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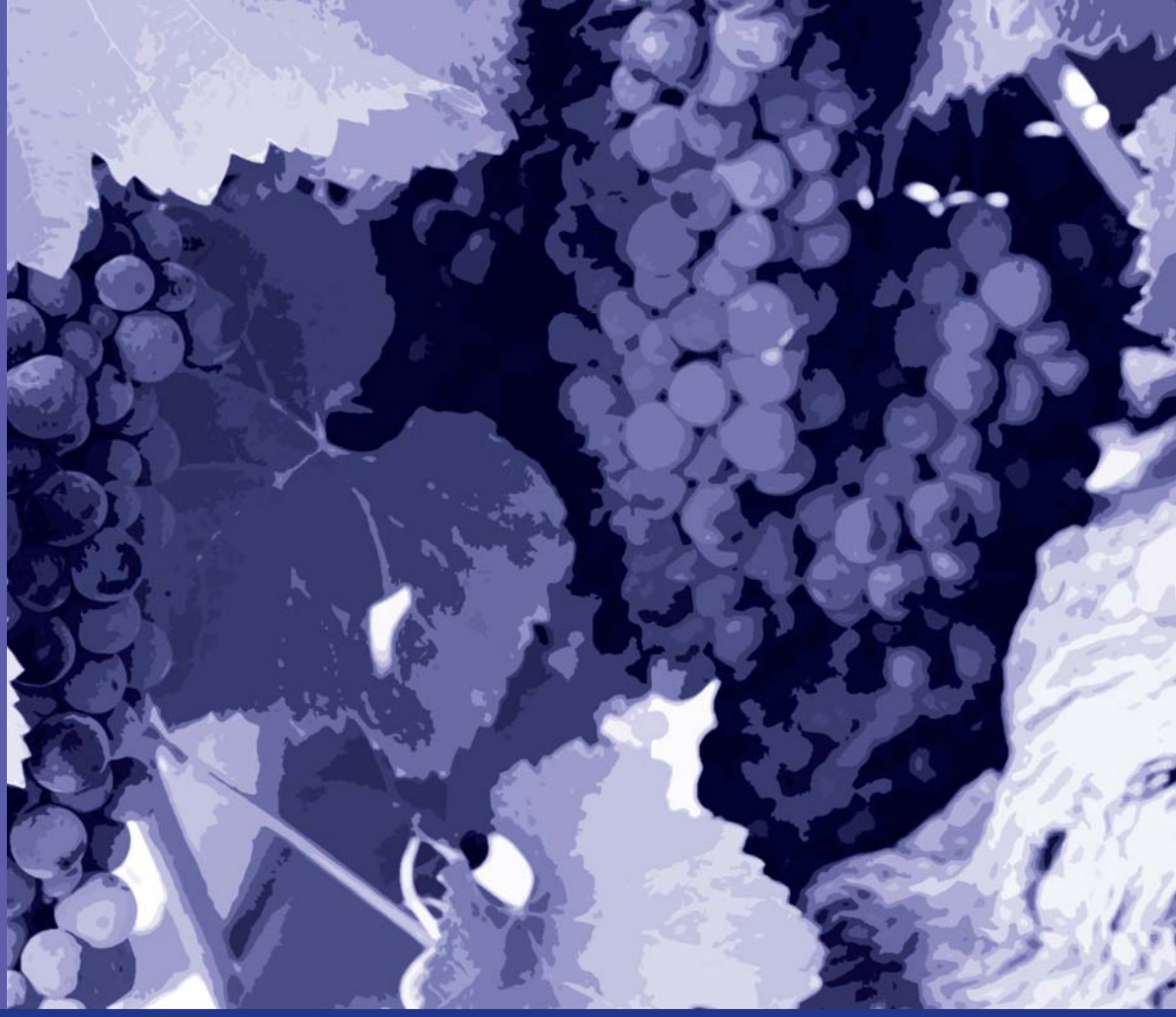

VITICARE ON FARM TRIALS

Manual 3.2 - Soil Profiling

Soil moisture monitoring

Infiltration

Soil organic matter

Soil sampling

Soil pH

Earthworms

Soil porosity

Root examination

Soil strength

Soil salinity

Soil structure

Cooperative
Research Centre
for
Viticulture

Core Participants

About the CRCV

The Cooperative Research Centre for Viticulture is a joint venture between Australia's viticulture industry and leading research and education organisations. It promotes cooperative scientific research to accelerate quality viticultural management from vine to palate. Australian grapegrowers and winemakers are key stakeholders in the CRCV, contributing levies matched by the Commonwealth Government and invested by the Grape and Wine Research and Development Corporation in the Centre.

For more information about the CRCV, please visit www.crcv.com.au.

Disclaimer

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Contents

Introduction

Introduction

The Cooperative Research Centre for Viticulture has conducted On Farm Trials since 1999. The initial trials were conducted in eight regions (Port Phillip, North East Victoria, Central Victoria, Adelaide Hills, Riverland, South West Slopes, Riverina and Hunter Valley) and provided Australian growers with the ability to formally assess and validate new science and technology. The trials were conducted over four growing seasons and helped growers to solve problems in their vineyards and improve their management practices.

In 2004 the On Farm Trials project expanded to cover more than 20 viticultural trials primarily in the Riverina, Riverland and Sunraysia regions. Rather than focusing on individual grower issues, the CRCV team has worked with regional grower groups to determine regional issues. The trials are still conducted on a participant growers' property but a team of people are involved to learn from the trial and to share the workload.

This booklet is part of a series that draws on knowledge gained from this experience in developing and delivering On Farm Trials.

Conducting a trial in your vineyard is not easy and is not a decision that should be made lightly. Although trials can be an excellent method for refining management practices, improving quality or looking for solutions to problems, there are many practical considerations involved in conducting a trial.

On Farm Trials can lead to management improvements in a number of areas. The information in this booklet will guide you through the various protocols involved with setting up On Farm Trials that aim to assess soil quality by moisture monitoring, soil infiltration, measurement of soil organic matter, soil sampling, measurement of soil pH, measurement of earthworm counts, soil porosity, root examination, soil strength, soil salinity, and soil structure.

Soil Moisture Monitoring

Aim

This trial aims to assess soil by moisture monitoring.

Important Points to Know

The measurement of soil moisture is critical in trials aimed at increasing winegrape quality or saving water through regulated deficit irrigation, partial rootzone drying, soil structure modification or mulching. Soil moisture monitoring is used to measure the effects of a treatment on:

- Vine water stress
- Vineyard evapotranspiration
- Root system extent
- Irrigation wetting pattern
- Changes in soil water holding capacity
- Rainfall effectiveness

Soil moisture is measured as either the soil water tension or total soil water content. Soil water tension is the suction a root must exert to extract water from the soil and is sometimes referred to as suction or matric potential. Soil water tension is a good indicator of vine water stress and is measured in pressure units of kilopascals (kPa) or centibars (cbars). Generally, when the entire rootzone soil water tension is greater than 50 kPa vines start to show symptoms of water stress. On the other hand, soil water content is a measure of the amount of water in the soil. Changes in soil water content are useful for estimation of the volume of water taken up by the vines and the amount of irrigation to apply. Total soil water content is measured as a percentage of a soil volume (%v/v) or as a depth of water per unit depth of soil (mm/m).

Soil water tension is recommended if the objective of the trial is to measure vine water stress. If the objective is to determine vineyard evapo-transpiration or changes in soil water holding capacity, then soil water content should be measured by one of the techniques listed below. Either soil water tension or content can be used to measure root system extent, the irrigation wetting pattern or rainfall effectiveness.

One of the limitations of soil moisture monitoring is the amount of soil that is measured. Instruments only measure a small part of the entire rootzone. It is therefore important to bury soil moisture sensors at the appropriate depth and position in relation to the rootzone, the wetting pattern and when the soil profile changes in soil texture.

There are further limitations with soil moisture monitoring equipment. It is costly to purchase and can be timely to operate. For these reasons a compromise can be made when soil moisture is measured in OFTs. Not all treatment plots are measured, particularly if monitoring for irrigation scheduling purposes. For example, if we had a trial that had 2 different treatments replicated 8 times, giving a total number of 16 treatment plots then we might only install soil moisture sensors in 4 treatment plots (2 for Treatment A and 2 for treatment B) (see Figure 1).

TAR1 - monitor	TAR3	TBR5	TBR7 - monitor
TBR1 - monitor	TBR3	TBR6	TAR7 - monitor
TBR2	TAR4	TAR5	TAR8
TAR2	TBR4	TAR6	TBR8

Figure 1. Example trial plan of treatments (TA and TB) and replicates (R1 to R4) and the selection of soil moisture monitoring sites.

Before You Get Started

The following requirements will help you prepare for this trial.

There are a variety of techniques to measure soil moisture.

Soil water content can be measured using:
- Neutron probes
- Capacitance probes
- Time domain reflectometry

Soil water tension can be measured using:
- Tensiometers (range 0-80 kPa)
- Gypsum blocks (range 30-1000 kPa)
- Watermark (range 10-200 kPa)

Some instruments can measure soil moisture automatically by computerised systems and others must be measured by hand. Handheld meters often have the capacity to store data for later processing on a computer. The book "Soil Water Monitoring" by P. Charlesworth (2000) is an excellent reference for more information on the methods and instruments to measure soil moisture.

Trial Timelines

Measure soil moisture at regular intervals (approximately three times a week) and before and after irrigation (or rainfall) events.

The time to measure soil moisture is highly dependent on the instrument being used. A maximum of 10 minutes per treatment plot to measure and record the soil moisture should be adequate.

Trial Method

1. Install sensors at the appropriate depth and position in relation to the rootzone and wetting pattern in 2 replicates for each treatment (see Figure 1).

2. Install sensors as per manufacturer recommendation.

3. Record and store readings for comparison with other treatments in current and future seasons.

4. Use a data sheet to record your measurements.

Infiltration

Aim

This trial aims to assess soil by infiltration capacity.

Important Points to Know

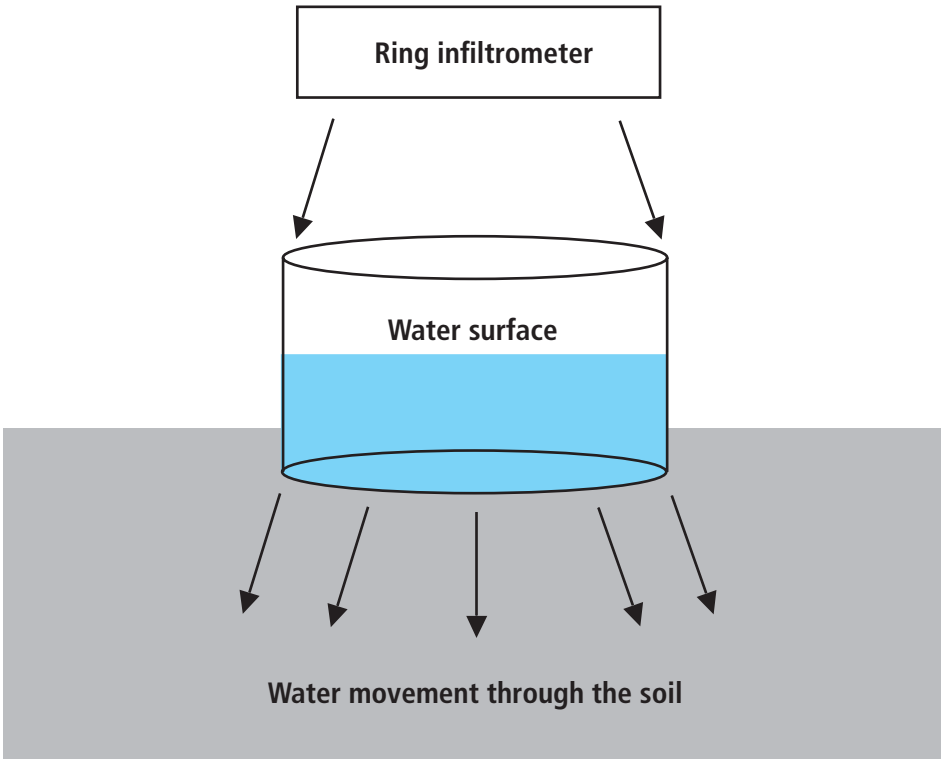
Infiltration capacity is the maximum rate at which water can enter a particular soil. It is well accepted that different soil types have different infiltration capacities. For example, sandy soils are freer draining than clays, resulting in higher infiltration capacities. High infiltration capacities will reduce run-off and risks of waterlogging. However, on the other hand, very high infiltration capacities, as found in sands, may be detrimental due to high nutrient losses through leaching.

Although different soils will have inherently different infiltration capacities, this can be altered through changes in soil management. As infiltration is related to soil structure, any practice that degrades the structure of the soil will have an adverse effect on infiltration. Therefore, monitoring infiltration rates under different soil management regimes is a good indicator of how the practice will influence the rate at which water can move into the soil.

There are several different methods of measuring infiltration, varying in accuracy and complexity. The method to be used here is the ring infiltrometer method, otherwise called infiltration rings. This is a relatively simple and accurate method that can be used to determine how different soil management methods influence the infiltration of water into the soil.

Most trials looking at soil management in the vineyard focus on the vine-row soil. Measures of infiltration should therefore be taken in the vine-row. If the trial is investigating soil management in inter-row an area then measurements should be taken in this area.

Ring infiltrometer
The ring infiltrometer consists of a metal ring that is pushed into the soil (Figure 1). Water is poured in, and the rate at which the water soaks into the soil is measured. There are many variations on this method, but they are all accurate when used according to the instructions.



Before You Get Started

The following requirements will help you prepare for this trial.

You will need 150-mm deep metal rings. Rings can be cut from empty, spotlessly clean, 20 litre oil drums (380 mm inside diameter). Sharpen one edge of the ring so that it is easier to push into the soil. Draw a line with a water-resistant marking pen on the outside of the ring 50 mm up from the sharp edge to mark the depth to push the ring into the soil. On the inside of the ring accurately draw two lines 90 and 100 mm up from the sharpened edge to mark the depth of water once the ring is installed in the soil.

Other items you will need include:

- A piece of flat board 500 mm x 300 mm x 19 mm
- Hessian bags
- Garden clippers
- Three 5 litre buckets with a small (2 mm diameter) hole in the base
- Metal or plastic rule (mm scale)
- Shovel
- About 50 litres of rain water
- Stopwatch
- Recording sheet and pen

Trial Method

Preparation

Preparation and measurement is done on three sites in the vine-row per treatment plot. Do not skip any steps. Do not try to measure on cracking clay soils or on freshly cultivated paddocks because results will be unrealistic. On stony and very hard soils, it may be difficult to get the ring into the soil. Don't force it; try different locations.

1. At each location clip any plants on the site down to ground level, being careful not to disturb the soil. If the area is covered with a mulch or compost, clear it away to expose the soil surface. Avoid trampling on the area where the measurement is to be made.

2. Place wet hessian bags on the soil surface at each measurement site, fill the holed bucket with rainwater and place it on the bag allowing the water to slowly drain onto the bag overnight and gently wet the soil.

3. The next day remove the bucket and bag and insert the metal ring, sharp edge first, by gently pushing down on the middle of the ring with the flat board until the line marked on the outside is level with the soil surface all around the ring. If it will not push in by hand, the soil may not have wet deeply enough and you should gently remove the ring, replace the bag, refill the bucket and try again the next day.

4. Seal any large gaps along the edges of the ring with 'putty' made from moist, reworked subsoil rolled out to the thickness of a pencil. Take care not to disturb the surface of the soil inside the ring.

Measurement

Once the site is prepared with the ring in place, the actual infiltration test can be done.

1. Gently fill the ring with rainwater until the level is just on the upper line drawn on the inside of the ring (the water should be 50 mm deep).

2. Using the rule and stopwatch, measure how far the water level drops in 6 minutes and record as 'DEPTH'. If the level drops by more than 10 mm in 6 minutes, record the number of minutes taken for the 10-mm drop (TIME). Refill with water and repeat the measurements several times until the times or the depths are similar to within 1 minute or 1 mm. Use the average of the most recent, similar values in your calculations.

The water intake rate in mm per hour is calculated as follows:
INFILTRATION RATE = DEPTH (mm) x 10

OR
INFILTRATION RATE = 600/TIME (min).

Interpreting results

Average the three values obtained from each treatment plot. The value obtained should be interpreted from the information in Table 1.

Rate of water entry(mm/h)	Soil structural assessment
0-10	Very poor structure quality
10-30	Poor structure quality
30-70	Moderate structure quality
> 70	Good structure quality

Note: These criteria cannot be applied to cracking clay soils.

Limitations of this method

Although this method has the advantage of being easy to use and easy to interpret, it does have its disadvantages.

The main disadvantage of using this method is that the water flows horizontally through the soil as well as vertically, thus giving results greater than would be achieved if the flow can be confined to just go down the profile, instead of across. There are ways to correct for this, but for comparative purposes they are not necessary - if it is assumed that the proportion of flow to go sideways is always similar.

As only a small area is used, this technique is very sensitive to worm and root holes, and other cracks in the soil. Any crack in the soil surface will result in much faster flow than would otherwise be achieved. As these cracks are not always visible when choosing a site it is not always possible to avoid them. That's why we have 3 or more measurements per treatment plot - to account for such variation.

Soil Organic Matter

Aim

This trial aims to assess soil by measurement of organic matter present.

Important Points to Know

Soil organic matter is material in the soil derived from living species. This includes the remains of plants and animals in various stages of breakdown, the cells and tissues of soil creatures and substances made by plant roots and soil microbes. Well-decomposed organic matter forms humus; a dark brown, porous, spongy material that has a pleasant earthy smell. It is quite a complicated mixture!

There are many beneficial roles that soil organic matter plays in soil, including:

- Provides food for soil microbes
- Provides nutrients to plants (particularly nitrogen, phosphorus and sulphur).
- Stabilises soil structure and increases water holding capacity
- Makes it easier for water to enter the soil
- Reduces run-off and erosion
- Improves the soil's ability to hold nutrients thereby reducing pollution potential
- Helps buffer the soil against changes in pH
- May protect plants against disease

Many factors affect soil organic matter levels:

- Soil depth - levels generally get lower as you dig deeper
- Soil type - sandy soils generally have lower soil organic matter than clays
- Management practices - cultivation breaks down organic matter
- Temperature - organic matter breaks down quicker in hot compared with cool climates
- Soil water content - organic matter breaks down quicker in wet compared with dry soil (until the air content of the soil gets too low)

Organic matter can be split into separate pieces or 'pools'. Each pool has a different function in the soil. The main pools are outlined in Table 1:

Table 1: The different pools of soil organic matter.

Organic matter pool	What is it?	What does it do?
Microbial biomass	Bacteria and fungi (i.e. the living part)	Decomposes the organic matter
Light fraction	Organic matter that has recently be incorporated	Food for microbes, releases soil nutrients
Soluble organic matter	Eg. root exudates	Moves through the soil profile - Binds soil particles, available for plant uptake
Protected organic matter	Protected chemically or physically	Can't be decomposed by microbes
Inert organic matter	Eg. charcoal	Does not breakdown, but helps soil structure
Humus	Well decomposed organic matter	Supplies nutrients

Before You Get Started

The following requirements will help you prepare for this trial:

- A tool for taking a soil sample (preferably a soil auger or core sampler although a shovel or trowel can be used)
- Buckets for sample collection
- Plastic sheet for mixing
- Labelled plastic bags to transport samples to the laboratory

Trial Timelines

Soil sampling can be done at any time of the year, although autumn and spring are the best times, as winter can be too wet and in summer the ground may be too hard.

As a conservative estimate, allow 10 minutes per sample for collection time, with _ hour required if using a mechanical sampler.

After all the samples are collected, the actual preparation time required prior to sending the samples off for analysis may take another _ hour.

Trial Method

1. Clear away any weeds and other organic material, until the soil surface is uncovered.

2. For each treatment plot, take at least 3 soil samples (approximately six cupfuls of soil) and place soil samples in a plastic bucket. Depending on the trial it may be necessary to take samples from different depth layers and to keep these depths separate for analysis.

3. Label the plastic bucket with the date, property, treatment and replicate.

4. Take the buckets of soil from each plot to a shed or sheltered place for drying. Spread the sample on a plastic sheet to air-dry. You will need one plastic sheet per treatment plot, especially if the soil is wet. Make sure the plastic sheets are labelled so that you know which treatment and replicate it came from. Place the samples and sheets where it can dry without being contaminated by other soil or fertiliser.

5. When the soil has dried break up any clods, pick out stones, and mix the sample well (side to side, end to end) using the plastic sheet to move the soil around. When mixing soil, be careful not to crush the soil aggregates too much, as intact soil aggregates are required for tests of dispersion and slaking (breakdown of structure upon wetting).

6. Most laboratories require approximately 2 cupfuls per treatment plot of the mixed soil for analysis (eg. after mixing, discard half, remix and remove two cupfuls). Place the 2 cupfuls in a plastic bag with the date, property, treatment and replicate clearly marked on the bag.

7. Check with laboratory to make sure sample(s) can legally be sent. If you are within a Phylloxera Risk Zone (PRZ) or Phylloxera Infested Zone (PIZ) then consult the National Phylloxera Management Protocol (http://www.phylloxera.org.au/regulation/preventionprotocol.html) before sending samples.

8. Use a data sheet to record all measurements.

Note: Sample sizes for different laboratories may vary. Check with your laboratory to see if they request a certain quantity of soil, or specify a certain collection method.

Laboratories determine organic carbon levels in two ways:

1. Loss on ignition - the soil is heated at very high temperatures and the organic matter is essentially 'burnt off' (Estimation only).

2. From organic carbon measurements - carbon compounds are determined by laboratory instruments and then converted to soil organic matter levels using a simple factor (More accurate).

Analysis

The analysis of soil organic matter status will have to be carried out in a laboratory. [For example in Victoria, State Chemistry Laboratory, Cnr. Sneydes & South Rds, Werribee, Vic, 3030. Ph. (03) 9742 8755]

Optimal values

There is very little information about organic matter levels in vineyards; most of the work in this area has been done in pasture or cropping situations. The values below are a rough guide to the general organic matter levels considered to be high, medium and low in South Australia.

Table 2: General organic matter levels (%) in different soil types in South Australia (adapted from Baldock and Skjemstad).

	Sand	Sandy	loamLoam	Clay loam/clay
Low	0.9	1.2	1.6	2.1
Moderate	0.9-1.7	1.2-2.4	1.6-3.1	2.1-3.4
High	>1.7	>2.4	>3.1	>3.4

Rather than comparing the level of organic matter to a set of values such as the one above, it might be better to compare your results from the different treatments. Remember that ***more organic matter usually means a 'healthier' soil.***

Soil Sampling

Aim

This trial aims to assess soil quality by sampling for the physical, chemical and biological components of the soil.

Important Points to Know

A consistent and appropriate soil sampling technique is essential to give accurate results of the physical, chemical and biological components of soil. The trial looks at the different techniques in soil sampling and the considerations that should be made in the context of assessing treatment responses.

A simple method of vineyard soil sampling is preferred due to the limited space available within vine rows. In addition, if samples are taken to determine soil nutrient status, it is imperative that these samples be taken in the vine row where most of the vine roots are located.

Before You Get Started

The following requirements will help you prepare for this trial:

- A tool for taking a soil sample (preferably a soil auger or core sampler although a shovel or trowel can be used)
- Buckets for sample collection
- Plastic sheet for mixing
- Labelled plastic bags to transport samples to the laboratory

Soil sampling equipment
Generally the equipment used will depend upon what is readily available but consideration must be given to appropriate method to suit the measurements that will be taken on the soil sample. Your options include:

a) Screw type soil auger
These augers are either mechanically or manually operated and are used to get an averaged sample down the profile. It is difficult to differentiate between soil layers using screw type augers.

b) Edelman soil auger (or Dutch auger)
With this type of auger, a reasonable intact sample with only slight mixing is obtained. Various designs and sizes are available to suit different soil textures. Sample can be taken from 10 cm to over 1 m depth.

c) **Soil core sampler**
Used to obtain intact soil cores to a shallow depth (10cm - 50cm). Made up of a section of metal tubing with provision for pushing it down into the soil either using body weight, through 'stepping' onto a 'foot bar', or a sledgehammer on the top. Alternatively, hydraulic soil samplers may be used to obtain intact soil cores to 1m - 3m depth. These are generally mounted on a tractor or trailer, making them difficult to use in the vine row due to restricted manoeuvrability of this machinery. The hydraulic soil sampler is more appropriate for between row sampling.

d) **Shovel**
The shovel is the essential farm implement. Take care when taking soil samples with a shovel that the sample is not biased to the top or the bottom of the soil profile. The sample must be evenly distributed to the depth of sampling so measurements of the soil properties are representative.

e) **Trowel**
Like the shovel, be careful that an unbiased sample is taken.

Trial Timelines

Soil sampling can be done at any time of the year, although autumn and spring are the best times, as winter can be too wet and in summer the ground may be too hard.

As a conservative estimate, allow 10 minutes per sample for collection time, with _ hour required if using a mechanical sampler.

After all the samples are collected, the actual preparation time required prior to sending the samples off for analyses may take another _ hour.

Trial Method

1. Clear away any weeds and other organic material, until the soil surface is uncovered.

2. For each treatment plot, take at least 3 soil samples (approximately six cupfuls of soil) and place soil samples in a plastic bucket. Depending on the trial it may be necessary to take samples from different depth layers and to keep these depths separate for analysis.

3. Label the plastic bucket with the date, property, treatment and replicate.

4. Take the buckets of soil from each plot to a shed or sheltered place for drying. Spread the sample on a plastic sheet to air-dry. You will need one plastic sheet per treatment plot, especially if the soil is wet. Make sure the plastic sheets are labelled so that you know which treatment and replicate it came from. Place the samples and sheets where it can dry without being contaminated by other soil or fertiliser.

5. When the soil has dried break up any clods, pick out stones, and mix the sample well (side to side, end to end) using the plastic sheet to move the soil around. When mixing soil, be careful not to crush the soil aggregates too much, as intact soil aggregates are required for tests of dispersion and slaking (breakdown of structure upon wetting).

6. Most laboratories require approximately 2 cupfuls per treatment plot of the mixed soil for analysis (eg. after mixing, discard half, remix and remove two cupfuls). Place the 2 cupfuls in a plastic bag with the date, property, treatment and replicate clearly marked on the bag.

7. Check with laboratory to make sure sample(s) can legally be sent. If you are within a Phylloxera Risk Zone (PRZ) or Phylloxera Infested Zone (PIZ) then consult the National Phylloxera Management Protocol (http://www.phylloxera.org.au/regulation/preventionprotocol.html) before sending samples.

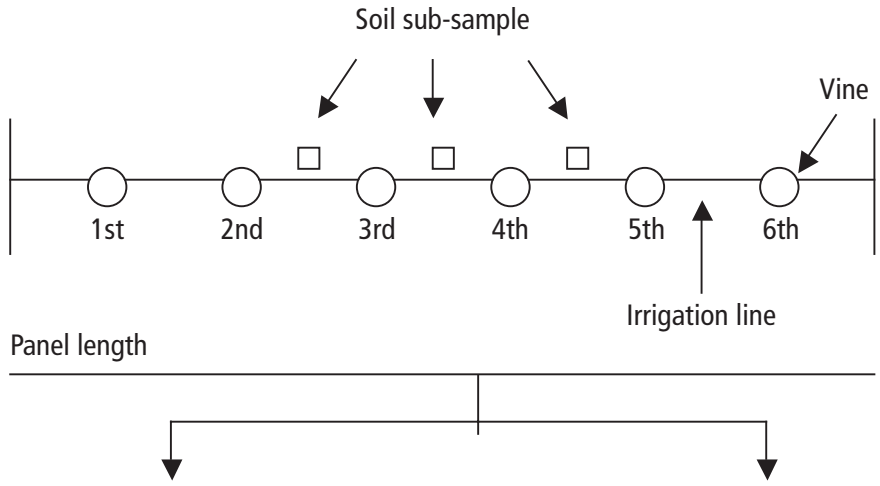
Note: Sample sizes for different laboratories may vary. Check with your laboratory to see if they request a certain quantity of soil, or specify a certain collection method.

How many samples should I take?
When determining the number of samples that should be sent to the laboratory for analysis, or the number of analysis that you carry out, there is a balance between the time, cost and statistical accuracy.

Method 1 - most statistically accurate, most time and cost
Take 3 sub-samples from each treatment plot (depending on the trial design this could be one panel of vines), group them together and send those individual samples to the laboratory.

For example, if we had a trial that had 2 different treatments replicated 4 times, giving a total number of 8 treatment plots then we would have to send 8 samples for analysis.

Method 2 - less accurate, minimising time and cost.
Take 3 sub-samples from each treatment plot (depending on the trial design this could be one panel of vines), group them together and then group the replicates for each treatment together. In the example above this will reduce the number of samples for analysis to 2.



Most Accurate	Less time and cost
1. Group sub-samples together	1. Group sub-samples together
2. Send individual treatment plot samples for analysis	2. Group samples from each treatment replicate together
	3. Send treatment samples for analysis

Although more samples do relate to greater precision in the results obtained, economics also play a major role i.e. the cost per sample will influence the number of samples analysed.

The labelling system on the samples sent to the laboratory must clearly identify where the sample came from (eg. S1R5P10 = Site 1. Row 5, panel 10). If replicates are combined then the sample must be clearly labelled with the treatment.

Depth of sample required

When soil sampling for nutrient analysis, the main determining factor is the depth of vine roots, as any nutrients past that point are not available to the plant.

Some assumptions may have to be made to determine depth of roots:

- Age of vine
- Soil type (if hard/dense B horizon, roots may have a limited depth)
- Soil pH (large changes in pH at a certain depth may restrict roots)
- Soil salinity (high salinity levels at depth will restrict roots)

However, as it is not always possible to sample at the bottom of the rootzone (they may go down to over 1 metre), compromises can be made. Sampling to 50 cm may be adequate as the majority of the fibrous rootzone is usually within the top 50 cm.

When soil sampling for analysis it is a good idea to separate surface and subsurface samples, as they will have different physical and chemical properties.

If it is difficult to separate surface from subsurface layers, a good rule of thumb is:

- Surface soil: 0-10 cm depth
- Subsurface soil: 40-50 cm depth

(These boundaries are conservative, to ensure that the samples taken are actually different layers.)

Generally, the surface will have higher nutrient levels than the subsurface, but these nutrients may not be in a form available to plants. Therefore, the subsurface results may give a more reliable indication of what nutrients are available to the vine roots.

Analysis

Analysis of the soil will have to be carried out in a laboratory. [For example in Victoria, State Chemistry Laboratory, Cnr. Sneydes & South Rds, Werribee, Vic, 3030. Ph. (03) 9742 8755]

Soil pH

Aim

This trial aims to assess acidity and alkalinity of soil, which can affect availability of nutrients to plants, micro-organisms and disease organism activity.

Important Points to Know

Soil pH refers to the acidity or alkalinity of the soil. It is a measure of the concentration of free hydrogen ions (H+) that are in the soil. The range is from 0-14, with a pH of 7 being neutral. Soil pH (measured in a water and soil solution) less than 5.5 indicate strong acidity; 5.5 to 6.5, moderate acidity; 6.5 to 7.5, neutral; 7.5 to 8.5, moderate alkalinity; 8.5 and above, strong alkalinity.

Soil pH outside the neutral range can influence the availability of specific nutrients to plants, as well as micro organisms and disease organism activity. The limited data available for vines suggests soil pH (measured in a weak calcium chloride and soil solution) should be in the range 5.5-8.0.

Viticultural practices, such as the use of urea or ammonium based nitrogenous fertilisers, have acidifying effects on soils and if current management techniques continue it is inevitable that soils in the vineyard will become more acidic over time (McNab 1995). Soil pH may be measured in a trial designed to specifically modify soil pH by addition of lime, or to assess the impact of applying nitrogen fertiliser, particularly if the soil is leached.

Soil pH can be measured in water (pH_w) or a weak calcium chloride solution (pH_{CaCl}). Chemistry laboratories generally measure both. The simplest method is to measure pH_w with a portable pH meter and this is described below. Alternatively, grape growers can determine soil pH using a colorimetric test kit.

Before You Get Started

The following requirements will help you prepare for this trial:

- Colorimetric test kit available from nurseries (includes mixing stick, plate, dye, barium sulphate, pH colour chart, instructions)
- Teaspoon
- Recording sheet

OR

- Hand held pH meter
- Clear plastic jar with screw-on lid
- Distilled or rain water
- Recording sheet

Trial Timelines

This measurement is best undertaken when soil sampling is conducted (See 'Soil Sampling' trial technique in this series). Soil pH should be measured in the fibrous rootzone (i.e. 0-20 cm depth) as well as the deeper rootzone (>20 cm depth). Make sure the soil samples are taken in the irrigation-wetting pattern.

With this in mind, the soil sampling can be done at any time of the year, although autumn and spring are the optimum times, as winter can be too wet and in summer the ground may be too hard.

The time required for the soil sampling is as per the 'Soil Sampling' trial technique: As a conservative estimate, allow 10 minutes per sample for collection time, with 1/2 hour required if using a mechanical sampler. After all the samples are collected, the actual preparation time required prior to sending the samples off for analyses may take another 1/2 hour.

For the preparation and measurement of pH using the test kit allow 5 minutes per sample.

For the preparation of samples to measure pH using the pH meter, more than one sample can be shaken at a time, so in most trials all samples could be prepared (excluding soil drying), shaken and settled in 0.5 hours. For the measurement of each sample allow 1-2 minutes.

Trial Method

1. Take three surface soil and three subsoil samples from each treatment plot (as per the 'Soil Sampling' technique in this series). Make sure surface soil and subsoil are not combined so that they can be analysed separately.

2. Allow the soil to dry in the air, then crush large aggregates and remove any gravel (as per the 'Soil Sampling' technique in this series).

Using a colorimetric test kit

3. Put half a teaspoon of soil on the plate.
4. Add enough dye to saturate the sample, mix well.
5. Sprinkle barium sulphate on to the soil and allow the colour to develop.
6. Compare the sample colour with the pH colour chart.

OR

Using a portable pH meter

Make sure to periodically calibrate your pH meter (refer to instrument instructions).

3. Unscrew jar lid and fill the lid level with soil. Do not compress the soil. Pour into jar.
4. Add 5 jar lids of distilled water and screw lid on tight. Shake for 5 minutes then allow to settle for 10 minutes.
5. Rinse the pH meter electrodes in rain or distilled water and dry gently with a tissue.
6. Take a reading by immersing the electrode in the suspension above the soil as per manufacturer instructions. Make sure the electrodes are fully covered. Take care to minimise electrode contact with soil at the bottom of the jar.
7. Gently stir the solution with the electrode while allowing the reading to stabilise. Record reading.
8. Rinse electrode before next reading.

Note:
The results from using a portable meter for pH_w are commonly higher by about 0.5-0.6 pH units than those using a colorimetric test kit (Rayment and Higginson 1992). If the pH is near critical levels you should have a more accurate laboratory test done.

Laboratory tests of pH are done using calcium chloride solution. The calcium chloride accurately mimics the soil environment and is able to remove more of the hydrogen ions that determine pH from the clay surface. The results in calcium chloride are commonly from 0.5 to 1.0 pH units lower than the pH determined in water (Rayment and Higginson 1992). For example, pH_{CaCl} 5 = pH_w 5.9. The difference between methods is more obvious in acidic soils.

Earthworms

Aim

This trial aims to assess the count of earthworms present in soil.

Important Points to Know

Earthworms are associated with a 'healthy' soil. They burrow into the soil, making pores that enhance water and air penetration into the soil, and improve soil structure. Earthworms play a vital role in mixing organic matter and other soil amendments into the soil. Earthworm waste (or cast) is also useful because it contains high levels of plant nutrients, bacteria and fungi.

Earthworms like:
- Moist but not waterlogged soil
- Plenty of food (eg. decaying plants, especially plants containing lots of nitrogen)
- Loam to clay soils

Earthworms dislike:
- Dry and waterlogged soil
- Soil that is cultivated
- Coarse, sandy soils and soils that are compacted or acidic

Different types of earthworms play different roles in the soil. For example, yellow tailed worms (Octolasion cyaneum) create large deep burrows, useful for improving water infiltration. By contrast, the phosphorescent worm (Microscolex phosphoreus) makes small burrows, which suggests it has only a small impact on infiltration but could be useful for rootzone nutrition. For further information about the role of the different types of earthworms, see Worm Wise II, A Pictorial Guide to the Paddock Earthworms of South Eastern Australia, by P. Mele and C. Hollier, Agriculture Victoria, Rutherglen.

Trial treatments that involve the addition of organic matter will have a positive impact on earthworm numbers, as will those that keep the soil moist for longer. There is a simple field method to measure earthworm activity by digging up a sample of surface soil and counting the number of earthworms

Before You Get Started

The following requirements will help you prepare for this trial:

- Shovel
- Plastic sheet
- Container
- Recording sheet

Trial Timelines

We recommend sampling in the wetter months (eg. between June and September in southern Australia). Earthworm numbers will be highest in July and August.

Trial Method

How many samples do I take?
For worm counts, take no less than 3 samples of soil per treatment plot. For example, if the plot is one panel (~8m long) then take samples of soil between the vines in the middle of the panel. For example, if there are 6 vines in a panel, sample between the 2nd and 3rd vines, the 3rd and 4th vines, the 4th and 5th vines. If there is an above ground irrigation line, take samples 5cm from either the right or left side of the line. If not, take samples directly underneath where the irrigation line would be (see Fig. 1).

To take a sample of soil for worm counts, cut out a block of soil in a square about 30cm by 30cm and to 10cm depth. Lift the block of soil out and turn it over onto the plastic sheet. Gently break the block apart and collect all the earthworms into the container. It is probably easier to count the earthworms after you've taken all the samples for each treatment unit.

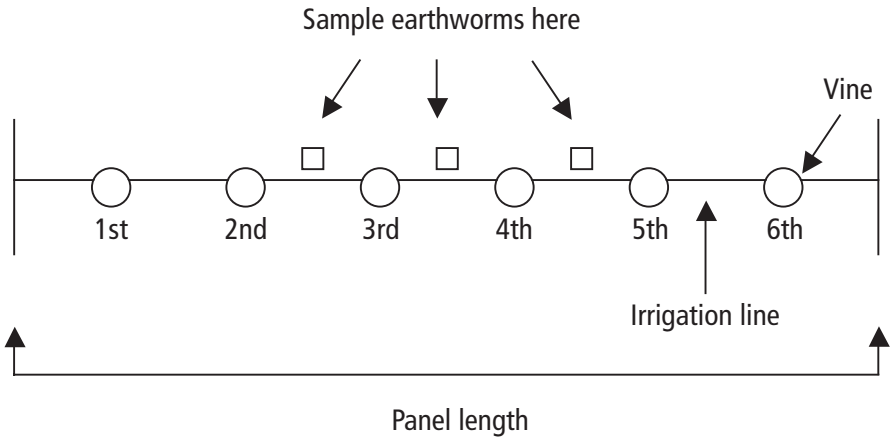


Figure 1: Example of the best place to take samples of soil in a treatment plot for earthworm counting (if one panel is one treatment plot in the trial design).

Calculations

To work out the number of worms per sample, simply divide by the number of samples taken. For example, if you counted 30 earthworms from one treatment plot, and you had taken 3 samples within that treatment plot, then the number of earthworms per sample is 10.

30 earthworms counted /3 samples=10 earthworms per sample

Interpreting the results

Scientists are still trying to decide on the ideal number of earthworms, particularly in a vineyard. The values below are a rough guide:

Earthworms per sample (30cm x 30cm x 10cm)

0-11 earthworms/sample	poor
14-23 earthworms/sample	good
>23 earthworms/sample	great

Rather than compare the number of earthworms to a set of values such as the one above, it might be better to compare your results from the different treatments. Remembering that more earthworms usually mean a 'healthier' soil. Graphing the data might make it easier to interpret. It might also be interesting to count the number of earthworms in the inter-rows or alternatively, another area of your property that is not under vines.

Soil Porosity

Aim

This trial aims to assess soil porosity, which affects soil aeration and drainage.

Important Points to Know

Soils need large pores and channels for adequate aeration and good drainage. Large pores that can be seen by the human eye are known as macro-pores. Meso-pores and micro-pores are too small to be seen by the human eye. Meso-pores are responsible for storing plant-available water. While micro-pores hold the water that is unavailable to plant roots, the movement of air through them is very slow.

For good plant growth the soil needs a balance of macro-, meso- and micro-pores. Soil with too many micro-pores will drain poorly and result in waterlogging. Clay subsoils often restrict water movement to depth and have a low porosity. Therefore, the porosity of the subsoil is often a good indicator of potential waterlogging of the surface soil.

Soil management can modify the porosity of a soil. Tillage and trafficking, particularly of wet soil, can destroy macro- and meso-pores, while cover crops and mulches can maintain and stabilise these pores. There is a simple field method to measure soil porosity by counting the number of pores on a face of a clod of soil. This is described below in more detail

Before You Get Started

The following requirements will help you prepare for this trial:

- Shovel
- Fuse wire (0.1mm and 0.5mm diameter)
- Recording sheet

Trial Timelines

This measurement is best undertaken when soil sampling is conducted (See 'Soil Sampling' trial technique in this series).

The time requirement for measurement per clod is dependent upon the number of pores visible, but to be conservative allow 10 minutes per soil clod.

Trial Method

Extract a moist sample of soil and on an undisturbed clod face, select a representative 25 mm square (i.e. 25 mm x 25 mm) and count all pores in the size range 0.1 0.5mm using the 2 wires as a guide (ignore cracks in the clod). (Cockroft 1970). Take three measurements for each treatment plot and each soil layer of interest. Each measurement should be taken on a soil sample from between the middle vines of each treatment plot.

If the topsoil is very crumbly (friable), then the macro-porosity is good, even though it is difficult to count the number of pores.

Optimal values

Number of soil pores (25 mm x 25 mm)	Soil water conductivity (mm/h)A	Classification
10	0.6	Poor
15	1.3	Acceptable for irrigation
20	2.3	
25	3.5	
30	4.9	Good for irrigation
40	8.5	
50	12.9	Excellent

Table 1. A Cockroft (1970)

Root Examination

Aim

This trial aims to assess root quality by examination of root systems.

Important Points to Know

It has been shown that grapevines respond to soil that is soft, friable, well aggregated and aerated, by developing vigorous root systems that permeate the soil evenly and deeply. On the other hand, compacted soil will have roots that are poorly distributed, shallow, stubby-ended and grow horizontally.

Visual observations of root growth and abundance in the soil are an integral measure of soil physical quality. Additionally, effective root depth is used to estimate available water, and to indicate the presence of restrictive layers or toxicity (eg. salinity) to vine roots. The presence or absence of vine roots is also dependent on climate, vegetation type and land management. For example, mid-row cover cropping or tillage will decrease root growth into the inter-row. All these factors will vary from region to region and with variety and rootstock.

Capturing some quantitative measure of root growth is a time consuming and labour intensive exercise. The best method is to excavate part of the rootzone and make an assumption regarding what the remainder of the rootzone is doing. As grapevine roots can grow to depths greater than 1 metre, an ideal tool is a backhoe excavator.

Before You Get Started

The following requirements will help you prepare for this trial:

- Backhoe
- Counting framework (eg. 1 m length of 100 x 100 mm weldmesh)
- Geologist's pick
- Recording sheet

Trial Timelines

The grapevine root system is best examined when in an inactive state. Because treatments applied in a trial may impact on the timing of root growth, examination should be avoided between bud burst and véraison, and for 6 weeks post harvest.

Allow 1 hour per treatment plot. This includes the time to dig a soil pit with a backhoe and count the number of roots to a depth of 1 m.

Trial Method

1. Dig a soil pit with a backhoe 30cm from the base of the middle vine in each treatment plot. Dig the pit parallel to the vine row so that it is approximately 1 metre wide and 2-3 m long and at least 1 metre deep.

2. Clean the face of the soil pit with the geologist's pick (or an air gun on a portable compressor) so there is no smearing from the backhoe.

3. Place the framework (1 m length of ten 100 cm^2 grids) vertically in the soil pit, in line with the vine.

4. Estimate the number of visible roots < 2 mm diameter within each of the ten 100 cm^2 grids.

5. Classify these as either; few (< 10), common (10-200) or abundant (>200).

6. Interpret root growth and the effective root depth from Table 1.

Ideally, the rootzone should be assessed in each treatment plot. However, due to the cost and time involved, assessment of 2 plots of each treatment is satisfactory.
For example, if we had a trial that had 2 different treatments replicated 8 times, giving a total number of 16 treatment plots, then the rootzone might be assessed in 4 treatment plots (2 for Treatment A and 2 for treatment B).

Interpreting results
Table 1. Interpretation of root assessment from a soil pit. Reproduced from Fitzpatrick (1996)

Root abundance (roots per 100mm x 100mm)	Depth class(m)	Growth suitability for many plants
> 200	0-0.50	Very Good
> 10	> 0.5	Very Good
> 200	0-0.15	Good
> 10	0.15-0.50	Good
10-200	0-0.50	Good
=10	> 0.5	Fair
10-200	0-0.15	Poor
< 10	0.15-0.50	Poor
< 10	0-0.5	Very poor

Effective root depth is defined as that soil depth, measured from the soil surface, where the amount of roots decreases to few (i.e. < 10 roots per 100 mm x 100 mm).

Soil Strength

Aim

This trial aims to assess soil strength.

Important Points to Know

Soil strength is a measure of the capacity of soil to resist deformation and refers to the amount of energy that is required to break apart aggregates or move implements through the soil. Soil strength will affect the ability of the roots to penetrate the soil. The growth of grapevine roots appears to become limited at 1 MPa penetration resistance and is severely retarded beyond 2 MPa.

Soil strength is influenced by a number of factors:

- Soil water content: as the soil becomes drier, soil strength increases and more force is required to break apart aggregates.
- Texture: dense fine textured soils (i.e. soils with a high clay content) stick together more than sands.
- Structure: small firm granular aggregates are more easily tilled than large solid slabs; aggregates with a stable macro- and micro- structure do not slake or disperse by wetting.

Soil strength can be modified by inputs of organic matter such as mulches, composts or cover crops; aggregate macro-structure becomes more stable. The application of gypsum to soil stabilises aggregate microstructure and prevents clay dispersion. Excessive tillage can break down both the macro- and microstructure of aggregates leading to hardsetting and crusting of surface soils.

There are a number of different methods for measuring soil strength:

1. Penetrometer
This has a stainless steel cone on the end of a shaft that is inserted into the soil and pushed through at a steady rate. A pressure sensor records the pressure (units of kPa or MPa) needed to push the rod into the soil. This measure must be done when the soil water content is at field capacity (1-2 days after deep penetrating rain or irrigation).

2. Bronzing rod
This method is simpler but less accurate than a penetrometer. The ease of pushing a bronzing rod (2.4-mm diameter) into the soil with the palm of the hand gives an estimate of soil strength. It must be done when the soil water content is at field capacity (1-2 days after deep penetrating rain or irrigation).

As the cost of purchasing a field penetrometer with pressure sensor may be prohibitive to most growers, the method described will be for the bronzing rod.

Before You Get Started

The following requirements will help you prepare for this trial:

- Bronzing rod (300 mm long 2.4-mm diameter manganese bronze rod)
- Recording sheet

Trial Timelines

The best time to carry out the measurement of soil strength is when the soil is at field capacity. This will occur approximately 24 hours after soaking rain.

The field capacity of soil is the water content when the soil moisture tension is approximately 10 kPa. This can be measured by a tensiometer.

The time requirement to dig a trench to 50cm and insert bronze rod into 3 layers of soil at 3 positions should take about 30 minutes.

Trial Method

It is important to assess the soil strength of each soil layer that will impact on root growth and water penetration. Ideally measure soil strength in each soil layer and at 3 positions in a soil pit (See 'Root examination' trial technique in this series). Alternatively, dig a trench adjacent to the middle 4 vines in a treatment plot so as to expose a face of soil in the vine line to at least 50-cm depth.

Bronzing rod

1. Push the rod into the soil, horizontally, with the palm of the hand. Repeat for each soil layer.
2. If the rod enters the soil without undue pain to the palm then penetration is less than 1 MPa (see Table 1).
3. If it is too painful shield the palm with coin and attempt inserting the rod again.
4. If the rod flexes and does not move into the soil, the penetration resistance is greater than 3 MPa (see Table 1).
5. Soil strength of each soil layer should be measured at a minimum of 3 positions within each treatment plot (see Figure 1 below).

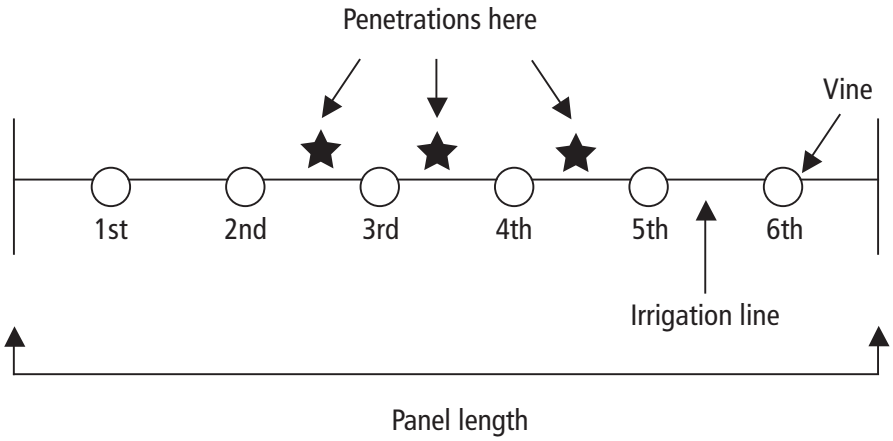


Figure 1: Example of the best place to measure soil strength in a treatment plot (if one panel is one treatment plot in the trial design).

Interpreting results

Table 1. Interpretation of soil strength test, measured at field capacity, using a 300 mm long, 2.4 mm diameter manganese bronze rod push horizontally into the soil using the palm of the hand. Modified from Cass et al. (1996).

Soil strength	Behaviour of Bronze rod	Relevance to root growth
< 1 MPa	Rod enters soil without inflicting undue pain.	Roots grow through soil without difficulty. Soil physical quality is good.
1 - 3 MPa	Rod can be pushed into soil using a shield on the palm.	Root growth may become restricted. Soil physical quality is moderate.
> 3 MPa	Rod flexes and moves into soil with reluctance using a shield on the palm.	Root growth is retarded except through cracks and old root channels. Soil physical quality is poor.

Soil Salinity

Aim

This trial aims to assess soil salinity.

Important Points to Know

Salinity is a measure of the concentration of soluble salts in the soil water. The most common salt is sodium chloride, however others include bicarbonates, sulphates and carbonates of calcium, potassium and magnesium. Vitis vinifera varieties are moderately tolerant of salinity (i.e. high total salts). However, a concentration of salts in the rootzone that is too high can damage plant health and reduce crop yields. A very high concentration of soluble salts can kill a crop.

Soil salinity can be measured by electrical conductivity (EC) using one of two methods to extract salt from the soil; the saturation extract or a suspension of 1:5 soil to distilled water. The most accurate and reliable method is the saturation extract. This method is generally not available to grape growers and must be done in a soil-testing laboratory. Alternatively, measurement can be done in the vineyard using an inexpensive EC meter and a suspension of 1:5 soil to distilled water.

Measurement of soil salinity could be required to determine the response of a trial site irrigated with saline water, particularly in combination with deficit irrigation. Treatments implemented to overcome an already saline soil will require monitoring for changes in soil salinity.

Before You Get Started

The following requirements will help you prepare for this trial:

- Portable handheld EC meter
- Plastic jars with screw-on lids
- Distilled or rain water
- Thermometer

Trial Method

Make sure to periodically calibrate your EC meter (refer to instrument instructions).

1. Take three surface soil and three subsoil samples from each treatment plot (as per the 'Soil Sampling' technique in this series). Make sure surface soil and subsoil are not combined so that they can be analysed separately.

2. Allow the soil to dry in the air, then crush large aggregates and remove any gravel (as per the 'Soil Sampling' technique in this series).

3. Unscrew jar lid and fill the lid level with soil. Do not compress the soil. Pour into jar.

4. Add 5 jar lids of distilled water (i.e. to make up a 1:5 solution) and screw lid on tight. Shake periodically over one hour.

5. Let the mixture stand undisturbed for half an hour or a little longer if the suspension is not clear. If the suspension cannot be clarified, the measurement can still be taken in the knowledge that EC will be slightly overestimated (0.01 to 0.03 dS/m). This error is acceptable for a field estimate that can be used to decide whether to submit samples for saturation extract analysis.

6. Rinse the EC meter electrodes in rain or distilled water and dry gently with a tissue.

7. Take a reading by immersing the electrode in the suspension above the soil as per manufacturer instructions. Make sure the electrodes are fully covered. Take care to minimise electrode contact with soil at the bottom of the jar.

8. Allow reading to stabilise. Record reading and solution temperature.

9. Rinse electrode before next reading.

If the solution was not at 25ºC at time of measurement then an approximate correction can be applied by increasing the value by 2% for each degree above 25ºC or decreasing the value by 2% for each degree below 25ºC (Rayment and Higginson 1992).

If you have scales and volumetric flask then the accuracy of the 1:5 soil to distilled water ratio can be improved by using 20 g of air-dried soil and 100 ml of distilled water (Rayment and Higginson 1992). Jar lids are used in the field when scales are not available.

If EC 1:5 values exceed 0.15 dS/m (sands), 0.18 dS/m (loams) or 0.3 dS/m (clays), then you should submit soil samples to a commercial laboratory for saturation extract analysis.

Interpreting results

Table 1. The salinity hazard for grapevines of soil as measured in a suspension of 1:5 soil to distilled water ($EC_{1:5}$) and a soil-water saturation extract (EC_{se}) (reproduced from Cass 1998).

Salinity Hazard	Sandy Loam	$EC_{1:5}$ (dS/m) Loam	Clay	EC_{se}	Effect on vines
Non-saline	<0.15	<0.17	<0.4	< 2	None
Slightly saline	0.16-0.3	0.18-0.35	0.41-0.8	2-4	Own rooted effected
Moderately saline	0.31-0.60	0.36-0.75	0.81-1.6	4-8	Some rootstock tolerate
Very Saline	0.61-1.2	0.76-1.45	1.6-3.2	8-16	No vines grow
Highly saline	>1.2	>1.45	>3.2	> 16	Vines die

Useful conversions

1 dS/m	= 1 mmho/cm
1 dS/m x 640	= 1 ppm
	= 1 mg/l
1 dS/m x 1000	= 1 ºS/cm
	= 1 EC unit

Soil Structure

Aim

This trial aims to assess soil structure.

Important Points to Know

Soil structure is one of the major factors affecting winegrape production and profitability. Poor soil structure can limit root development, water infiltration and water availability for crop growth. Good soil structure allows water and air to move freely into the soil therefore avoiding waterlogging and run-off. Plant roots are able to explore a larger volume of soil and thus access more water and nutrients stored in the soil.

The deterioration of soil structure occurs by two processes:
- Slaking of aggregates
- Dispersion of clay

Slaking is defined as the rapid disintegration by pure water (eg. rain water) of large aggregates (> 2-5 mm) of soil into smaller aggregates (most of which are < 0.25 mm). As slaked soil dries the small aggregates settle together and provide smaller pores than the previous large aggregates. Slaking occurs because of a lack of strong organic bonds between soil particles and micro-aggregates.

Dispersion is when dry soil is wet with pure water (eg. rain water) and the clay structures that bind the fine aggregates and large particles (sand and silt) breakdown. 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 enhanced when the soil has high levels of exchangeable sodium concentrations, and from excessive tillage when the soil is wet.

Soil structure can be modified by inputs of organic matter such as mulches, composts or cover crops; aggregate macro-structure becomes more stable. The application of gypsum to soil stabilises aggregate microstructure and prevents clay dispersion. Excessive tillage can break down both the macro- and microstructure of aggregates leading to hardsetting and crusting of surface soils. There is a simple method to measure soil slaking and dispersion by placing an aggregate in water and observing its breakdown. This is described below in more detail.

Before You Get Started

The following requirements will help you prepare for this trial:

- A handful of soil from each soil layer
- Shallow, clear, open containers
- Rain water or distilled water

Trial Timelines

The time required for the soil sampling is as per the 'Soil Sampling' trial technique. The trial can be done at any time of the year, although autumn and spring are the best times, as winter can be too wet and in summer the ground may be too hard.

As a conservative estimate, allow 10 minutes per sample for collection time, with 1/2 hour required if using a mechanical sampler.

See 'Soil Sampling' technique in this series for the time required for soil sampling. Excluding the waiting time, the actual time required to perform the test is only about 15 minutes. It is possible to have more than 1 sample tested at the same time.

Trial Method

A recent version of the slaking and dispersion test (Cass et al. 1996) is detailed below:

1. For each soil layer, collect a handful of soil and place it in a container to air-dry for 24 hours at room temp (approximately 20∞C). Avoid excessive disruption of the soil. (Refer to 'Soil Sampling' technique in this series).
2. From each sample, select three aggregates about the size of a pea.
3. Place them carefully, equally spaced apart, in a shallow container filled with rain or distilled water. (You can also do the test using irrigation water if you are interested in its effect on structural stability).
4. Watch the aggregates closely during the first few minutes and note whether they float on the surface or sink, and the rate at which smaller particles break away from the larger sample (slaking).
5. After 2 hours record whether slaking was complete, partial or absent.
6. Leave the dish untouched for 20 hours and then assess dispersion. A 'cloudy' or 'milky' halo around the slaked fragments of the aggregate indicates partial dispersion. Complete dispersion is indicated when the base of the container is completely covered with a layer of clay leaving only a pile of sand where the aggregate was placed.
7. If no dispersion occurred take another sample from the air dried soil, remove any gravel, stones and plant fragments and moisten with rain or distilled water while kneading into a ball of about 40 mm diameter. Add small amounts of water as necessary until the ball of soil just begins to stick to the hand.
8. Break the ball of soil open and remove some soil to make 3 pea size balls and place them in a clear container as described above.
9. Watch and record the results.

Interpreting Results

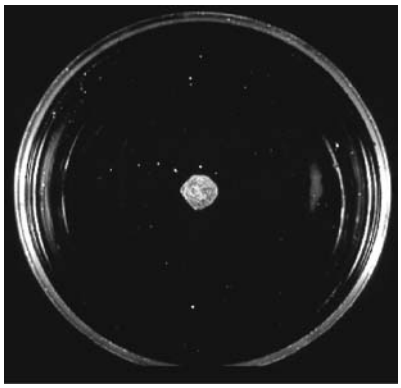


Figure 1: The aggregate remains stable

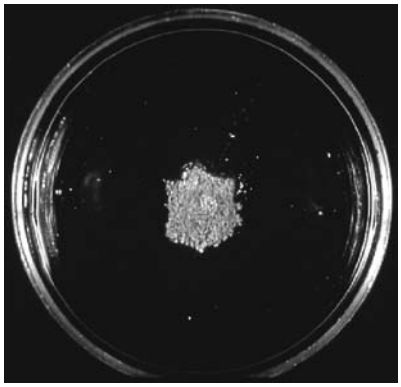


Figure 2: The aggregate has slaked into micro-aggregates

Figure 3: Partial dispersion: the dispersed clay spreads into thin streaks and crescents on the bottom of the container.

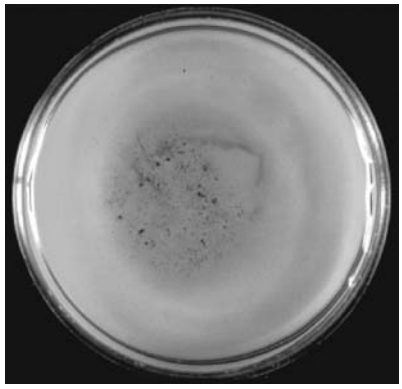


Figure 4: Complete dispersion: a cloud of dispersed clay covers the bottom of the dish and the aggregate has almost disappeared

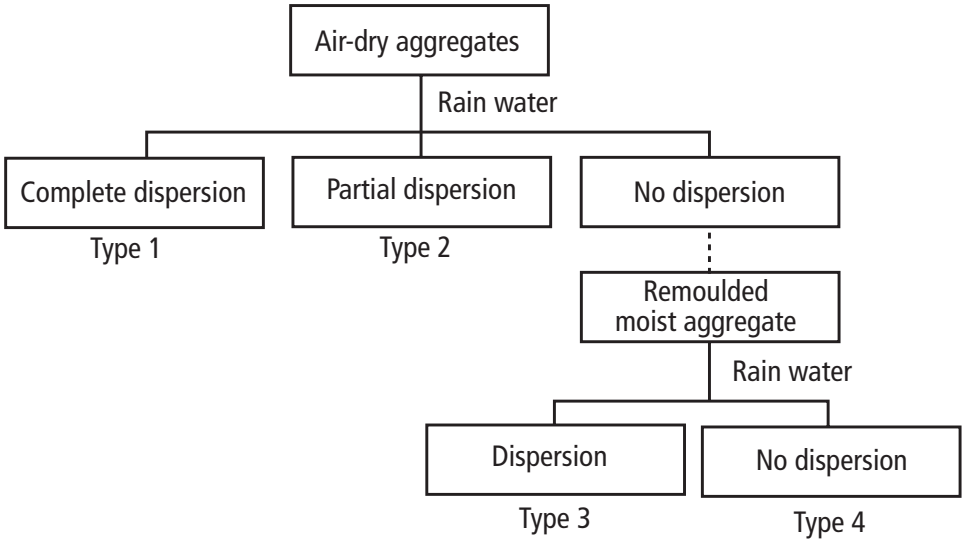


Figure 7-5 Interpretating the skating and dispersion properties of soil aggregates (after McGuinness 1991)

Type 1 : Highly dispersible soil, very poor micro-structural stability
Type 2 : Poor micro-structural stability
Type 3 : Moderate micro-structural stability
Type 1 : good micro-structural stability

Figure 5: Interpreting dispersion properties of soil aggregates (McGuinness, 1991)

Type 1: a cloud will cover the bottom of the dish in a very thin layer. A small heap of sand may be left where the aggregate was left (Figure 4).

Type 2: a cloud of dispersed clay will form around the aggregate that usually spreads into thin streaks and crescents on the bottom of the container (Figure 3).

Type 3: this soil only disperses after the clay has been worked. This means that very sound management practices can avoid crusting and erosion, but there is little room for error.

Type 4: The aggregate structure of the soil is pretty stable. The soil should not crust, and will have good rates of water entry. It may still be susceptible to compaction.

Resources

Some useful resources for evaluating soil moisture

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