soil will be too disturbed when the ring is driven into the ground. An advantage of metal rings is they can have thin walls but are strong. Guttering down-pipe and other forms of thin walled, hard plastic pipe, e.g., sewerage pipes also work well (Figure 11).

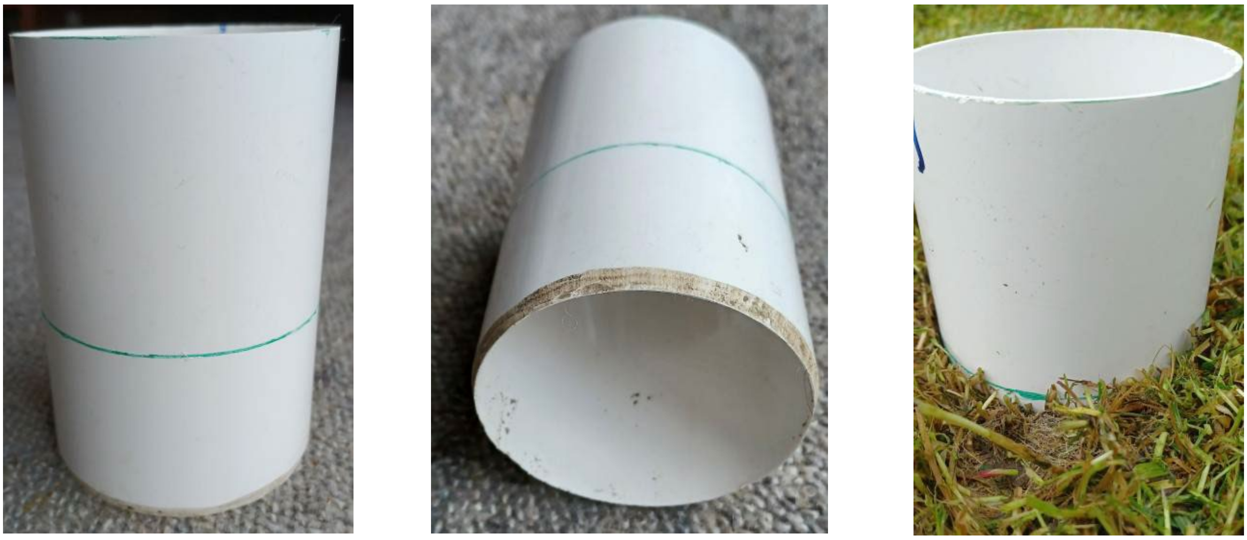


Figure 11. Ring infiltrometer made from 12 cm long, 8 cm diameter guttering down pipe, showing sharpened end for driving into soil and inserted into the soil to the depth mark.

The pipe can be almost any diameter, but the larger the diameter the more soil is enclosed and therefore the more accurate the result. Bigger also means more water to carry around. Eight centimetres is considered to be the minimum viable diameter (Figure 10).

Ring length is also not fixed but 10 cm is the minimum ring length to aim for and 15 cm would allow more water to be used, again improving accuracy. Sharpen one end of the ring on the outside as shown in Figure 11, to make it easier to drive the ring into the soil.

Mark a clearly visible line on the outside of the ring, 5 cm (2") from the sharpened end of the pipe. A mortise gauge is handy to do this accurately. This marked distance is critical, as the ring needs to be pushed deep enough into the soil to minimise the sideways movement of water but not so deep that the water has to travel a long way down the ring before it can exit.

Clear the test location from as much vegetation and residues, such as twigs and leaves as possible (Figure 12), making sure you don't stand or walk on the test area.

Figure 12. Ground preparation – clearing as much vegetation and residue from the test location as possible.

Figure 13. Simple method for driving ring into ground – wooden batten and club hammer.

As soils are inherently variable even across small distances, several tests should be undertaken for each location. Putting multiple rings in place so you can run the test at the same time in different spots can be helpful, however if there are too many you won't be able to keep an eye on all of them.

The test is best done on soil that is close to, but not completely at field capacity[6], as pushing rings into hard dry soil also causes the soil to shatter rendering the results invalid. Soil moisture also has a major impact on the rate of infiltration – dry soil will take the water in much faster. If the soil is not moist enough and the test cannot wait, you can dampen the soil by placing a few layers of hessian (eg., sacks) on the test spots and then place a bucket with a small hole (e.g., 2 mm) in the bottom, onto the hessian and fill the bucket with water. Leave the bucket and hessian for at least 24 hours, allowing the water to properly disperse through the soil, i.e., so it is not waterlogged.

Set up the test by driving a ring into the ground using a wooden batten and a mallet or club hammer (see Figure 13), making sure it goes in absolutely vertically and without wobbling side to side as it goes in. If it does go askew, remove it and start on a new location. If the ring wobbles as it is driven it, it creates gaps in the soil down the side of the ring, where the water will preferentially drain, invalidating the test. Drive the ring into the ground until the line marked at 5 cm on the outside is exactly level with the soil surface.

A fancier approach involves using a hole saw to cut an approximately 4 cm deep, circular slot into the piece of wood that the ring can snugly fit into (Figure 14); this keeps the wood stable on the ring as it is driven into the ground, making it easier to get the ring in vertically without wobbling. Use the hole saw in a drill press to ensure the slot is exactly vertical. This can be made even easier by adding a shaft to the piece of wood that allows the ring to be driven in from a standing position. This not only saves older knees and backs, but it helps to make sure the ring goes in perfectly vertical.

[6] Field capacity (full point) is the soil moisture level that remains after excess water (such as from significant rainfall) has drained away and the drainage rate has slowed - usually two to three days after a significant rain event.

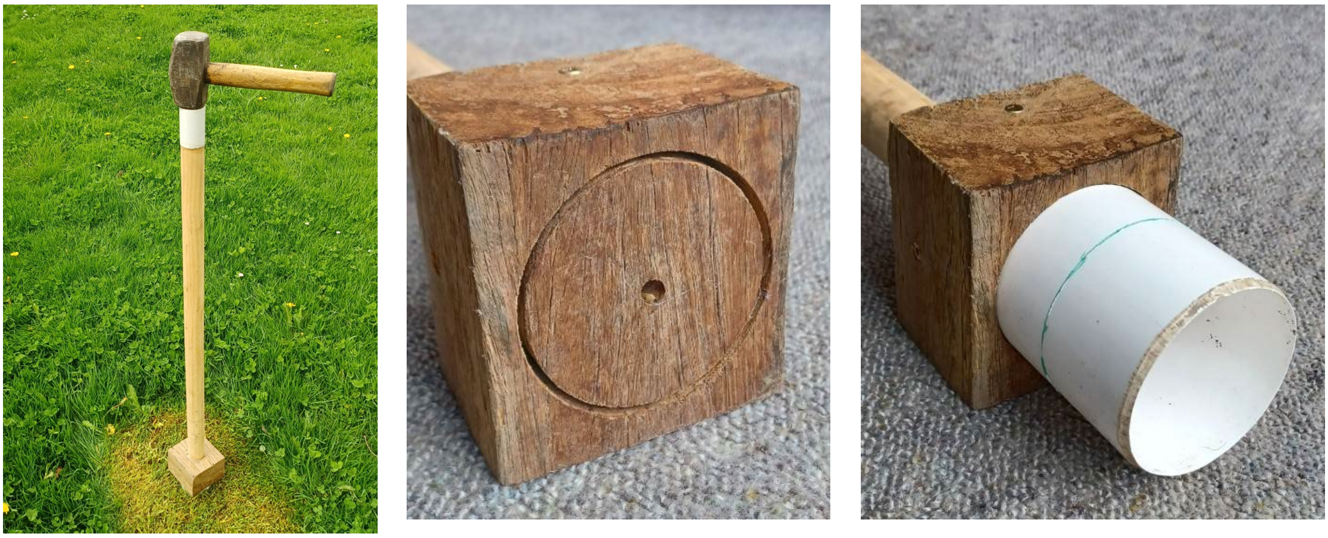


Figure 14. 'Fancy' ring driver, with 4 cm deep slot cut in a wood block with hole saw, that the ring snugly fits in with a thick wood shaft to allow ring to be driven from standing position.

7.2.1. Adding the water

Use clean water for the test.

To get the most precise results, the rings are often filled multiple times, even if the ground has been pre-wetted as described above. Often the first batch of water will soak in quite quickly and then slow down. Some tests recommend doing a fixed number of batches, e.g., two or three, others require that the infiltration time stabilises, i.e., two consecutive runs that take the same time. While providing greater accuracy this can become very time consuming, especially on low permeability soils.

It is important to put the water into the ring gently, so as not to stir up the soil as fast application will clog the soil pores and invalidate the test. If the test is being done where there is vegetation covering the soil and holding it together, such as pasture, then it is possible to just gently pour the water into the ring. Where the soil is bare, and especially where it has been cultivated, more advanced techniques are required.

Figure 15. Infiltration ring filled with water.

Professional ring infiltrometers have specialist diffusers to minimise water impact. In America the 'glad wrap' technique is popular; a piece of glad wrap is put inside the bottom of the ring and up and over the sides, the water is then poured into the glad wrap, which is then carefully pulled away. See the videos in the further resources section below for demonstrations.

The depth of the water in the rings also impacts the rate of infiltration; a greater depth of water will exert more pressure. Having more than 15 cm depth of water is not recommended.

7.2.2. Results assessment

If you are 'just' interested in comparing among a number of locations in the same area (mid-row, wheel tracks etc.) then you can simply fill each ring to the top and time how long it takes for all the water to soak into the ground, to the point that the surface is glistening. You can then compare the times taken for the different test locations and also at different dates. However, this does not tell you what your actual infiltration rate is.

If you want to **measure** your infiltration rate then you need to use a known amount of water. The simplest way this is done is by having an internal mark inside the ring 50 mm up from the mark on the outside that indicates soil level. When the ring is filled with water is up to the 50 mm mark it thus equals 50 mm of rainfall. Time how long it takes for all the water to infiltrate into the soil so the surface is just glistening. To calculate the hourly soil infiltration rate; divide 60 (i.e., 60 minutes in an hour) by the number of minutes the water took to disappear and then multiply that by the depth of water i.e., 50 mm. For example if it took two hours (120 minutes) for the water to disappear and there was 50 mm of water (N.B. millimetres), 60 ÷ 120 = 0.5. Multiply the 0.5 x 50 mm = 25 mm/hr infiltration rate.

There are also a range of other approaches to measuring the rate, a number of which are shown in the videos and written materials listed in 'further resources' below.

7.3. Further resources

- Murray Catchment Management Authority short video demonstrating ring insertion and water filling, using the between the lines timing technique **https://youtu.be/YsEYs3YfkKE**
- Tennessee State University Extension detailed video showing using the glad wrap and measured amount of water methods **https://youtu.be/9KSdTFHA_E4**
- University of Nebraska – Lincoln detailed video using the glad wrap and measured amount of water methods **https://youtu.be/iz415J3AOI4**
- University of Wisconsin College of Agriculture and Life Sciences have a comprehensive video on both infiltration and slake tests **https://youtu.be/d1M7EFqqsMM**
- Australian Wine Research Institute - Vineyard activity guides: Measuring the infiltration rate of water into soil using the ring infiltrometer method **https://www.awri.com.au/wp-content/uploads/v_activity_infiltration_rate.pdf**

8. SOIL PROBES AND PENETROMETERS - TO MEASURE SOIL DENSITY AND COMPACTION

When to do it: When soil is moist especially on silt and clay soils.

Where to do it: Anywhere you think there could be problems and as a comparison among different areas.

What it tells you: How dense (tight) soil is and whether compaction layers (pans) are present.

Equipment needed: A soil probe or penetrometer

Time required: A few seconds per spot.

8.1. Soil probe

Soil probes are relatively cheap $100-300 (or make your own), robust, and are simple to use. A soil probe is a stiff steel rod, about half an inch wide and a metre long with a handle (Figure 16). The tip is pointed and slightly wider than the rod so it is easier to pull it back out of the soil.

Figure 16. Soil probe.

This test involves simply pushing the probe into the ground to 'feel':

- how dense the soil is – does it slide in easily or does it take some effort?
    - Soil moisture can make a big difference to how easy it is to insert a probe so this is best done when soil is moist - ideally several days after rain or irrigation.
    - The harder it is to insert the probe, the poorer the soil structure and/ or compaction level, both of which impact root health and root growth.
- if there are compact layers, the pressure to get the probe into the ground will change as you push the probe down.
    - If it starts easily, then goes hard, then soft again, this a sure indication of a pan, i.e., a thin (~5 cm) layer of particularly dense soil that is likely to be too hard for roots and other soil organisms, such as worms, to penetrate.
    - changes in soil layers / stones, through changed resistance and also the sound of the probe tip scraping past the stones.

A key advantage of a probe over a spade is it's really quick to push into the ground so you can do many more tests and also get much deeper than is practical with a spade. The two tools complement each other well though, for example, a probe can be used to find areas with a pan and then the spade used to excavate to find out more about the pan.

You can also use a probe to find buried items like irrigation mains. **N.B. check there are no electrical cables in the area as the probe could push through the insulation and electrocute the user.**

8.2. Penetrometers

A penetrometer (Figure 17) is the same as a probe but it also measures how much force is required to push the rod into the soil.

Soil penetrometers allow a more quantitative assessment of soil density than a standard probe. The disadvantage of a penetrometer is they are more expensive and delicate than a basic probe.

Figure 17. Soil penetrometer.

Soil density determines how easily plant roots can penetrate soil. Roots push through soil in a similar fashion to the penetrometer.

Most penetrometers are the mechanical dial type – these are the less expensive option. Digital versions which have additional functions, such as measuring depth and pressure at the same time, are also available but generally unnecessary for most orchard situations.

Getting an accurate reading from a penetrometer takes a bit of skill. Pushing too hard or fast will give an artificially high reading – you need to push at a steady and constant rate and pressure. Soil moisture has a big impact on resistance; the best reading will be achieved when the soil is well moistened. However, if the soil is too wet, compaction could be underestimated because the soil acts as a liquid. If the soil is too dry, compaction could be overestimated because roots will be able to more easily penetrate the soil as it becomes wetter. Consistency in how the penetrometer is used and soil moisture content is key for obtaining meaningful results and for comparing between years and timings.

The ability of roots to penetrate soil reduces linearly from 0 to 200 PSI (0 to 14 bar). As a general guide, root penetration will be very limited between 200 and 300 PSI (14 to 21 bar) and above 300 PSI (21 bar) roots cannot penetrate the soil at all.

8.3. Further resources

- A detailed video from University of Wisconsin Integrated Pest and Crop Management **https://youtu.be/Zq_785JqRq8**
- More detailed information from Penn State University Extension "Diagnosing Soil Compaction Using a Penetrometer (Soil Compaction Tester)" **https://extension.psu.edu/diagnosing-soil-compaction-using-a-penetrometer-soil-compaction-tester**

9. VISUAL SOIL ASSESSMENT [VSA]—THE GOLD STANDARD

When to do it: When soils are moist.

Where to do it: Several representative locations or as a comparison of different areas.

What it tells you: It gives you a scored assessment of your overall soil health as well as a soil education.

Equipment needed: A spade, plastic basin, hard board that fits in the bottom of the basin, thick plastic bag, knife, water bottle, tape measure, VSA orchard field guide, score cards. A new abridged version of the test has been brought out which has a reduced equipment list and streamlined testing procedure.

Time required: Twenty five minutes per site.

9.1. Background

Visual soil assessment (VSA) is the gold standard of farming systems for soil testing. VSA was developed in 1999 by Graham Shepherd to provide farmers and growers with a rigorous way of assessing their soils. VSA was validated by researchers at Manaaki Whenua – Landcare Research and several other New Zealand research organisations. It is now used globally, particularly in temperate climatic areas, and is supported and recommended by the Food and Agriculture Organization (FAO).

VSA is a suite of integrated tests, and includes some of the tests listed earlier in this booklet such as worm counts. VSA has also been customised for different production systems including for vineyards and orchards.

If you want to do the most thorough, comprehensive and accurate DIY soil health, a VSA is what you need.

9.2. Test method

A VSA involves digging up a section of soil – same as for the worm counts. Then you work your way through a score card listing a range of assessments to score indicators such as soil structure, porosity, colour, mottles, and then earthworms, soil smell, rooting depth, and ponding. These scores are then weighted and added up to give an overall soil health score.

See the references section below for links to VSA resources. They include detailed instructions with pictures for each assessment. The way the tests are done also addresses issues such as different soil textures affecting test results (as noted for many of the tests in this booklet) so that scores are comparable among quite different production systems, soil types etc.

9.3. Further information

- For more information on VSA visit Mr Shepherd's website **https://www.bioagrinomics.com/visual-soil-assessment**.
- The orchard VSA guide which is generic for all perennial woody crop including kiwifruit is **https://www.fao.org/docrep/pdf/010/i0007e/i0007e03.pdf**