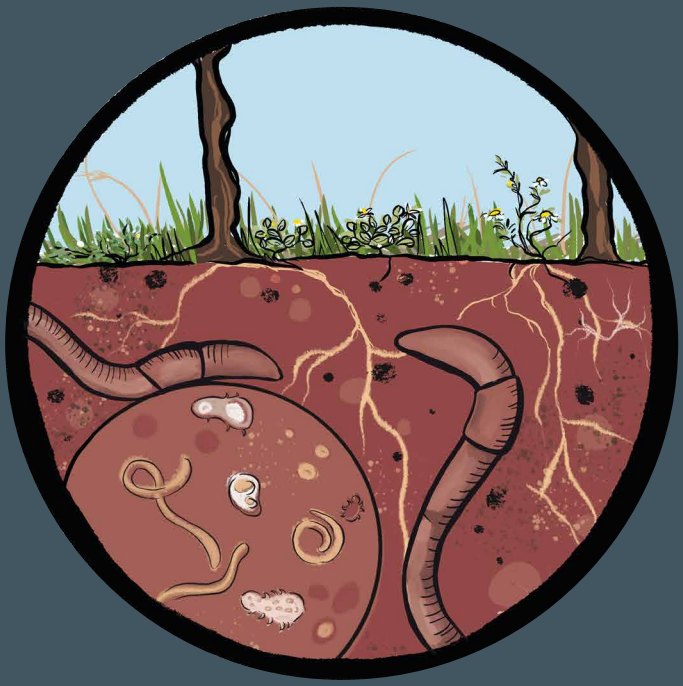
SOIL HEALTH INDICATORS

FOR AUSTRALIAN VINEYARDS

BY DR MARY RETALLACK



ECO VINEYARDS
GROWING RESILIENCE NATURALLY

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ACKNOWLEDGEMENT OF COUNTRY

EcoVineyards proudly acknowledge the Aboriginal and Torres Strait Islander Peoples, and their ongoing cutural and spiritual connection to this ancient land on which we work and live.

As the Traditional custodians we recognise theirwealth of ecological knowledge and the importance of caring for Country.

We pay our respect to elders past and present and extend this respect to all Aboriginal and Torres Strait Islander Peoples.

CONTENTS

1 EARTHWORMS

WHAT: Earthworms are often referred to as 'ecosystem engineers' as they help to decompose plant material to increase plant available nutrients, aerate and create soil pores which in turn improves soil structure and aggregate stability.

An earthworm has a long digestive tract with a gizzard that grinds both live and dead organic matter to produce finely ground and nutrient rich casts.

Did you know that earthworms do not have lungs but breathe through their skin.

They avoid dry soil as they need to keep their skin moist to breathe and they do not like waterlogged soil because they may drown.

Soil moisture, aeration, temperature, and texture affect earthworm populations. Little or no organic residues in the soil and/or high soil temperature and low soil moisture are stressful to earthworms.

- Earthworms prefer temperatures below 30°C and a pH of 6 to 7, they are most active in late autumn to early spring
- They live in soils with good soil structure with sufficient pores to retain moisture and air, and minimal soil disturbance is important
- They need access to organic matter and their abundance and activity may reflect the amount and quality of plant residues available
- Pesticides that are used to control insects, fungal and bacterial diseases can be very toxic to earthworms, and they will avoid areas that have been heavily dosed with these chemicals including ammonia-based fertilisers and/or regular use of cumulative chemicals such as copper.

There are certain pesticide families that are considered as harmful to earthworms i.e. neonicotinoids, strobilurins, sulfonylureas, triazoles, carbamates and organophosphates (Pelosi et al., 2014).

There are over 1,000 species of native earthworms in Australia and approximately 80 introduced species that are also beneficial.

Introduced species may dominate and their distribution can be patchy, as they were originally introduced with plants transported from Europe.

There are three main types of earthworms that you are likely to see in the soil:

- **Surface dwellers (epigeic)** – inhabit the surface layer, in compost or dung piles near the soil surface without forming permanent burrows. They feed on decaying roots and leaves and other organic residues and detritus (i.e. *Lumbricus rubellus,* red marsh worm, red wriggler, dung worm).
- **Topsoil (endogeic)** – live in the top 20cm of topsoil and eat large amounts of soil and the organic matter in it, although species sometimes come to the surface to search for food (i.e. *Aporrectodea caliginosa,* grey worm, small field worm; *Aporrectodea trapezoides,* southern worm; *Aporrectodea rosea*, pink worm, rosy tip worm).
- **Deep burrowers (anecic)** – live in permanent burrows up to 3m deep. They feed by coming to the surface to collect organic matter and pull this down into their burrows where they consume it (i.e. *Aporrectodea longa,* black-headed worm, large field worm; *Octolasion cyaneum,* blue-grey worm; *Megascolides australis,* giant Gippsland earthworm).

Earthworms are active in the surface layer of soil in the cooler, wetter months of May to September once the soil has been moist for several weeks.

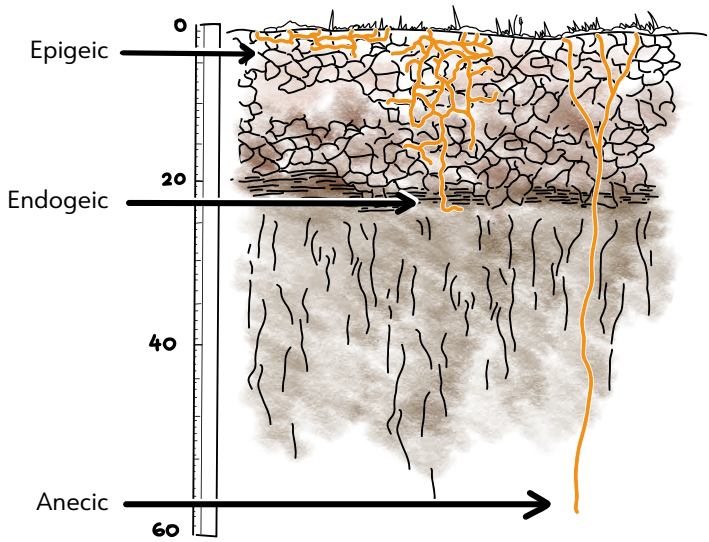


FIGURE 1: The preferred habitat of three main types of earthworms

Around Adelaide, South Australia *Gemascolex stirlingi*, giant Mount Lofty earthworm is commonly found. The endangered *Megascolides australis*, giant Gippsland earthworm is found in the Gippsland region of Victoria. Both species are native to Australia.

However, introduced species of earthworms are most commonly distributed across south-eastern Australia.

Aporrectodea trapezoides, southern worm as well as *Aporrectodea caliginosa*, grey worm or small field worm is often found in the highest densities along with *Aporrectodea rosea,* pink worm.

Eisenia fetida, the tiger or common compost earthworm is rarely found in agricultural soils, as it thrives on rotting vegetation, compost and manure and they are commonly used in the process of vermicomposting.

Earthworm ID

It may be difficult to see the colouring and tell which is the head of an earthworm, which is located on the end closest to the swollen band, called the clitellum (or saddle), that encircles the animal.

To identify all the features clearly, wash the earthworm and it will often stretch out and the colouring will also be clearer to see.

It is best to identify mature earthworms as colours can change with maturity. Adults (or sexually mature) earthworms can be easily recognised through the presence of the saddle.

To differentiate between native and exotic earthworms, count the segments between the head and the saddle:

- native earthworms have less than 20 segments
- exotic earthworms have more than 20 segments.

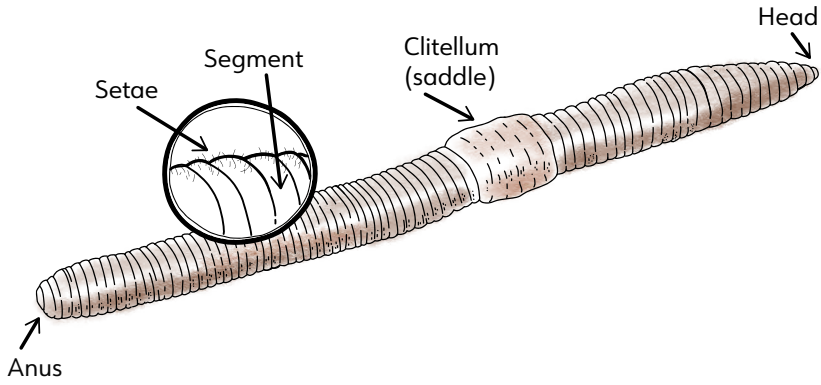


FIGURE 2: Earthworm diagnostic features

Commonly found earthworms in Australia and distribution

red marsh worm, red wriggler, dung worm, *Lumbricus rubellus*

Colour: reddish brown or reddish violet, iridescent dorsally, and pale yellow ventrally, wriggles vigorously when handled

Size: length 50 to 130 mm

Location: epigeic, generally found in dung and/or areas of high fertility (not often found in paddocks)

Photo: James Lindsey (CC BY-SA 3.0)

pink worm, rosy tip worm, *Aporrectodea rosea*

Colour: pale pink or grey with pink head region, prominent red vein on the upper side of the body

Size: length 25 to 40 mm; diameter 2.5 to 4 mm

Location: endogeic, found to a depth of 10 cm

Photo: nzwormdoctor (CC BY-NC)

orange-saddle worm, *Microscolex dubius*

Colour: pale, white to yellow with an orange saddle with a white tipped tail

Size: length 40 to 60 mm; diameter 2.5 to 4 mm

Location: thought to dominate recently disturbed soils

Photo: Σάββας Ζαφειρίου (CC BY-SA 3.0)

FIGURE 3: Commonly found earthworm species in Australia. Distribution maps of Australia [ALA, CC BY 3.0 AU]

southern worm, *Aporrectodea trapezoides*

Colour: dark grey/black along the entire upper length of the body and pale on underside

Size: length 80 to 140 mm; diameter 3.5 to 8 mm

Location: endogeic, active to about 20 cm depth; close to roots

Photo: Mike Hedde (CC-BY-NC 4.0)

grey worm, small field worm, *Aporrectodea caliginosa*

Colour: pale pink above the saddle

Size: length 60 to 80 mm; diameter 2 to 4 mm

Location: endogeic, found to a depth of 20 cm

Photo: Chih-Han Chang (Wikipedia)

blue-grey worm, *Octolasion cyaneum*

Colour: yellow pigment on tail (4 segments), and sometimes before saddle

Size: length 80 to 180mm; diameter 5 to 8 mm

Location: anecic, creates large, deep burrows, active to soil depth of 40 cm

Photo: James K. Douch (CC BY-SA 3.0)

black-headed worm, large field worm, *Aporrectodea longa*

Colour: dark grey black around the head (on the dorsal side), with the rest of the body pale brown area in front of saddle (head end) is darker than area behind saddle (tail end)

Size: length 100 to 170 mm; diameter 4 to 9 mm

Location: anecic, burrows down to around 200 cm and produces large casts at burrow head

Photo: Malcolm Storey, 2009, www.bioimages.org.uk

giant Mount Lofty earthworm, *Gemascolex stirlingi*

Colour: reddish, brown, grey with a pink saddle

Size: length 200 to 250mm; diameter 10 mm

Location: will come to the surface during rain events

Distribution: in and around the Mount Lofty Ranges, South Australia

Photo: Emma Linsenmeier (CC-BY-NC 4.0 (Int))

giant Gippsland earthworm, *Megascolides australis*

Colour: dark purple head and a blue-grey body

Size: length average 800 mm (can grow up to 3,000 mm); diameter 20 mm

Location: anecic, the subsoil along stream banks

Distribution: Gippsland, Victoria

Photo: isabelleabwood (CC BY-NC)

FIGURE 3: Commonly found earthworm species in Australia. Distribution maps of Australia [ALA, CC BY 3.0 AU]

WHY: Higher numbers of earthworms indicate conditions that are favourable (soil moisture, organic matter, and low chemical residues) for soil health and plant growth.

Water and plant roots can penetrate more readily where earthworms have burrowed. Nutrient rich castings deposited by earthworms are rich in phosphorus and nitrogen, as well as beneficial bacteria and fungi which can help to increase crop yields.

Earthworms help to aerate the soil, facilitate root growth, improve water infiltration, reduce surface runoff, incorporate dead plant matter into the soil, decompose dead plant matter, increase plant-nutrient availability, help to improve soil structure and stability, they act as biocontrol propagators, help control soil borne pests and support carbon sequestration.

HOW: Carry out earthworm counts between May to September when the ground has been moist for several weeks and at the same time each year. You may wish to compare the number of earthworms found between an undisturbed and disturbed site.

Count the number of earthworms that are longer than 25 mm in an intact spade full of soil (20 cm wide x 20 cm deep).

Put the soil on a light-coloured sheet or board so you don't lose any of the earthworms. Take 3 to 5 samples from a representative area and average the result.

One 20 x 20 cm sample is 1/25th of a square metre. i.e. 25 samples would equal 1 m^2.

Multiply the number of earthworms in each sample hole by 25 to get the number of earthworms per m^2.

ASSESSMENT TOOLS: Shovel, light coloured sheet or board, a small container to collect the earthworms (with a layer of wet cloth in the bottom to keep the worms moist) and some water to wash the worms to assist with identification.

FIGURE 4: Counting earthworms in a vineyard [Photos: Mary Retallack]

Earthworm count

Scoring guide	Poor	Moderate	Good	Very good
Score	**0**	**1**	**2**	**3**
Earthworms (# per 20cm cube of soil)	0	3 to 5	6 to 9	More than 10
Earthworms, multiply number above by 25 (per m^2)	Less than 75	More than 75	More than 150	More than 250

Please note that regions with sandy soils and climates with higher temperatures are likely to be at the lower end of the scale and regions with cooler temperatures and soils with higher organic matter are likely to be at the higher end.

Higher copper accumulation and/or chemical residues may also reduce earthworm counts.

More information:

FiBL (2022) Earthworms – architects of fertile soils. Technical Guide No. 1629.

Hort Innovation, earthworms in orchards.

Kiewa Catchment Landcare Group, Common introduced paddock earthworms.

Mele, P., and Hollier, C. (1995) Worm Wise II – A pictorial guide to the paddock earthworms of south-eastern Australia.

Merfield, C. (2022) DIY Soil Health Tests. Bragato Research Institute.

MLA, Increasing earthworms in pastures.

Pelosi, C., Barot, S., Capowiez, Y., Hedde, M., Vandenbulcke, F. (2014) Pesticides and earthworms. A review. Agron. Sustain. Dev. (34) 199 - 228.

2 SOIL MACROORGANISM DIVERSITY

WHAT: Which types (richess/diversity) and how many (abundance) soil arthropods do you have in your soil?

There are many microorganisms that we can't easily see without the aid of a microscope including bacteria, fungi, protozoa, and nematodes. In fact, a handful of soil may contain more living organisms than there are people on the face of the earth.

However, there are also many macroorganisms or soil invertebrates which include arthropods (insects, mites, and spiders) and earthworms that we can see without the assistance of a microscope and are also important for healthy soil function.

WHY: Soil organisms derive their energy and nutrients from breaking down plant and animal material. A diversity of soil organisms is required to aid in the breakdown of organic matter, nutrient cycling, and plant availability.

As soil organisms die, they decompose and release plant available nutrients. Earthworms and dung beetles can help to improve soil structure and water holding capacity. A diversity of predator microorganisms is also important to provide pest and disease suppressive soils and ensure ecological balance.

HOW: The diversity of soil organisms can be assessed by counting the different types (or morphospecies) which are visually distinct organisms and the number of each in a soil sample.

A simple way to identify different soil organisms is to look at the size of each specimen (either less than 1 mm, 1 to 5 mm or greater than 5 mm) and the number of legs (none, six, eight or many).

As a minimum assess the soil organism diversity at a single point along your point-to-point transect or measure at three to five separate locations and calculate an average of the results.

Assess a spade full of soil (an intact cube of soil 10 cm deep) and retain the top 5 cm to for the visual assessment. You can either pull the soil apart manually with your hands or place the soil in a 10 mm sieve and shake the macroorganisms onto a viewing sheet.

Assess the diversity of species found over a 5-minute period. You may need to take a minute to let your eyes adjust focus to movement in the soil sample. Place your specimens into a collection container i.e. an ice cube tray or container with compartments to view the different types.

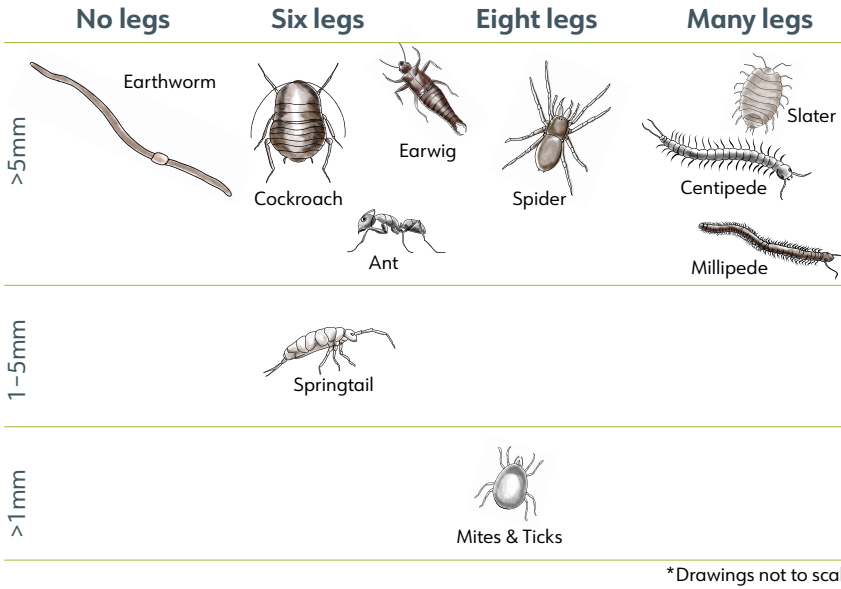


FIGURE 5: Soil macroorganism identification in the field

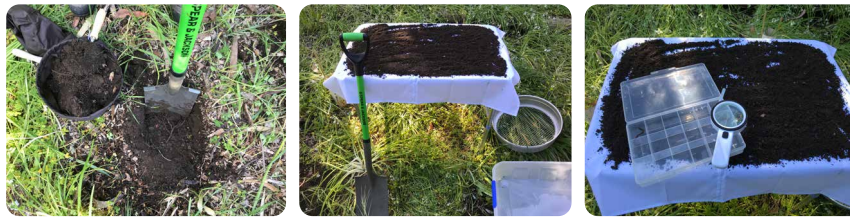


FIGURE 6: Assessing soil macroorganisms in the field. Soil reducer (left), spade, 10mm sieve and folding table with white cloth (centre), sample ready for assessment with a collection container and handheld magnifier (right)


FIGURE 7: Assessing soil macroorganisms in the field. [Photos: Mary Retallack]

ASSESSMENT TOOLS: Shovel, tray, or fold up table (cover in white cloth), 10mm soil sieve (if available), handheld magnifier or hand lens, forceps, a field guide to arthropods, mobile phone (with a stopwatch).

Scoring soil macroorganism diversity (types)

Scoring guide	Poor	Moderate	Good	Very good
Score	**0**	**1**	**2**	**3**
Results (# of types)	0	3 to 5 types	6 to 9 types	More than 10 types

Modified from NQ Dry Tropics (2019) NQ Dry Tropics RASH Manual 2019, NQ Dry Tropics, Townsville.

If you have confidence in identifying soil organisms you may wish to further distinguish the types (or morphospecies) into functional groups such as predators (assassin bugs, spiders, scorpions, centipedes, earwigs, ants), pests (Portuguese millipedes) and other/detritovores (earthworms, slaters, termites, springtails, cockroaches).

You may also wish to join the iNaturalist community to assist with arthropod identification or access the CSIRO, Key to Invertebrates

More information:

Bulbert, M., and Ginn, S. (2007) Quick invertebrate guide. Australian Museum

DPI NSW, Soil biology basics.

3 SOIL MICROORGANISMS

WHAT: Soil microorganisms are too small to see with the human eye, but we can observe their activity by measuring the amount of decomposition that occurs when cotton calico strips (or other natural materials) are placed in the topsoil (0 to 15 cm).

WHY: The cotton is used as a food substrate for fungi and bacteria. The more they break down the cotton, this provides an indication of the rate of decomposition activity there is in the soil.

HOW: This is a comparative test, so choose several sites for comparison (e.g. best / worst soils) or to assess the impact of a range of soil additives on soil microbes.

Place 3 strips per site for a good representation spaced approximately 1 metre apart.

Use unbleached calico (natural cotton fabric), cut it into 20 x 15 cm strips. Draw a line using a marker 5 cm from the top edge and ensure this edge is protruding from the soil surface when installed.

At each strip site, create a vertical slit in the soil with a flat spade. Then place the calico strip on the spade with the line closest to the handle, and the other end wrapped over the bottom of the spade.

Insert the calico strip into the soil so that the line is flush with the soil surface. Push back the soil to make sure you have good contact with both sides of the calico. Mark each site close to the calico strip using a bamboo stake with bright flagging tape on top (or similar) as you need to find them later!

The time required to see decomposition depends on your location, season, moisture, and soil type.

Generally, 3 to 5 weeks in spring is a good guide and starting point.

Warm and wet weather will help decompose the cotton faster, while cold and dry conditions will be slower.

Carefully remove the strips (dig them out, don't pull them as they will tear) and wash them in water to remove all the soil. The strips will have concentrated bacteria and fungi on them so be careful with hygiene, i.e. use gloves, and don't breathe in close to strips.

Compare the amount of decomposition on the strips. Look for where your activity is highest in the soil profile as that is your active zone. Estimate how much calico is eaten away as a percentage and compare sites. Carry out the tests over time to see if there is a trend developing.

ASSESSMENT TOOLS: Shovel, calico strips x 6 (cut cotton approximately 200 mm long x 150 mm wide), wooden/bamboo stakes and flagging tape.

Place three calico strips (A, B, C) in an area of high disturbance (vineyard) and three (D, E, F) in an area of low disturbance, adjacent to native vegetation or revegetated area to compare the difference.

GROWER SOLUTION: If you do not want to cut up lots of calico strips you can purchase pre-cut cotton calico unbleached strips in packs of 240 units.

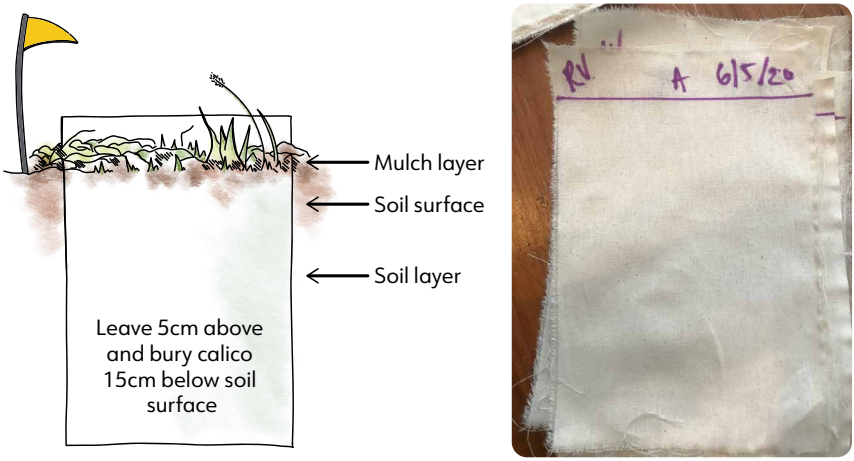


FIGURE 8: How to install calico strips in the ground [Photo: Mary Retallack]

Scoring the level of microorganism activity

Scoring guide	Poor	Moderate	Good	Very good
Score	**0**	**1**	**2**	**3**
Soil microorganism activity (%)	0	50	75	100

FIGURE 9: Installed in August and retrieved in September (6 weeks) in different soil types [Photo: Mary Retallack (left) Peter Freckelton (right)]

FIGURE 10: Installing and checking calico strips in vineyards [Photos: Mary Retallack]

Soil your undies!

You may have also heard of the Cotton Australia initiative called soil your undies! We invite you to **soil your undies...** all in the name of soil health.

All you need to do is bury a pair of 100 per cent white cotton undies (or an old cotton t-shirt) in topsoil horizontally about 7 to 10 cm deep for two months and then check the level of decomposition.

If there's not much left of the undies you have good biological activity and soil moisture, which indicates healthy soil. These same soil organisms can break down plant materials in much the same way.

We would love you to share your findings with the Twitter community using the hashtag **#soilyourundies and #EcoVineyards**

For more information, see Cotton Australia's quick and dirty how to guide or view the #soilyourundies video series on YouTube

FIGURE 11: A before and after from EcoGrower Sarah Keough from Bleasdale, Langhorne Creek [Photos: Sarah Keough (left and centre)] and Lulu Lunn from Tintookie Vineyard, Blewitt Springs, SA (cotton tails buried for 5 weeks in winter), all that remained was the elastane which was holding the cotton together! [Photo: Mary Retallack (right)]

FIGURE 12: You can use cotton singlets buried horizontally to achieve the same result [Photo: Mary Retallack]

4 SOIL PENETRATION RESISTANCE

WHAT: The amount of resistance a plant root encounters in the soil can be estimated by using a penetrometer, which measures the resistance to vertical penetration. Push a penetrometer into the ground to feel how dense the soil is, does it slide into the soil easily or does it take some effort? If there are compacted layers, it will take more pressure to break through these layers, similarly a plant root may encounter greater resistance to growth.

WHY: Soil strength or penetration resistance is measured in megapascals (MPa). Soil strength is influenced by soil water content, texture, and structure. As the soil dries out, the soil strength increases, and more force is required to break apart soil aggregates. Grapevine root growth is reduced at 1 MPa and severely retarded beyond 2 MPa (2.5 MPa is considered a critical point).

Fine textured clay soils stick together more readily than sandy soils. Soil compaction is a result of compressed structure which results in less available air, water, and root spaces. Therefore, there is less area for water storage, the total volume that the soil can hold is reduced, soil dries out sooner and can't hold as much water when recharged. Similarly, water penetration is slower and more will run off in a heavy downpour.

HOW: The best time to carry out a measurement of soil strength is when the soil is at field capacity, which normally occurs approximately 24 to 48 hours after a soaking rain event. Assess soil that will potentially impact on root growth and water penetration. For example, compare the soil strength in the undervine area, where there is a wheel compaction zone and in the midrow area for comparison. Assess the amount of resistance and the depth that you are able to push the rod into the ground before encountering resistance (or how far you need to push through a compacted zone).

ASSESSMENT TOOLS: A hydraulic penetrometer (soil compaction probe with a steel cone on the end of a shaft and a pressure sensor at the other end) or handmade rod using modified pot plant hanger.

GROWER SOLUTION: You may wish to use a screwdriver or fashion a hand-made penetrometer from a 50 cm plant hanger instead of purchasing an expensive hydraulic penetrometer. Cut the round hook off the bottom, sharpen to a point, and use a file to create 10 cm markers along the side of the steel rod and you are ready to start assessing soil resistance by feel (without a pressure sensor).

FIGURE 13: Soil penetrometer (left and middle) and home-made soil penetrometer (right) [Photos: Mary Retallack]

Soil penetration resistance

Scoring guide	Poor	Moderate	Good	Very good
Score	**0**	**1**	**2**	**3**
Soil penetration resistance (MPa)	Greater than 3	2 to 3	1 to 2	Less than 1
Soil penetration depth classes (depth at 2.5MPa)	Less than 15cm	15 to 30cm	30 to 45cm	Greater than 45cm

Aim to keep the soil strength below 2 MPa to ensure optimal conditions for grapevine root growth (2.5 MPa is considered a critical point)

For more information please see:

Soil Care (2008) Northern Rivers Soil BMP guide, Perennial horticulture, Best management practices for soil health.

Proffitt, T., and Haselgrove, L. (2023) Understanding, measuring, and ameliorating soil compaction in vineyards. Australian and New Zealand Grapegrower and Winemaker. 710, 20-30.

5 WATER INFILTRATION

WHAT: An infiltrometer measures the rate at which a fixed volume of water soaks into the soil and provides an indication of how effectively water enters the soil during a rainfall event.

WHY: By storing moisture in the soil (rather than in dams above ground) it will be available at depth in the soil profile when the plants need it.

The water holding capacity of the soil is related to its texture, structure, and ground cover. The better the soil structure and level of organic matter, the better the infiltration and water holding capacity. This leads to greater volumes of plant-available moisture at depth and increased capacity for soils to sustain populations of soil microbes throughout the year.

HOW: The rate of water infiltration is measured by pouring a volume of water into an infiltrometer ring installed in the ground to a sufficient depth of a few centimetres to prevent leaks. Assess when the soil is moist, or wet the soil with 1 to 2 L through the infiltrometer prior to assessing to reduce preferential flow through soil cracks.

Place a ruler on the inside of the infiltrometer. Pour the water gently through an open hand into the infiltrometer ring and record the start height (you may wish to fill the infiltrometer to the top of the cylinder). Start your stopwatch and record how much water in mm is absorbed into the soil over a six-minute period.

Multiply the result by 10 to determine the infiltration rate in mm per hour (i.e. 4 mm per minute x 6 minutes x 10 = 240 mm per hour)

You may wish to compare between bare ground or wheel compaction zone or an area with ground cover to compare the difference. As a minimum, assess the water infiltration at a single location along your point-to-point transect or measure at three to five separate locations and calculate an average of the results. If you are testing an area where there are ground cover plants, trim the vegetation close to ground level and test. Be consistent with your approach from year to year.

ASSESSMENT TOOLS: Stainless steel soil water infiltrator (100 mm diameter x 300 mm long) or PVC ring (160 mm diameter by 160 mm long) with a hardwood board and mash hammer for installing the PVC ring with a bevelled bottom to make it easier to push into the soil, ruler, mobile phone (with a stopwatch), and 1 to 2.5 litres of water per assessment (depending on the diameter and water holding capacity of your infiltrometer).

FIGURE 14: Water infiltrometer (left) and home-made water infiltrometer (right) [Photos: Mary Retallack]

FIGURE 15: Installing a water infiltrometer [Photos: Mary Retallack]

FIGURE 16: A water infiltrometer made from PVC pipe (left) and stainless-steel soil water infiltrator (right) [Photo: Mary Retallack]

FIGURE 17: Measuring the water infiltration rate over a 6-minute period [Photos: Mary Retallack]

Scoring water infiltration rate

Scoring guide	Poor	Moderate	Good	Very good
Score	0	1	2	3
Water infiltration rate (mm/hr)	0 to 25	25 to 100	100 to 250	More than 250

Modified from NQ Dry Tropics (2019) NQ Dry Tropics RASH Manual 2019, NQ Dry Tropics, Townsville.

Aim to achieve a minimum infiltration rate of at least 2 mm per minute (or 120 mm per hour) to ensure rainfall is not lost to evaporation in a light rain event or by runoff during a heavy downpour!

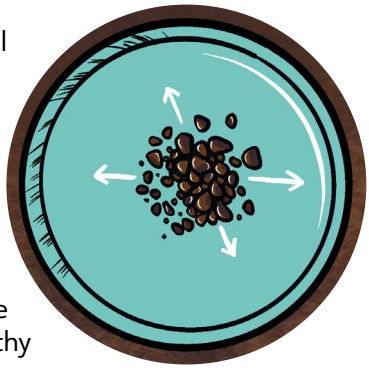
More information:

Masters, N.R. (2019) For the love of soil, strategies to regenerate our food production systems. Printable Reality, New Zealand.

Soil Care (2008) Northern Rivers Soil BMP guide, Perennial horticulture, Best management practices for soil health

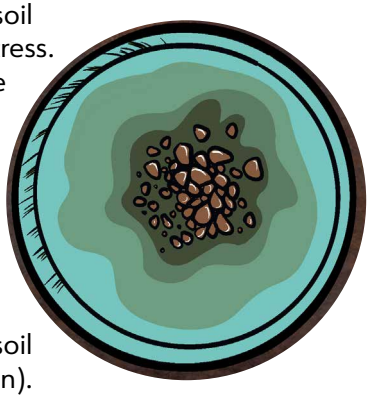
6 SOIL AGGREGATE STRENGTH (SLAKING AND DISPERSION)

WHAT: Soil aggregates are clumps of soil particles that are held together by moist clay, organic matter, exudates from worms, and by fungal hyphae. They range in size from the micro level (less than 0.25 mm in diameter) to the macro level (greater than 0.25 mm in diameter). They can be different shapes and sizes and the areas in-between provide spaces to accommodate air and water, which are all needed for healthy grapevine growth.



Slaking

Aggregate strength refers to the ability of soil aggregates to keep their structure under stress. Soil aggregates that hold together indicate stable soil structure in good condition.



Dispersion

WHY: Good soil structure is important for healthy plant growth, soil aeration, root penetration and water storage. Poor soil structure can limit root development, the rate of water infiltration, water holding capacity and aeration (see the section on soil penetration resistance and water infiltration). The deterioration of soil structure occurs via the slaking of aggregates and dispersion of clay particles.

When placed in deep water, soil aggregates will either:

1. **Remain intact, or**
2. **Slake (aggregate falls apart), and/or**

   Slaking is the rapid disintegration of macro-aggregates of soil into micro-aggregates by rainwater. Slaking occurs because of a lack of strong organic bonds between soil particles and micro-aggregates.

3. Disperse (water becomes cloudy)

Dispersion occurs when dry soil is wet with rainwater and the clay structures that bind the fine aggregates and large particles (sand and silt) break down. The clay particles then go into suspension in the water.

As the soil dries out, the clay particles block the pores between the remaining aggregates. This blockage prevents the flow of water and air through the soil. Dispersion is also a potential indicator of soil sodicity.

HOW: Take three surface soil (0 to 15 cm) and three subsoil samples (30 to 50 cm for a sub-surface sample in the rootzone) from each sampling point along a monitoring transect and select three aggregates about the size of a pea (3 to 5 mm) from each sample. Assess sandy soils when there is moisture in the profile as dry sandy soil will rarely have aggregates.

Place the aggregates in a shallow container filled with rain or distilled water. Alternatively, you can use the vineyard water source to assess the effect it may have on your soil aggregates.

Watch the aggregates closely in the first few minutes and observe if they float on the water surface or sink to the bottom and the rate that smaller particles break away from the larger sample. After two hours record if slaking is complete, partial, or absent (or you can also do a quick test over a 10 minute period to assess any initial results).

Leave the same dish untouched for about 20 hours and then assess dispersion. Assess to determine if a cloudy or milky halo has developed around the slaked fragments of the aggregates and partial dispersion has occurred.

Complete dispersion is indicated when the bottom of the container is completely covered with a layer of clay, leaving only a pile of sand where the aggregate was placed.

ASSESSMENT TOOLS: A shallow, clear, and open container (or a small paint pallet), rain or distilled water, smartphone (to record time and take photos) and a recording sheet.

Scoring soil aggregate strength

Scoring guide	Poor	Moderate	Good	Very good
Score	0	1	2	3
Slaking (%)	More than 70 slaked	20 to 70 slaked	Slight slaking around the edges of aggregate	Aggregate remains intact
Dispersion	Strong dispersion (cloudy water)	Moderate dispersion	Slight dispersion (cloudy water around aggregate edges)	No dispersion

More information:

CRCV (2006) Vineyard activities 5: Assessing soil structure. CRCV, Adelaide.

Merfield, C. (2022) DIY Soil Health Tests. Bragato Research Institute.

NQ Dry Tropics (2019) NQ Dry Tropics RASH manual 2019, NQ Dry Tropics, Townsville.

FAO (2008) Visual soil assessment – vineyards. Rome, Italy.

7 LEGUME NODULATION

WHAT: Legume cover crops such as faba bean, field pea, vetch, lupin, clover, sub-clover and medic that are grown in vineyards have the capacity to fix nitrogen.

WHY: Legumes need to be adequately nodulated and contain an effective strain of rhizobia to ensure atmospheric nitrogen is converted to ammonia within the nodule.

The presence of nodule formation and health will be influenced by soil pH, nutrient availability, and the use of herbicides as their residues may negatively impact root development and rhizobia survival.

HOW: Assess legume roots to determine the colour and abundance of nodules once plants are 12 weeks old.

Use a shovel to carefully dig up a soil sample to a depth of 30 cm including the plant to be assessed. Carefully, wash the soil from the plant material so you can assess individual roots. Assess the roots using the scoring chart below.

For a legume plant to effectively fix nitrogen it will need a minimum of 20 nodules on the root system that are pink in colour (if they are white, they are not fixing nitrogen).

The pink colour signifies the presence of leghemoglobin which is produced when the nodules are colonised by the nitrogen-fixing bacteria rhizobia.

ASSESSMENT TOOLS: A shovel, water to wash roots and white background to assess root condition.

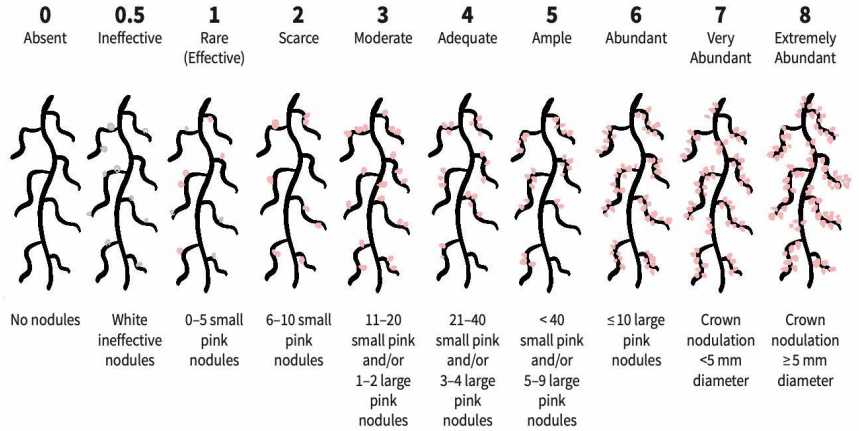


FIGURE 18: A nodule-scoring chart that can be applied to legumes that more than 12 weeks old. Yates et al. (2016)

FIGURE 19: *Medicago truncatula*, barrel medic root nodules [Photos: Ninjatacoshell (CC-BY-SA-3.0)]

Scoring legume nodulation

Scoring guide	Poor	Moderate	Good	Very good
Score	**0**	**1**	**2**	**3**
Legume nodules per plant (#)	0 to 10	11 to 20	21 to 40	More than 40

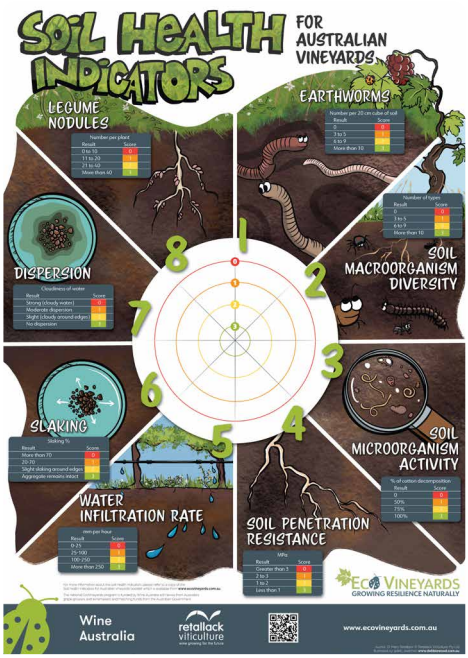
More information:

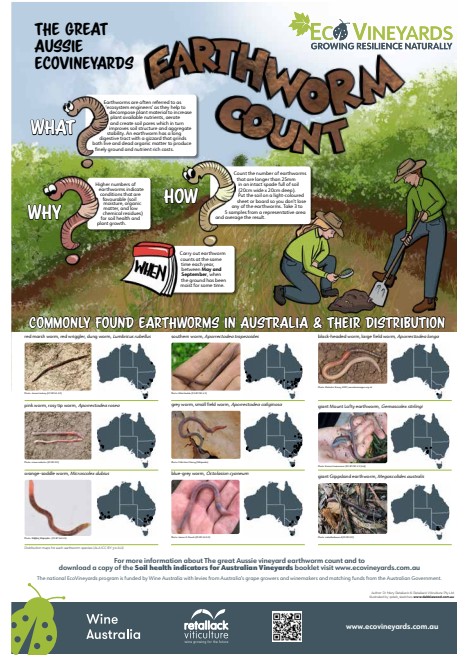
MLA (2021) How do I assess effective nodulation in legume pastures. MLA, North Sydney

Yates, R.J., Abaidoo, R., and Howieson, J.G. (2016) Field experiments with rhizobia. In: Working with rhizobia, ACIAR, Canberra.

To continue your reading on vineyard soil health please visit the EcoVineyards knowledge hub:

- EcoVineyards best practice management guide on soil health in Australian vineyards: Part A (chemical and physical)
- EcoVineyards best practice management guide on soil health in Australian vineyards: Part B (biology)
- **Check out the Getting to know the earthworms in your vineyard video series and record your progress on the Soil health indicators for Australian vineyards and Great Aussie EcoVineyards earthworm count posters.**





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