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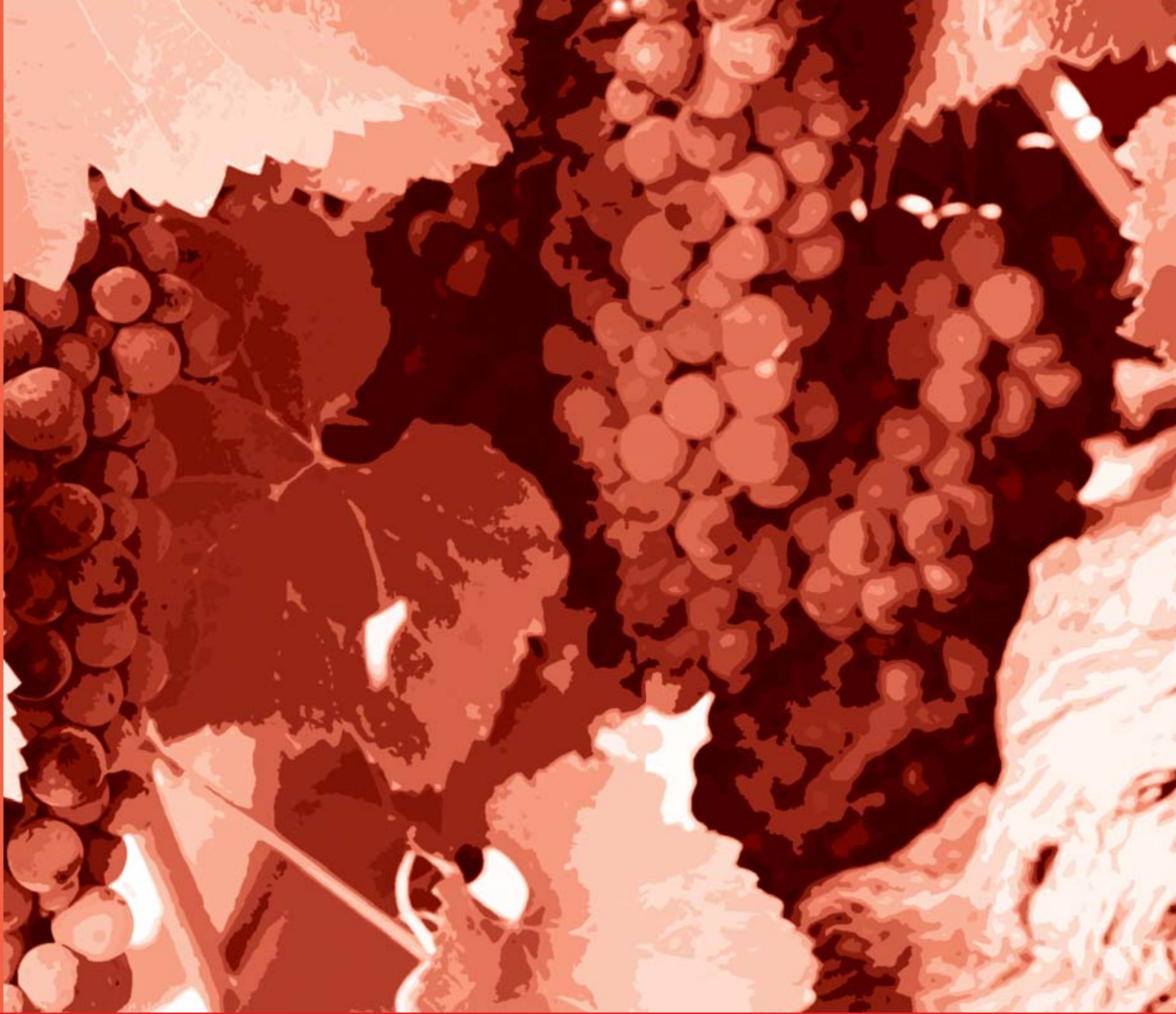

VITICARE ON FARM TRIALS

Manual 2.1 - Improving Soils 1

Improving soil acidity

Managing hard-setting and crusting of under-vine soil surface

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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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 improve soil acidity and help manage under-vine crusting of soil surface in the vineyard.

Improving Soil Acidity

Aims

This trial aims to improve soil acidity in a vineyard by:

- o Evaluating liming materials capable of increasing soil pH within the vineyard;
- o Determining the most appropriate application techniques; and/or
- o Determining the most appropriate rate of application.

Important Points to Know

Vineyards with low soil pH values located in high rainfall zones have a need to determine the effects of increasing subsoil pH on grape production and quality. If current soil management practices continue (i.e, high rates of nitrogen fertilisation and declining soil organic matter levels) it is inevitable that soils in vineyards will become more acidic. To prevent the irreversible effects of soil degradation that are a consequence of a very low soil pH, management strategies that maintain or increase soil pH levels should be adopted to protect the long-term viability of Australian viticulture.

Positive and Negative Aspects

It is important to determine the risks associated with lime application at the proposed site and assess these against the potential benefits. Some risks may preclude trialing treatments at a particular site, whilst at other sites it may be sufficient to monitor a potential risk and have a contingency plan in place if it occurs. The advantages and disadvantages of using lime in vineyards are listed below. These may be used as a guide to risks that can develop.

Risks of a liming trial can include:

- The rate of lime application required to increase soil pH and therefore the cost of lime;
- The detrimental effects on soil if acidification is allowed to continue without a liming program;
- The uncertainty of obtaining a fruit yield response to lime application;
- Timing of application of lime in respect to seasonal conditions (i.e. lime will not move through the soil profile without rain/irrigation); and
- Method of lime application (surface/subsurface, banded/broadcast).

In light of these issues, some questions worth considering are:

- Which risks are important at your site?
- Which risks would not prevent the trial proceeding but should be monitored?
- What plans need to be put in place to reduce the impact of any risks occurring?

Cost Benefit Analysis

Although the practice of liming is predominantly to prevent/decrease soil degradation resulting from high acidity, identifying associated production benefits of such a program is also important from an economic perspective. Thus, measurements of yield and quality parameters are suggested.

In order to determine the financial viability of a liming program, a cost/benefit analysis should be completed to relate the monetary requirement of liming to a production basis. Due to differences in soil types and management practices, a yield response to lime application cannot be guaranteed. However, such a program should also be considered in terms of the long-term soil degradation that will result if soils are allowed to acidify to pH (water) values of 4.8 or lower. It must also be remembered that by increasing soil pH you are protecting the soil from ongoing degradation, thus ensuring continual productivity.

Before You Get Started

The following points will help you prepare for this trial:

- Understand the site suitability in terms of current soil pH levels in the vineyard and the soil management history;
- Know what the appropriate liming products are for the trial;
- Organise labour to apply liming products and conduct monitoring;
- Have suitable application equipment available. This will be dependent on the method of application - surface or subsurface. Suitable machinery is required to both distribute the lime, and incorporate it into the soil.

Site Suitability

Before proceeding with a liming trial it is essential to determine whether the soil is acidic. If the soil pH as determined in water is less than 6.0 the application of lime may lead to an increase in yield. It is highly advisable to test soil pH in the surface (0-10 and 10-20 cm) and subsurface (20-40 and 40-60 cm) soil layers and/or where the vine roots are actively growing (they may grow deeper).

It must also be noted that other soil problems may exist which could prevent roots from accessing soil moisture at depth or contributing to nutrient deficiencies. An assessment of the soil conditions in the vineyard should be carried out according to the following guidelines.

Soil Characteristics:

The digging of a soil pit will aid in assessing the soil condition. Soil characteristics that can be determined using a soil pit are:

- Soil pH down the profile (sampled at different depths)
- Presence of organic matter
- Texture changes (observe any changes in soil type down the profile)
- Colour changes
- Waterlogging (a mottled colour will indicate prolonged waterlogging)

Irrigation:

In irrigated vineyards it is likely that soil acidification will be more severe under the dripper lines, especially when nitrogen fertigation is practiced. As highly soluble nitrates leach down the profile, the associated changes in chemical balances lead to greater soil acidity.

Topography and climate:

Soils low in organic matter content and high in sand content have a low buffering capacity. These soils will acidify more rapidly than soils that have a higher buffering capacity and contain a high proportion of clay and organic matter. Conversely, soils with a high buffering capacity will require proportionally more liming material to achieve an increase in soil pH. In addition, those vineyards that receive a high annual rainfall (>600 mm) will be prone to higher rates of nitrate leaching and therefore acidification compared to vineyards in lower rainfall environments.

Liming Products to Choose From

Several liming products can be trialed to determine their effectiveness in increasing soil pH:

- Calcium carbonate - available as ground limestone, agricultural lime and shell lime. It is cheap but is the least reactive form of lime. The finely ground premium grades are most effective, as particle sizes greater than two mm are of little value due to their low rate of dissolution.
- Calcium hydroxide - available as slaked or hydrated lime. It is more reactive than calcium carbonate but rather expensive for agricultural use.
- Calcium oxide - available as burnt lime or quicklime. It is the most reactive form of lime. It must be stored in a dry place because it heats and swells as it absorbs moisture.
- Mixtures - of the above listed products are also available.

Determining the Rate of Application

The rate of lime application depends upon the buffering capacity of the soil. It is essential to calculate the correct rate of application to avoid under or over liming.

When you have determined the correct rate of liming application, increase the pH by one unit then monitor soil pH for a year after application, applying more lime if required.

The quality of the liming material used will be determined by what is called the neutralising value (NV), or the ability of that lime to neutralise the acids in the soil. In determining the neutralising value, both the moisture content and particle size (fineness) of the product is considered. The finer the material, the more rapidly it will neutralise acidic compounds in the soil, as finer material has a greater surface area in contact with the soil.

Neutralising values of liming materials are calculated based on their performance relative to pure agricultural lime (NV = 100). This information can be used to determine cost comparisons between liming materials.

For example Gillear Lime has an NV of 77, compared to pure agricultural lime, which has an NV of 100:

$$\frac{\text{Gillear lime}}{\text{Pure ag lime}} = \frac{77}{100} = 0.77 \times 100 \text{ (to express as a percentage)} = 77\%$$

Therefore, if using Gillear Lime, we would have to apply 23% more (100%-77%) than if we were applying pure agricultural lime. This calculation can be used to compare any two liming products, as long as the NV is known.

Potential Treatments

Having established that the soil is acidic and below a pH of 6.0 (measured in water), an improvement strategy needs to be considered. One or more of the following treatments could be tested:

1) Surface application of lime (rate based upon the buffering capacity of the soil determined by laboratory analysis).
2) Surface application of very fine "liquid" lime products (rates as determined above).
3) Surface application of composted organics (could be included as part of other compost studies).
4) Sub-surface application of lime with a slurry injector.
5) Application of more soluble products through irrigation lines (needs to be tested, as carbonate precipitates could block irrigation hoses).

Measurements and Monitoring

There are numerous measurements that are applicable to a lime application trial. Unfortunately there is no single set of measurements that are applicable to all trials. The correct measurements can only be selected once the objectives of the trial have been clearly defined. Following is a list of potential measurements.

The following table includes potential measurements for improving acidity trials, their time involvement, and difficulty.

Measurements	Time*	Difficulty*
Vine vigour - shoot length	3	A
Baumé/Brix	1	A
Juice pH	1	B
Titratable acidity	1	C
Grape yield	2	A
Colour (Anthocyanins)	2	C
Soil pH	1	B/C
Earthworms	1	A
Soil biology/organic matter	1	C

**Time is where 1 = few minutes per replicate, 2 = 15 minutes per replicate, 3 = >30 minutes per replicate; Difficulty is where A = easy, no laboratory skills and/or measurement equipment required, B = some laboratory skills and/or measurement equipment required, and C = laboratory skills and/or sophisticated measurement equipment required. Refer to complete Table 2.2 in Section #2: Trial Design and Variability*

Trial Timelines

This trial involves the application of liming products to the soil and the assessment of soil pH and biology. The time requirement to carry out this trial includes application of liming materials (0.5 day), soil pH sampling (0.5 day), biology assessments (0.5 day), and trial harvesting for yield/quality parameters (0.5 day).

Trials involving the use of liming materials should be run for a minimum of three years. An increase in soil pH may not be observed in the first year post-lime application, depending upon when the lime was applied. It is advisable to apply lime before the autumn break and allow good rains to assimilate the lime into the soil prior to the following growing season.

Shaded areas in the following table indicate when measurements or samples suggested above are to be taken. See the measurement manual in this series for more information about measurement protocols.

	Dormancy	Bud burst	Shoots 10 cm	Flowering	50% capfall	Berry set	Berries pea-size	Bunch closure	Veraison	Harvest	Post-harvesty
Soil pH*											
Earthworms											
Soil biology/ organic											
Shoot length											
Grape yield											
Grape pH											
Baumé											
Titratable acidity											
Colour											

**Soil measurements should be monitored in the year after treatment, then at two to three yearly intervals to determine the effect on surface and sub-surface conditions.*

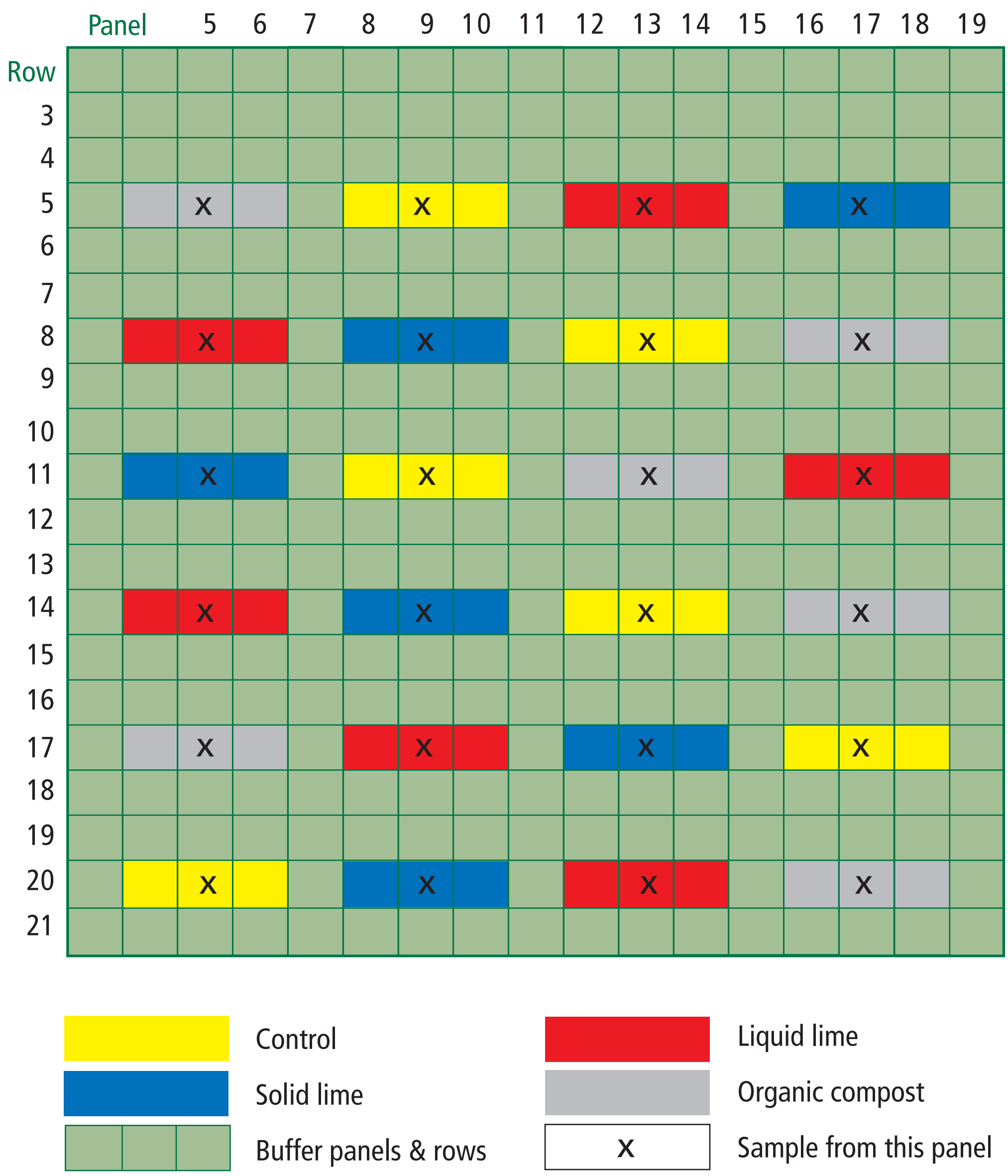
Lime Trial Designs

Treatments will need to be replicated within the trial area at least six to eight times, more if the area is not very uniform. One of the treatments should be a control, which will often be current practice. It is advised not to have more than three or four treatments to allow enough time for management of the trial.

Plots (or experimental units) can be different shapes and sizes, but a common plot in a liming trial consists of three rows by three panels of vines. The middle panel is used for taking measurements (for example, Row 5 Panel 5).

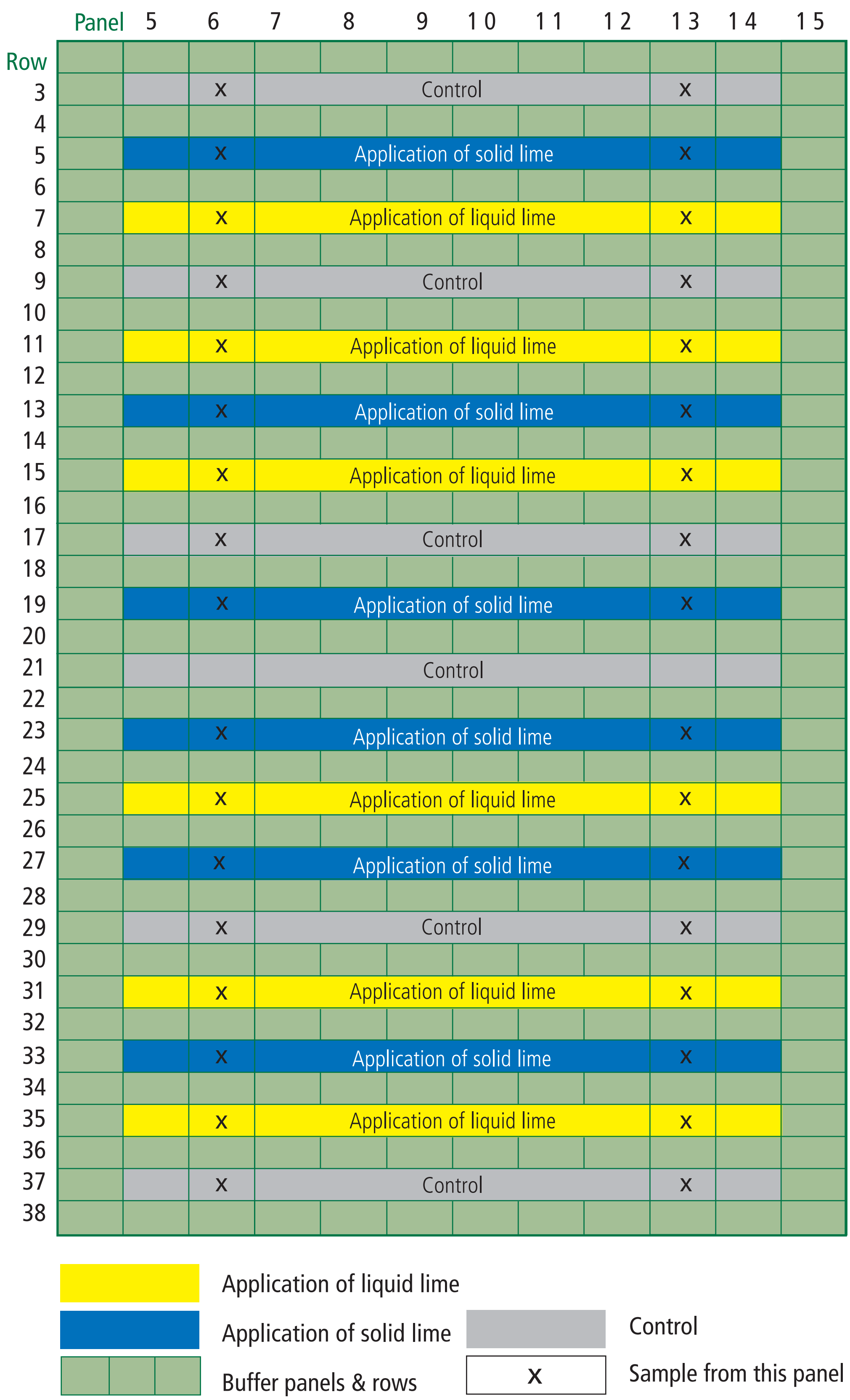
Buffering is important to identify clear treatment areas and to avoid contamination between treatment areas. Buffer zones are marked as panels with grid-lines in the following designs.

Design 1: An example of a randomised block design that could be used to assess three soil improvement practices (for example, solid versus liquid lime).



Design 1 gives an example of a trial layout in which the treatments are three different methods of lime application plus a control (no lime). The trial has four treatments and six replications, arranged in a randomised block design, with the blocks being rows (or, more strictly, groups of three adjacent rows).

Design 2: An example of a trial design that can be used to test soil improvement practices (for example, solid versus liquid lime) using rows as experimental units.



Design 2 gives an example of a trial layout in which the treatments are two different methods of lime application plus a control. It uses rows as experimental units as opposed to panels, which can make management of the trial (e.g. sowing of crops, lime applications) a little easier.

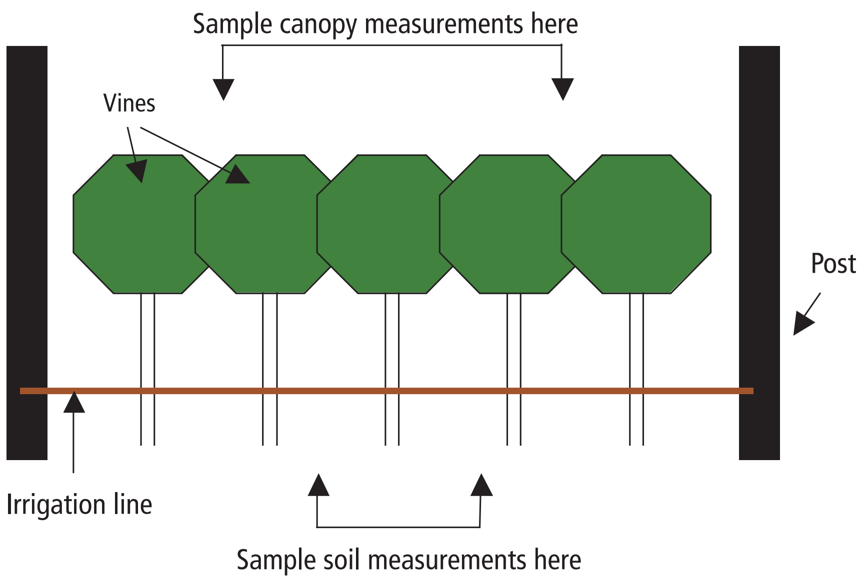
When using rows as experimental units, it is normally anticipated that a maximum of three treatments are trialed due to the potential workload expected. This trial has three treatments and six replications, again arranged in a randomised block design, with the blocks being groups of three adjacent experimental units.

It is recommended to only sample the middle vine in panels marked with an X (Designs 1 and 2) when taking vine measurements. If there are more than three vines per panel, only sample from the middle vines of the panels mentioned above (see Figure 1).

When taking soil measurements always sample from between two vines in the middle of each middle panel.

These recommendations will ensure that there is no contamination between plots; in some situations they may be waived provided that contamination is not a possibility. The approach described here also guarantees objectivity in the sampling, which will prevent the experimenter's bias from jeopardizing the results.

Figure 1: A diagrammatic explanation of where, within a panel, measurements can be taken.



Managing Hard-setting and Crusting of Under-vine Soil Surface

Aims

A trial examining how to manage hard-setting and crusting of under-vine soil could aim to:

- o Evaluate treatments for their potential to minimise hard-setting and crusting of surface soil in the vine-row;
- o Improve water infiltration into soil;
- o Decrease water usage per hectare (increase water use efficiency);
- o Improve vine health;
- o Improve machinery access to vineyard rows; and
- o Increase grape production.

Important Points to Know

Crusting of the soil surface occurs when soil aggregates are broken down by the impact of water droplets, with soil particles subsequently setting into a hard crust. Crusting extends only to the top 10 mm of soil as the aggregates under the crust are protected from further impact of water droplets.

Hard-setting is similar to crusting in that it is also caused by the breakdown of soil surface aggregates by water droplets or flooding, but the effect extends to depths greater than 10 mm.

Both crusting and hard-setting can result in poor water and nutrient movement into the root zone. Hard-setting can also result in poor root growth and impaired root function due to greater resistance to penetration. Surface crusts can also trigger erosion on slopes as the smooth soil surface increases the rate of run-off.

Water ponding and prolonged waterlogging can be indicators of hard-setting and/or crusting soil. Soil may remain saturated at the surface for several weeks following heavy rain, impeding the movement of vehicles within the vineyard.

Soil types and/or management practices can contribute to crusting and hard setting. The soils that are most prone to hard-setting and/or crusting are usually those with low levels of organic matter and/or soil chemistry imbalance.

Organic matter

Organic matter plays an important role in binding soil particles together. If the soil breaks apart (slakes) in distilled water, it means that low levels of organic matter cause the crusting. Frequent cultivation and maintaining a "clean" under-vine bank through herbicide application reduces the level of organic matter in the soil. Organic matter also protects the soil surface from the physical impact by water. As organic matter decomposes, the compounds produced also assist in maintaining aggregate stability. The growth of under-vine cover crops or voluntary plants during dormancy can provide a favourable soil structure for root growth in the following season through the creation of bio-pores and decay of dead plant material. Crusted or hard-set soils low in organic matter generally have low earthworm numbers (< 10/m2 in the top 50 mm), low number of bio-pores (2 to 10 mm diameters) or macro-pores (< 15 % of soil volume) and low infiltration of water (< 15 mm/h).

Soil chemistry

High levels of sodium in the soil cause soil aggregates to disperse upon wetting, as the clay-sodium-clay bond is very weak. In contrast, the clay-calcium-clay bond is quite strong. Hence, the addition of calcium reduces crusting and hard-setting by holding clay particles together and preventing separation in water.

Many Australian soils, particularly the duplex soils, have naturally high sodium concentrations. Excessive application of saline water or highly saline ground water can cause sodium accumulation in the surface soil. In addition, even soils irrigated with good quality water can be leached of components which assist in binding clay particles together (e.g. calcium, carbonates), increasing the likelihood of dispersion. Calcium can be replaced through gypsum application, which displaces sodium to form clay-calcium-clay bonds, helping clay particles to bond together. Therefore, organic materials, gypsum, or a combination of both may be applied in a trial to evaluate their impact on hard-setting and crusting of the under-vine soil surface.

Positive and Negative Aspects

It is important to determine the risks associated with managing hard-setting and crusting soils at the proposed site. These risks must be weighed up against the potential benefits that a particular treatment may impart. Some risks may preclude trialing treatments on a particular site. At other sites, it may be sufficient to monitor a potential risk and have a contingency plan in place if it occurs. The potential risks in managing hard-setting and crusting soils in vineyards through mulch application are listed below.

Potential risks of a trial assessing hard-setting and crusting of under-vine soil surface include:

- If a site with hard-setting and/or crusting has an impenetrable soil layer within 500 mm of the surface, waterlogging could result.
- Variable water distribution throughout the vine root-zone and/or across the trial site may mask the benefits of treatments imposed.
- Water applied only to the vine-row may decrease cover crop growth during the season.
- During a dry season the cover crop and grapevines vines will compete for water and nutrients.
- Rainfall distribution will affect the benefit of treatments imposed (e.g. low rainfall during winter/spring will decrease the amount of dry matter produced by a cover crop).
- Sites prone to frosts will require careful timing of organic matter application to the under-vine row.
- Conflicting soil management practices, e.g. cultivation may compromise treatment effects.
- Some mulches, e.g. straw, may increase the risk of fire.
- Budburst may be delayed due to cooler soil temperatures.
- Both cover crops and mulches can harbour pests and diseases.

If soil dispersion is an issue then gypsum addition could reduce crusting/hard-setting problems. Gypsum application is highly unlikely to have any detrimental impacts on vine growth and production.

The response of soils to the addition of gypsum depends on their dispersion class. If soil tests indicated slaking and dispersion, then the addition of both gypsum and organic matter could be considered.

In light of these issues, some questions worth considering are:

- Which of these risks are important at your site?
- Which of these risks would not prevent the trial proceeding but should be monitored?
- What plans need to be put in place to reduce the impact of any risks occurring?

Cost Benefit Analysis

In order to determine the economic viability of a soil improvement program a cost/benefit analysis should be completed to relate the economic requirement of soil improvement to a production basis. The risks associated with a soil improvement program in vineyards must be weighed up against the benefits. However, it must be remembered that by conditioning the soil you are also protecting it from degradation and ongoing soil loss over a long period of time.

Before You Get Started

The following points will help you prepare for this trial:

- Labels for treatment plots (ear tags or flagging tape work well);
- A supply of organic matter and gypsum, and labour to apply it;
- Access to a slasher that throws onto the vine-row;
- If cover crop is to be used, fertiliser will be required for its establishment;
- A seeder will be required to sow the cover crop; and
- Possible changes in irrigation system - drip or micro-spray preferred.

Site Suitability

One or more of the following site characteristics will make your site highly suitable for conducting this type of trial:

- Surface soil exposed in vine-row
- Soil forms a crust >1mm
- Has a hard-setting surface (assessed by penetrometer at field capacity)
- Low in organic matter (<1.5%) (as determined from a recent soil test)
- Soil slakes or disperses
- Sodium concentration high (SAR) >3
- Displayed run-off during irrigation or rain

If your site has none of the above characteristics, the soil is unlikely to be displaying hard-setting and/or crusting properties.

Soil

If the sub-soil in the vine-row is within 500 mm of the surface, check the following points:

- o Soil disperses partially
- o Soil disperses completely
- o Is the sodium concentration high (SAR >3)

Vines

- o Young vines slow to establish
- o Low vegetative growth
- o Declining health of vines
- o Declining productivity
- o Poor ability to ripen crop
- o No roots in top 100 mm

Water/Irrigation

- o Annual rainfall exceeds 650mm
- o Use saline irrigation water (>1.0 dS/m)
- o Use pure irrigation water (<0.01 dS/m)

Potential Treatments

Determining whether soil slaking or dispersion occurs will indicate the type of treatments that can be trialed. The following is a list of these potential treatments:

1) Cereal straw mulch
2) Composted mulch
3) Cover crop of grasses (vine-row)
4) Cover crop of legumes (vine-row)
5) Cover crop (inter-row) mown and thrown onto vine-row soil
6) Vegetation in vine-row killed by herbicide prior to bud-burst
7) Gypsum (in various form)

Measurements and Monitoring

There are numerous measurements that are applicable to a soil improvement trial. Unfortunately there is no single set of measurements that are applicable to all trials. The correct measurements can only be selected once the objectives of the trial have been clearly defined. The following is a list of potential measurements.

The following table includes potential measurements for improving hard-setting and crusting soil trials, their time involvement and difficulty.

Measurements	Time*	Difficulty*
Vine vigour - shoot length	3	A
Plant nutrient status (petiole analysis)	1	C
Weed density and composition	1	A/B
Soil moisture/water infiltration	2	B/C
Baumé/Brix	1	A
pH	1	B
Titratable acidity	1	C
Soil physical parameters	1	B/C
Root density	1/2	A/B
Colour (anthocyanin)	2	C
Yield	2	A
Bunch number	1	A
Pruning weight	2	A
Soil biology/organic matter	1	C
Earthworms	1	A
Vine growth stages (phenology)	1	A

**Time is where 1 = few minutes per replicate, 2 = 15 minutes per replicate, 3 = >30 minutes per replicate; Difficulty is where A = easy, no laboratory skills and/or measurement equipment required, B = some laboratory skills and/or measurement equipment required, and C = laboratory skills and/or sophisticated measurement equipment required. Refer to complete Table 2.2 in Section #2: Trial Design and Variability. Refer to complete Table 2.2 in Section #2: Trial Design and Variability*

Trial Timelines

The ideal time for establishment of this trial is from post harvest to budburst. Assessment of the variability of the proposed vineyard block would be advised during the season prior to establishment. The time required to carry out the treatments will be for application of cover crops and/or gypsum and lime products (three hours). Time required to carry out measurements such as soil moisture and earthworm counts is approximately 0.5 day, and another 3 hours for soil biological matter and weed incidence.

Shaded areas in the following table indicate when measurements or samples suggested above are to be taken. See the measurement manual in this series for more information about measurement protocols.

	Dormancy	Bud burst	Shoots 10 cm	Flowering	50% capfall	Berry set	Berries pea-size	Bunch closure	Veraison	Harvest	Post-harvesty
Soil moisture											
Earthworms											
Soil physical parameters											
Plant nutrient status											
Grape yield											
Vine growth stage (phenology)											
Soil biology organic matter											
Weed incidence											

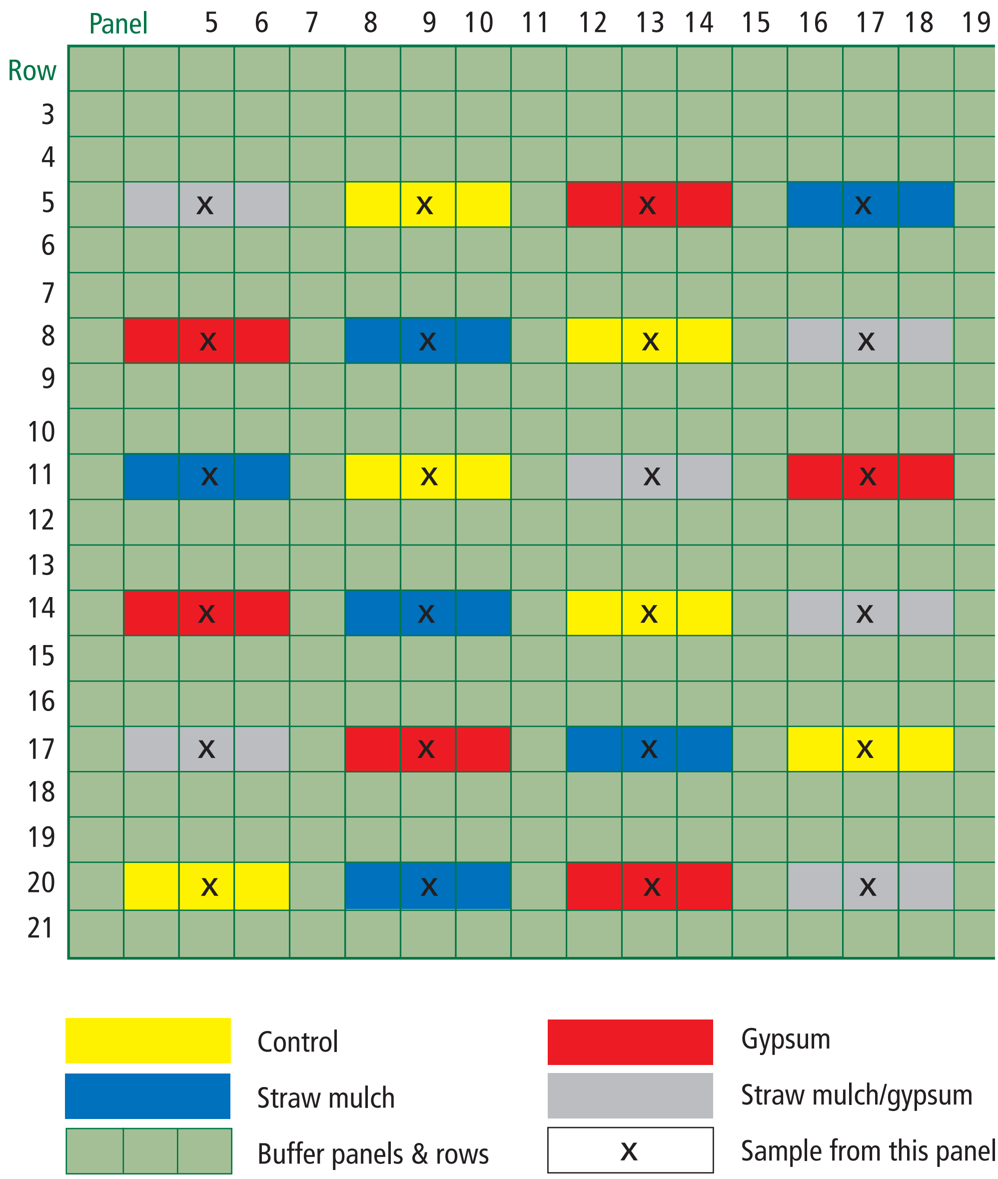
Trial Designs for Soil Improvements

Treatments will need to be replicated within the trial area at least six to eight times, more if the area is not very uniform. One of the treatments should be a control, which will often be current practice. It is advised not to have more than three or four treatments, to allow enough time for management of the trial.

Plots (or experimental units) can be different shapes and sizes, but a common plot in a soil improvement trial consists of three rows by three panels of vines.

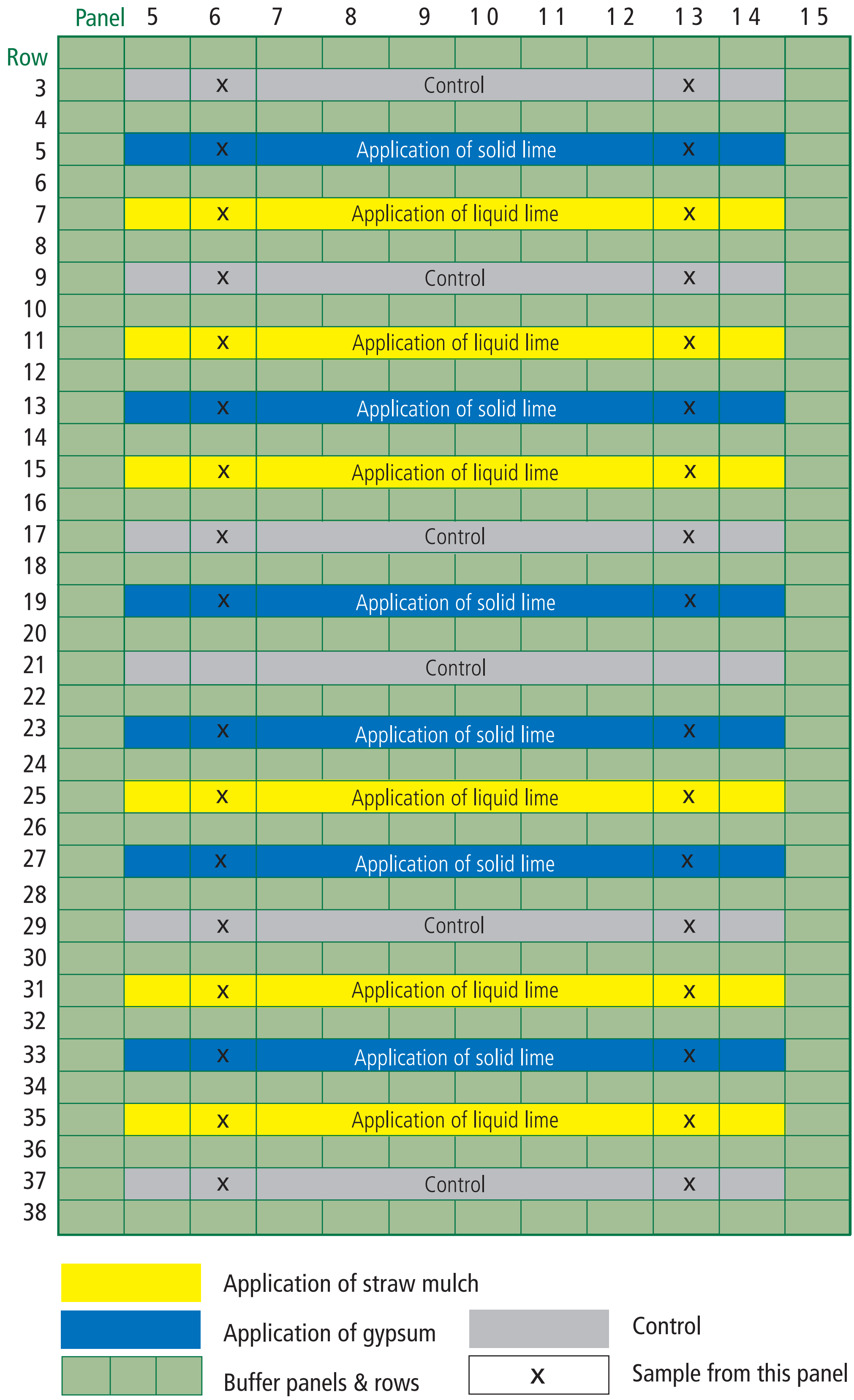
The middle panel is used for taking measurements (for example, Row 5 Panel 5). Buffering is important to identify clear treatment areas and to avoid contamination between treatment areas. Buffer zones are marked as panels with grid-lines in the following designs.

Design 1: An example of a randomised block design that could be used to assess soil improvement practices (for example, gypsum, straw mulch and a combination of these).



Design 1 gives an example of a trial layout in which the treatments are three different methods to improve the soil plus a control (no application). The trial has four treatments and six replications, arranged in a randomised block design, with the blocks being rows (or, more strictly, groups of three adjacent rows).

Design 2: An example of a trial design to test soil improvement practices (for example, straw mulch versus gypsum) using rows as experimental units.



Design 2 gives an example of a trial layout in which the treatments are two different applications to improve the soil plus a control. It uses rows as experimental units as opposed to panels. This can make management of the trial (i.e. gypsum or other applications) a little easier.

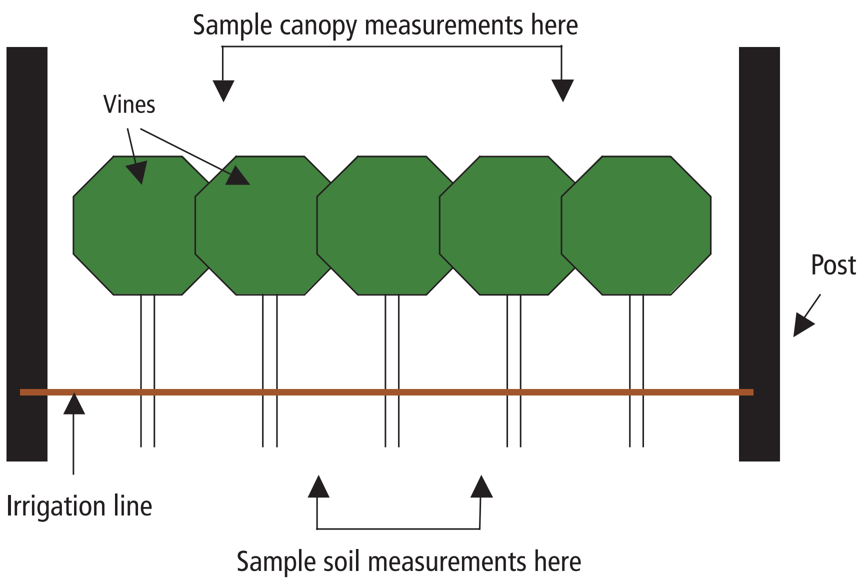
When using rows as experimental units, it is normally anticipated that a maximum of three treatments are trialed due to the potential workload expected. This trial has three treatments and six replications, again arranged in a randomised block design, with the blocks being groups of three adjacent experimental units.

It is recommended to only sample the middle vine in panels marked with an X (Designs 1 and 2) when taking vine measurements. If there are more than three vines per panel, only sample from the middle vines of the panels mentioned above (see Figure 1).

When taking soil measurements always sample from between two vines in the middle of each middle panel.

These recommendations will ensure that there is no contamination between plots; in some situations they may be waived provided that contamination is not a possibility. The approach described here also guarantees objectivity in the sampling, which will prevent the experimenter's bias from jeopardizing the results.

Figure 1: A diagrammatic explanation of where, within a panel, measurements can be taken.



Resources

Some useful resources for liming trials include:

- Cass A. (1998) Measuring and managing chemical impediments to growth. The Australian Grapegrower and Winemaker 415: 13 - 16
- McNabb S. (1990) Soil acidity and nitrogen fertilisers. The Australian Grapegrower and Winemaker 361: 28 - 29
- Robinson J.B. (1989) Soil acidity in vineyards. The Australian Grapegrower and Winemaker 304: 91 - 92
- Wheaton A. and Everett M. (2003) Managing hard-setting and crusting of under-vine soil surface In: Laukart, N. and Joyce, D.C. (edts) 'Participatory On-Farm Trials for Viticulture Manual.' (Cooperative Research Centre for Viticulture, Adelaide, S.A.).

Some useful resources for soil improvement trials include:

- Buckerfield J. and Webster K. (2001) Managing earthworms in vineyards - improve incorporation of lime and gypsum. The Australian Grapegrower and Winemaker Annual Technical Issue 449a: 55 - 61
- Schefe C. and Slattery W. (2003) Ameliorating acidity of viticultural soils In: Laukart N. and Joyce D.C. (edts) 'Participatory On-Farm Trials for Viticulture Manual.' (Cooperative Research Centre for Viticulture, Adelaide, S.A.).
- Wheaton A.D. (2002) Creating the best environment for root growth and water infiltration. The Australian and New Zealand Grapegrower and Winemaker 461: 21-23
- Wheaton A.D., McKenzie B.M. and Tisdall J.M. (2002) Management of a sodic soil for winegrape production. The Australian Journal of Experimental Agriculture 42: 333-339.
- Wilkinson K. (2003) Managing soil moisture using mulches In: Laukart N. and Joyce D.C. (edts) 'Participatory On-Farm Trials for Viticulture Manual.' (Cooperative Research Centre for Viticulture, Adelaide, S.A.)
- Wilkinson K., Sicard S. and Hackett S. (2003) Managing competition with cover crops In: Laukart N. and Joyce D.C. (edts) 'Participatory On-Farm Trials for Viticulture Manual.' (Cooperative Research Centre for Viticulture, Adelaide, S.A.)