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Soil pH changes in drip irrigated vineyards



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Soil pH changes in drip irrigated vineyards

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1 ABSTRACT

Grapevines, like most plants, are affected by soil pH. In acidic soils, root growth is restricted resulting in a reduced ability of the vine to explore the soil volume for water and nutrients whilst in alkaline soils vines can suffer from zinc, iron, manganese and copper deficiencies. Building on previous work conducted for Land and Water Australia, this project aimed to investigate the occurrence of extreme soil pH in Australian viticultural soils and to develop and refine a calculator of soil pH change and deliver it to growers. Key outputs from the project included assessment of soil pH change in 6 major Australian viticultural regions (Hunter Valley – New South Wales, Central Ranges/Southern Highlands – New South Wales, Murrumbidgee Irrigation Area (MIA) – New South Wales, Eastern Victoria, Western Victoria and Margaret River - Western Australia); further development of a "Calculator of soil pH change" following analysis of ash alkalinity of wine grapes and assessment of the effect of water quality on soil pH; and presentation of the refined Calculator to grower groups in each viticultural region.

2 EXECUTIVE SUMMARY

Grapevines, like most plants, are affected by soil pH. In acidic soils, root growth is restricted resulting in a reduced ability of the vine to explore the soil volume for water and nutrients whilst in alkaline soils vines can suffer from zinc, iron, manganese and copper deficiencies.

Previous work has shown that long term use of ammonium or urea based nitrogen fertiliser results in acidification whilst in some other districts, soil pH has tended toward alkalisation, presumedly due to the composition of irrigation water.

The Australians and Natural Resource Management 2002 report published by the National Land and Water Resources Audit (NLWRA) estimated annual losses caused by soil acidification in viticultural regions in Australia in 2000 to be as high as $118M. These losses were considered to be too high by the industry and would, in many cases, be the difference between making a profit and a loss. In response to these claims, Scholefield Robinson Horticultural Services (Scholefield Robinson) completed a project for Land and Water Australia (LWA) in 2003-2004 entitled "Vineyard Acidification Audit" in which the pH and buffering capacity of Australian viticultural soils was assessed and a Calculator of Soil pH Change developed to allow assessment of the risk of soil pH change in drip irrigated vineyards.

However, this LWA funded project highlighted the need for more work to refine the Calculator of Soil pH Change and to assess soil pH in other viticultural regions of Australia considering that only vineyards in South Australia were investigated. This GWRDC-funded project aimed to address these requirements by investigating the occurrence of extreme soil pH in Australian viticultural soils and by further development and refinement of the Calculator of Soil pH Change, which was then presented to growers.

Assessment of soil pH change in drip irrigated vineyards

Soil samples were collected from vineyards in New South Wales (Hunter Valley, Central Ranges/Southern Highlands, Murrumbidgee Irrigation Area), Victoria (Eastern Victoria, Western Victoria) and Western Australia (Margaret River) by regional viticulturists or growers according to a simple sampling protocol. This involved collecting composite topsoil and subsoil samples from under drippers, the mid row and an external reference point. The samples were analysed for several parameters including soil pH, organic carbon and exchangeable cations. Key issues highlighted by the soil analysis data include:

- In many regions, the pH values of the vine row and mid row topsoil and subsoil samples are higher than the external reference site. This suggests that most growers in acid soil areas are well aware of the risk of soil acidity and have applied lime at some stage.
- In Western Victoria, the pH of the topsoil sample from the vine row in 3 of the sites was lower than the topsoil sample from the mid row. This suggests that acidification of the vine row soil has occurred even if lime had been applied previously.
- There was no consistent effect of water alkalinity on soil pH change.
- Topsoil samples from several sites in Western and Eastern Victoria are considered sodic. Taking soil pH, cation exchange capacity and salinity into consideration, there is probably some risk of dispersion in these soils.
- In many vineyards, topsoil samples from the vine row had lower concentrations of exchangeable potassium compared to the mid row or external reference point. This reflects the significant amount of potassium removed in grapes each harvest.

Further development of Calculator of Soil pH Change

Further development of the Calculator of Soil pH Change required analysis of ash alkalinity of wine grapes and assessment of the effect of water quality (particularly alkalinity) on soil pH.

To determine the ash alkalinity of wine grapes, sixteen samples of wine grapes (11 red and 5 white, six varieties) collected at harvest from several South Australian vineyards were freeze dried and analysed for basic cations and chlorine, sulfur and phosphorus using X-ray fluorescence spectroscopy (CSIRO Land and Water, Adelaide). From the difference in molar concentrations of the cation and anion analyses, ash alkalinity was calculated. In general, ash alkalinities were higher in red compared to white wine grape varieties, whilst all red and white wine grape varieties had higher ash alkalinities than published data for table grapes. Previously, only values for table grapes were available.

Water analysis data for various water sources (i.e. surface water (rivers, dams, etc.) and groundwater (bore)) were sourced for each major viticultural region from Government operated websites. There was considerable variation between samples especially those from ground water sources and also within years at an individual sampling site. This highlights the need for growers (especially those relying on ground water) to have a sample of their own irrigation water analysed which will enable them to make appropriate management decisions.

The chemistry surrounding water alkalinity is very complex and much depends on the form of alkalinity present. When water alkalinity was considered significant and therefore included in the Calculator of Soil pH Change it had an overbearing effect on all other factors but the actual soil pH measurements did not reflect this. In fact, the Calculator usually predicted soil pH change in surface soil layers more accurately when water alkalinity was not taken into consideration. Clearly, more work is needed to understand the role of water quality on soil pH change.

Presentation of the calculator of soil pH change to growers, researchers, etc

The refined Calculator of Soil pH Change was presented to grower groups in each viticultural region. It was well received by growers and viticulturists and many expressed interest in accessing and using the Calculator and as such, one of the principal aims of the project was achieved.

Outcome/Conclusions

The Calculator of Soil pH Change is a valuable tool available to grape growers and viticulturists across Australia. Although not absolutely accurate, it can be used to provide a reasonable estimate of the rate of soil pH change as a result of a set of particular vineyard management practices. In fact, it may be viewed as a ‘learning tool’ as it enables growers/viticulturists to alter management strategies to limit soil pH change. It should be remembered that the Calculator was designed to be used in conjunction with but not instead of regular soil testing which remains the most reliable method of assessing soil pH.

Despite considerable effort, it was not possible to achieve prediction of the effect of water alkalinity on soil pH. Clearly, the effect of water quality (alkalinity) on soil pH in drip irrigated vineyards requires further attention.

Apart from being used to validate the Calculator of Soil pH Change, soil tests conducted on soil samples collected from vineyards in several main viticultural regions of Australia highlighted that soils in several Victorian vineyards had begun to acidify again following past application of lime and in some vineyards, sodicity is a potential problem that requires attention. Previous experience showing a decline in soil potassium reserves in vine row soils in older vineyards was supported by the results.

3 BACKGROUND

Grapes are known to be moderately sensitive to soil acidity. In acidic soils, root growth is restricted, and the major effect on the vine may be related to its inability to explore the soil volume for water (Kirchof *et al.* 1990; Robinson, 1993). Grapevines are also known to be affected by high pH as they are susceptible to zinc, iron, manganese and copper deficiency. In calcareous alkaline soils, iron deficiency is often difficult to treat.

Previous work has shown acidification occurs under mature vineyards after long use of high rates of nitrogen fertiliser (Seeliger & French 1971) whilst in some other districts, soil pH has tended toward alkalisation, presumedly due to the composition of irrigation water (Robinson, 1993). Clark *et al.* (2002) have also shown alkalisation occurs following use of saline irrigation water with a high Sodium Adsorption Ratio.

The Australians and Natural Resource Management 2002 report published by the National Land and Water Resources Audit (NLWRA) estimated annual losses caused by soil acidification in viticultural regions in Australia in 2000 to be as high as $118M.

Using an average price of $1500 per tonne for that 2000 vintage, these predicted losses equate to approximately 80,000 tonnes of grapes. Assuming that these losses occur in the 20,000 hectares of vineyards in areas with acid soils or soils prone to acidification as a result of vineyard management (as suggested in the Australians and Natural Resource Management 2002 report) then the predicted losses would equate to 4 tonnes per hectare, which was considered by the industry to be too high and would, in many cases, be the difference between making a profit and a loss. Obviously, with the downward pressure on grape prices in recent seasons, the potential negative effects from soil acidification on viticultural production become more serious.

In response to these claims, Scholefield Robinson Horticultural Services (Scholefield Robinson) completed a project for Land and Water Australia (LWA) in 2003-2004 entitled "Vineyard Acidification Audit" which was designed to further explore the potential formation of extreme pH conditions in drip irrigated vineyards.

This project assessed the pH and buffering capacity of Australian viticultural soils and developed the Calculator of Soil pH Change to allow the risk of soil pH change to be assessed and assist in soil management.

The principal outcomes of this LWA project were:

- An assessment of soil pH status and pH buffering capacity (pHBC) of Australian viticultural surface soils, through interrogation of data from the NLWRA Australian Soil Test Inventory.
- Development of the Calculator of Soil pH Change to predict the potential for accelerated acidification or alkalisation to occur in viticultural soils managed under different vineyard systems.
- Evaluation of the Calculator of Soil pH Change using strategic sampling of soils in four representative vineyards in three South Australian viticultural regions.

However, the project highlighted the need for more work to address the following:

- To refine the Calculator of Soil pH Change, more data was required on:
  - ash alkalinity of various varieties of wine grapes;
  - information of wetting patterns under drippers in various soils;

  - total alkalinity data for bore waters and surface waters in various grape growing regions of Australia, to allow further "generic" use of the model.
  - information on the loss of alkalinity or acidity via leaching.
- Further validation of the Calculator of Soil pH Change in other viticultural regions of Australia. In this LWA study, only vineyards in South Australia were investigated.

This GWRDC project aimed to build on this work to further investigate the occurrence of extreme soil pH in Australian viticultural soils and to further develop and refine the Calculator of Soil pH Change and deliver it to growers.

4 PROJECT AIMS AND PERFORMANCE TARGETS

4.1 Project Aims

The main objective of the project when it commenced in 2006 were to build on the work conducted in the Land and Water project conducted in 2003-2004. It was proposed that this would involve:

- Further development and validation of the Calculator of Soil pH Change.
- Further assessment of soil pH change in drip irrigated vineyards in the major viticultural regions of Australia.
- Presenting the results of this assessment and the refined and validated Calculator of Soil pH Change to grower groups etc. in the major viticultural regions of Australia.

The project end date was extended from January 2007 to June 2007 in order to:

- Allow for delays due to issues surrounding the sudden lack of availability of GWRDC "Research to Practice – Hand on" groups and the resulting need to identify possible growers and viticulturists who would be able to collect soil samples and provide vineyard information.
- Enable the results of the project to be presented at grower meetings in the major viticultural areas as planned.

It was initially planned to disseminate information from the project in industry publications during the project. This will now be conducted following acceptance of this report by GWRDC and several industry publications have requested articles.

5 METHODS

5.1 Assessment of soil pH change in drip irrigated vineyards in major viticultural regions of Australia

5.1.1 Site selection

In order to validate the refined Calculator of Soil pH Change and to assess actual soil pH change in some of the major viticultural areas of Australia, soil samples were collected from vineyards in each of the following regions:

- Hunter Valley, New South Wales – 3 vineyards.
- Central Ranges/Southern Highlands, New South Wales – 4 vineyards.
- Murrumbidgee Irrigation Area (MIA), New South Wales – 3 vineyards.
- Eastern Victoria – 3 vineyards.
- Western Victoria – 4 vineyards.
- Margaret River, Western Australia – 3 vineyards.

5.1.2 Soil sampling

Soil samples were collected by regional viticulturists or growers according to a simple sampling protocol (Appendix 6.1). This involved collecting composite topsoil and subsoil samples from under drippers and mid row as well as an external reference point.

In summary, samples were collected from:

- 6 regions
- 3-4 vineyards per region.
- 1 site at each vineyard.
- 3 sampling positions per site (under dripper, mid row and an external reference point).
- 2 sampling depths (topsoil and subsoil).

Hence about 120 individual composite soil samples were collected.

Each sample was analysed by CSBP Laboratories for the following:

- EC,
- pH_{Ca},
- organic C (Heanes method),
- exchangeable cations (Ca, Mg, Na and K),
- extractable aluminium and carbonate
- pH buffer capacity derived from organic C and CEC or clay content using a pedotransfer function.

Participating grape growers and viticulturists were also asked to complete a questionnaire regarding vineyard details and management practices. A copy of this questionnaire is shown in Appendix 6.2.

5.2 Further development of the Calculator of Soil pH Change

5.2.1 Ash alkalinity of various wine grape varieties

Ash alkalinity (see Slattery *et al*., 1991) enables the estimation of removal of alkalinity with each grape harvest and the resultant effect of acidifying soil. In the initial development of the

Calculator of Soil pH Change, a single published value of ash alkalinity for table grapes grown in Queensland (Moody and Aitken 1997) was used due to a lack of data on the alkalinity of wine grapes.

To further develop the Calculator of Soil pH Change, sixteen samples of wine grapes (11 red and 5 white, six varieties; Table 1) were collected at harvest from South Australian vineyards, freeze dried and analysed for basic cations and chlorine, sulfur and phosphorus using X-ray fluorescence spectroscopy (CSIRO Land and Water, Adelaide). From the difference in molar concentrations of the cation and anion analyses, ash alkalinity was calculated. It is recognised that this method may result in errors as nitrate and other trace element cations are not accounted for, but these errors are considered to be very small and hence insignificant for grapes.

5.2.2 Assessment of water alkalinity effects on soil pH change

It was originally planned that water samples from each vineyard from which soil samples were collected would be collected and analysed. However, due to the recent drought gripping much of South Eastern Australia, it was decided that using more reliable long-term water analysis data in the Calculator of Soil pH Change would be of more value. As such, water analysis data for various water sources (i.e. surface water (rivers, dams, etc.) and groundwater (bore)) were sourced for each major viticultural region from the following Government operated websites:

- Victoria – Victoria Water Resources Data Warehouse (www.vicwaterdata.net)
- New South Wales – NSW Water Information (www.waterinfo.nsw.gov.au)
- Western Australia – WA Water Resources Data (portal.water.wa.gov.au)

Apart from the effect of water alkalinity on soil pH in drip irrigated vineyards, the availability of detailed water chemistry for irrigation water through these public sources enabled consideration of the potential usefulness of sodium adsorption ratio (SAR) to flag the need for gypsum to counter the effect of sodium applied with irrigation water. A simple re-arrangement of the SAR equation enables the estimation of a calcium (gypsum) requirement that offsets the sodium added in irrigation water. This has been added to the Calculator of Soil pH Change.

5.2.3 Assessment of potential leaching losses utilising existing data

Leaching is a potential cause of losses of alkalinity from the soil and hence a source of acidification and so it was initially planned to include a leaching component in the Calculator of Soil pH Change. However, it was found during validation assessment that the calculator predicted soil pH changes more accurately when a leaching component was not included.

Clearly, more information is needed to determine the possible role of leaching in soil pH change in drip irrigated vineyards.

5.3 Presentation of soil pH calculator to growers, researchers, etc.

Following refinement and validation of the calculator of soil pH change, the calculator and soil analysis data was presented to grower groups in each viticultural region. The information from this project will also be promulgated in the scientific literature, in industry and grower publications and in the media in relevant grape growing regions following receipt of this final report.

6 RESULTS AND DISCUSSION

6.1 Assessment of soil pH change in drip irrigated vineyards in major viticultural regions of Australia

6.1.1 Soil analysis data

Complete soil analysis data for Eastern Victoria, Western Victoria, Hunter Valley (New South Wales), Central Ranges/Southern Highlands (New South Wales), Murrumbidgee Irrigation Area (New South Wales) and Margaret River (Western Australia) are presented in Appendix 6.3.

6.1.1.1 Soil pH

pH (calcium chloride) values for topsoil and subsoil samples from various positions within vineyards across Australia are shown in Figure 1 and Figure 2.

Figure 1 – pH (calcium chloride) of topsoil samples from various positions in vineyards across Australia

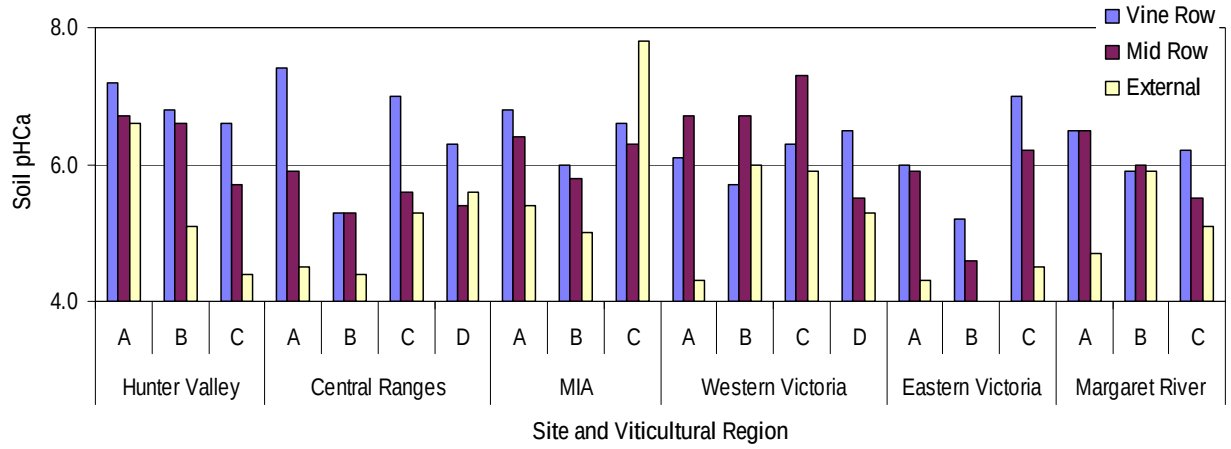
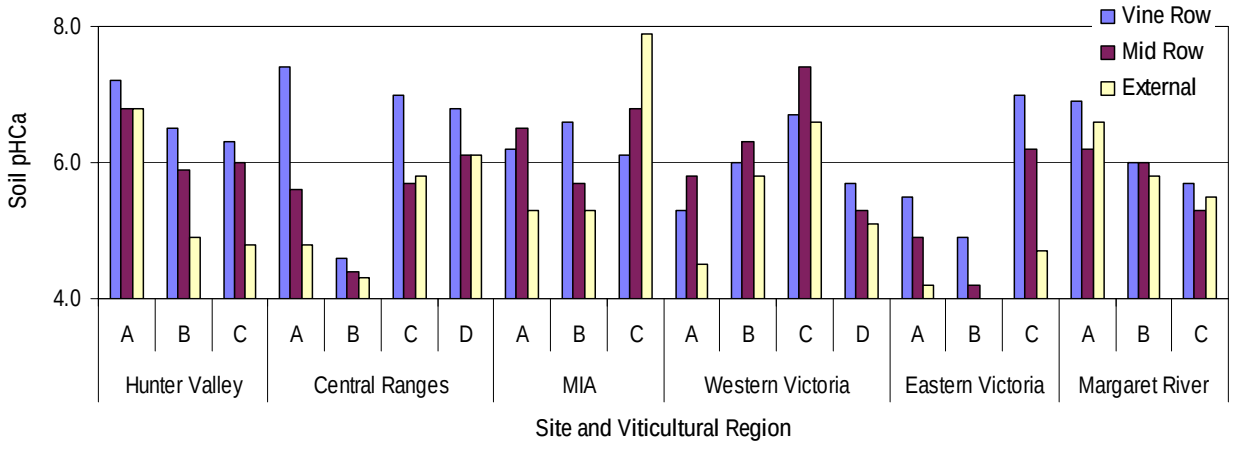


Figure 2 - pH (calcium chloride) of subsoil samples from various positions in vineyards across Australia



The key issues highlighted by this data are:

- In many regions, the pH values of the vine row and mid row topsoil and subsoil samples are higher than the external reference site. This suggests that, in many vineyards, lime has been applied to increase the pH of the soil or that the irrigation water used is alkaline and has had an alkalising effect on the soil.

- In Western Victoria, the pH of the topsoil sample from the vine row in 3 of the sites is lower than the topsoil sample from the mid row. This suggests that acidification of the vine row soil has occurred.

Clearly, most growers in acid soil areas are well aware of the risk of soil acidity and have applied lime accordingly as shown by the higher pH values of the vine row compared with mid row or external soils. The higher subsoil pH values for the vine row soils in many blocks also indicate that some movement of lime into the subsoil layers has occurred or that lime has been applied at depth.

In 3 of the Western Victoria sites, the lower pH values for the topsoil samples from the vine row compared to the mid row suggests that some acidification has occurred in these blocks even though lime may have been applied in the past. In the case of Western Victoria B, the pH of the topsoil was expected to be much higher than that obtained as this block is irrigated with reclaimed wastewater that has a high alkalinity value which should have offset any acidifying effect from nitrogen fertilisers or grape removal. The lack of an alkalising effect from the irrigation water in this block may be related to the form of alkalinity present in the water which is not known. The potential effects of water alkalinity on soil pH are dealt with in more detail in Section 6.3.2.2.

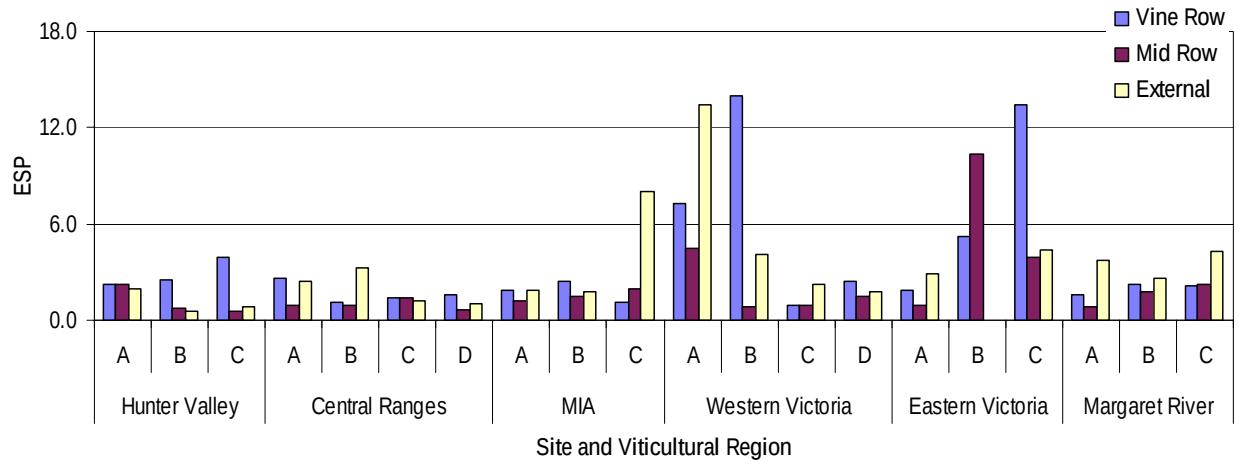
The lower pH values for the topsoil samples from the vine row compared to the mid row in 3 of the Western Victoria sites highlights the need for growers and viticulturists to remain vigilant to the risk of soil acidification and to consider applying lime if needed.

In the case of the MIA, acidification of the topsoil in the vine row was expected to have occurred considering the high yields obtained, the use of acidifying nitrogen fertilisers like urea and the lack of neutralising alkalinity in the irrigation water. However, very little acidification of the topsoil has occurred at any of the sites sampled. Records supplied by growers for these vineyards indicate that lime has been applied at each of these sites in recent seasons which may explain the lack of acidification seen. Application of lime in the MIA would not normally be expected and it would be interesting to investigate whether lime was applied in response to low soil pH or for some other reason. Acidification of deeper subsoil layers was not investigated.

6.1.1.2 Sodicity

In the majority of vineyards, the topsoil and subsoil samples from the various positions are considered non sodic (ESP<6) (Figure 3).

Figure 3 – Exchangeable sodium percentage (ESP) of topsoil samples from various positions in vineyards across Australia



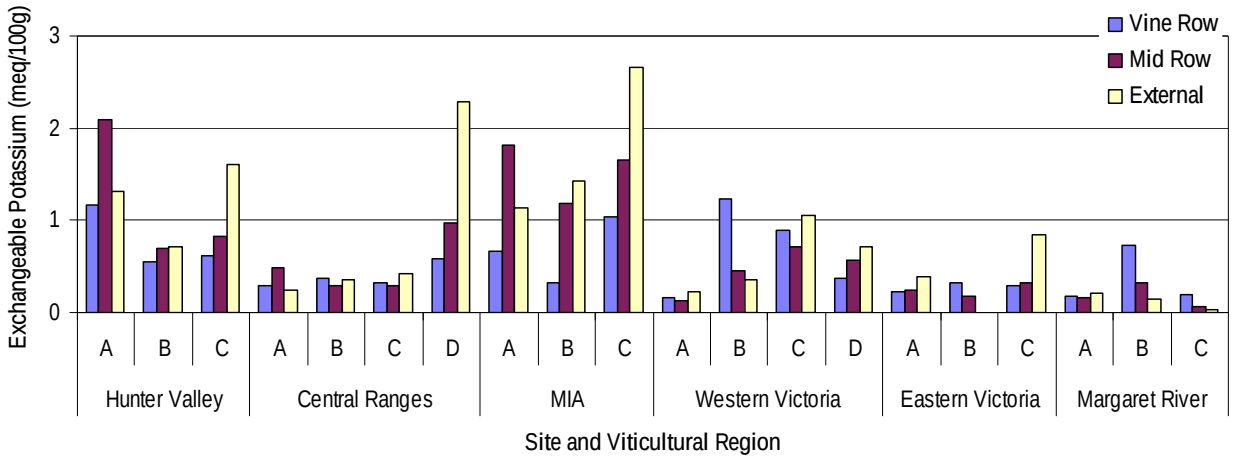
The exceptions are Sites A and B from Western Victoria and Sites B and C from Eastern Victoria. The topsoil samples from the vine row in these sites are considered sodic (ESP>6). The topsoil samples from the vine row and mid row in Eastern Victoria B also have ESP values near 6. Whether these soils are structurally unstable and will disperse when wet depends on the pH (acid soils are less likely to be dispersive than alkaline soils), cation exchange capacity (soils with higher cation exchange capacities are more likely to be dispersive) and salinity (saline soils are less likely to disperse as the salt provides "protection" against dispersion) of the soils. Taking these factors into consideration, there is probably a greater risk of dispersion in Western Victoria B and Eastern Victoria C than the other sites that are considered sodic.

In recent years, the use of exchangeable sodium percentage as an indicator of soil sodicity has been questioned. Considering the difficulty in assessing the risk of dispersion using ESP, the use of physical soil dispersion tests should be promoted. Unfortunately, it was not possible to conduct physical dispersion tests on the soil samples collected in this project. Even so, it is important that vineyard managers understand that the use of sodic irrigation water (i.e. water with a high SAR value) may result in the need for regular gypsum applications to counter dispersion following winter rainfall and to displace adsorbed sodium (e.g. see Clark *et al*., 2002).

6.1.1.3 Potassium

In the majority of vineyards, the concentration of exchangeable potassium in the topsoil samples from the vine row is lower than the soil samples from the mid row or external reference point (Figure 4). This was also observed previously in SA vineyards.

Figure 4 – Exchangeable potassium (meq/100g) in topsoil samples from various positions in vineyards across Australia



The lower concentrations of exchangeable potassium in the topsoil samples from the vine row compared to the mid row or external reference point in many of the blocks was expected. Grapes contain significant amounts of potassium and so considerable amounts of potassium can be removed at vintage depending on yields obtained. This would explain why higher yielding vineyards such as those in the MIA showed bigger reductions in exchangeable potassium in the vine row soil compared to lower yielding vineyards such as those in the Central Ranges.

These results highlight the need for growers to be aware that considerable amounts of potassium can be removed in the form of grapes. It does not necessarily mean that growers need to apply potassium fertilisers as many Australian soils contain considerable amounts of potassium and it has been well documented that high potassium levels in grapes can result in poor wine quality especially for red wine grape varieties. Growers should therefore use soil and plant tests along with knowledge of the amount of potassium removed in the form of grapes when deciding on the need for potassium fertilisers.

6.2 Further development of Calculator of Soil pH Change

Hard and electronic versions of the upgraded Calculator of Soil pH Change are shown in Appendix 5.

6.2.1 Ash alkalinity of various wine grape varieties

Ash alkalinity values for several grape varieties are presented in Table 1. To enable growers to utilise the Calculator of Soil pH Change for other varieties, values for general red and white wine grape varieties were included.

Table 1 – Ash alkalinity of selected grape varieties

Variety	Grape Ash Alkalinity (kg $CaCO_3$/kg)	Dry wt factor
Table grapes[a]	0.010	0.13
Shiraz	0.014	0.30
Cabernet Sauvignon	0.014	0.30
Merlot (single sample)	0.010	0.30
Riesling	0.011	0.25
Semillon	0.012	0.25
General wine grape varieties		
Red	*0.014*	*0.30*
White	*0.011*	*0.25*

[a] – sourced from Moody and Aitken, 1997

Although they do not appear large, the differences between the varieties are considerable. For example, consider a block with a yield of 15 tonnes per hectare. If this block contains Shiraz, the amount of alkalinity removed in the grapes is 210kg $CaCO_3$ per hectare. However, if the block contains Riesling, the amount of alkalinity removed in the grapes is 165kg $CaCO_3$ per hectare.

The inclusion of ash alkalinity values for various wine grape varieties in the Calculator of Soil pH Change enables a more accurate assessment of the loss of alkalinity (i.e., gain in soil acidity) from the vineyard soil, especially where high yields are obtained. In general, ash alkalinities are higher in wine grapes than table grapes, as are berry dry weights.

6.2.2 Assessment of water alkalinity effects on soil pH change

A selection of water analysis data for each viticultural region sourced from the various websites (Section 5.1.2) is shown in Table 2. One of the most interesting aspects of this water quality data is the variation between samples including those from the same source (e.g. Murrumbidgee River). The level of variation for ground water sources was considerable as shown by the minimum and maximum values. This highlights the need for growers (especially those relying on ground water) to have a sample of their own irrigation water analysed which will enable them to make appropriate management decisions.

Table 2 – Water analysis data for various sites in each viticultural region

Values in bold are averages for years shown. Values in parentheses are minimum and maximum values for the same period.

Viticultural Region	Location	Sample type	Years data collected	Alkalinity (mg/L)	Cations (mg/L)		
					Calcium	Magnesium	Sodium
Victoria*							
Western Victoria	Goulburn River @ Murchison	Surface	1977 - 1990	24.8 (12.0 - 37.0)	4.0 (1.7 - 6.1)	5.0 (3.1 - 6.4)	17.3 (9.9 - 30.0)
	Gt Western (reclaimed waste water)[a]	Reclaimed waste water	2003 - 2004	298.0	13.9	24.0	304.0
Eastern Victoria	Milawa[b]	Ground	2007	220.0	5.9	5.1	95.0
	Little Yarra River @ Yarra Junction	Surface	1977 - 1990	10.6 (6.8 - 15.0)	1.9 (1.4 - 5.1)	1.4 (1.1 - 1.8)	9.3 (7.9 - 11.0)
New South Wales**							
Hunter Valley	Wollombi Brook @ Bulga	Surface	1978 - 1999	87.6 (41.0 - 160.0)	12.4 (5.9 - 23.1)	16.0 (7.3 - 29.8)	82.6 (35.3 - 166.0)
	Hunter River @ Denman	Surface	1978 - 2005	181.9 (80.0 - 269.0)	34.0 (27.2 - 39.0)	23.6 (19.3 - 27.0)	41.8 (28.0 - 58.0)
	Muggyrang Creek @ Pokolbin	Surface	1977 - 1990	449.1 (188.8 - 610.2)	62.8 (29.6 - 81.1)	52.9 (20.5 - 87.1)	150.5 (57.3 - 226.1)
Murrumbidgee Irrigation Area	Murrumbidgee River @ Gundagai	Surface	1976 - 2001	39.4 (17.0 - 68.0)	6.5 (2.9 - 12.1)	3.8 (1.2 - 7.1)	6.6 (2.5 - 13.0)
	Murrumbidgee River @ Darlington Point	Surface	1982 - 2000	47.5 (32.0 - 79.0)	10.9 (5.2 - 33.0)	4.8 (2.3 - 11.8)	8.8 (6.0 - 15.0)
	Lachlan River @ HillstonWeir	Surface	1976 - 2002	142.9 (87.3 - 202.0)	28.2 (16.3 - 38.1)	21.0 (11.9 - 31.5)	42.3 (23.0 - 55.6)
Central Ranges/Southern Highlands	Maules Creek @ Avoca East	Surface	1982	135.0 (129.0 - 146.0)	28.4 (25.5 - 33.4)	10.7 (9.3 - 13.2)	25.3 (23.8 - 28.1)
	Blackmans Swamp Creek @ Near Orange	Surface	1976-1977	184.6 (167.8 - 201.4)	22.2 (19.4 - 25.1)	12.9 (9.7 - 16.0)	54.7
Western Australia***							
Margaret River	Cowaramup Borehole Line	Ground	1987 - 1988	113.1 (6.6 - 241.0)	5.1 (2.0 - 11.0)	5.2 (3.0 - 7.0)	102.0 (38.0 - 205.0)
	Busselton Coast Basin	Ground	1977 - 1988	22.1 (1.0 - 242.0)	6.3 (2.0 - 17.0)	9.7 (3.0 - 40.0)	74.3 (20.0 - 377.0)
	Cowaramup	Ground	2006	62.7 (28.0 - 230.0)	8.8 (4.0 - 14.0)	8.7 (6.0 - 18.0)	67.8 (40.0 - 160.0)
	Chapman Brook @ Road Bridge	Surface	1983 - 1985	15.3 (13.9 - 18.0)	5.6 (5.0 - 6.0)	9.6 (8.0 - 11.0)	60.6 (53.0 - 70.0)
	Upper Chapman Brook @ Warner Glen Road	Surface	1983 - 1985	6.1 (5.7 - 6.6)	3.8 (2.0 - 5.0)	8.2 (7.0 - 10.0)	60.0 (55.0 - 70.0)
	Margaret River @ Blunsdon Road	Surface	1988 - 1997	4.6 (2.9 - 7.4)	1.2 (1.0 - 1.5)	5.0 (4.2 - 5.6)	42.8 (34.4 - 50.0)
	Wilyabrup Brook @ Woodlands	Surface	1982 - 1983	28.5 (18.9 - 47.6)	14.7 (7.0 - 26.0)	30.6 (8.0 - 64.0)	225.6 (55.0 - 451.0)

* - Data sourced from http://www.vicwaterdata.net except [a] sourced from grower and [b] sourced from North East Water.
** - Data sourced from http://www.waterinfo.nsw.gov.au
*** - Data sourced from http://portal.water.wa.gov.au

Clues to the possible involvement of irrigation water alkalinity in soil pH changes were obtained in the initial development of the Calculator of Soil pH Change. It was found that the Calculator correctly predicted acidification of some acidifying Riverland vineyards, including the time taken to reach the then current soil pH, but only when Murray River water alkalinity was

ignored. Conversely, Padthaway soil pH values increased with irrigation, probably due to precipitation of calcium carbonate ($CaCO_3$) from the irrigation water.

Much thought was placed on trying to account for the effects of irrigation water alkalinity and leaching on soil pH in drip irrigated vineyards. Irrigation water alkalinity is due mainly to the presence of bicarbonate ions, but expression of an effect of water alkalinity on soil pH is likely to depend on the concentrations of sodium and calcium in the water. Most of the acidification reactions occur within the upper, dripper-wetted volume of soil during summer and it seems that when irrigation water has a high sodium bicarbonate content, the bicarbonate ions may be leached from the surface 30 cm of soil by winter rains or excess irrigation water resulting in no net change to soil pH. It is probable that irrigation waters with a positive Langelier[1] (or saturation) index will precipitate calcium carbonate in the surface soil layers and contribute alkalinity that should be taken into account – this is the mechanism that is thought to be occurring in the Padthaway area.

Initially, a water alkalinity module was included in the Calculator of Soil pH Change in an attempt to take this important potential source of alkalinity into consideration. However, the level of complexity that would be added to the calculator to account in detail for both water chemistry and a leaching fraction went against one of the principal aims of the project which was to provide growers with an easy to use and understand Calculator of Soil pH Change. Considering this and the large amount of variation in water alkalinity readings available (Table 2), it was decided that water alkalinity would not be included in the Calculator of Soil pH Change. This action is supported by findings during attempts to validate the predictions made using the Calculator of Soil pH Change (Section 6.2.3) which showed that *validation of the calculator gave much better results when alkalinity of the irrigation water was ignored*. This was also observed in a limited way in our previous project.

Further consideration of this complex water and soil chemistry is required and it may be possible to account for these factors in a simple way in a future version of the Calculator of Soil pH Change.

6.2.3 Validation of the Calculator of Soil pH Change

This project has allowed a wider range of vineyard soils to be used in validating the calculator. The results are shown in Table 3. To attempt to validate the Calculator, the mathematics were modified slightly so that the 'critical' pH became the current pH measured in the vine row. It is then possible to calculate a time period during which the vineyard, using recent management practices, has attained the vine row pH using the mid row pH as a starting value. As mentioned above, the alkalinity of the irrigation water was ignored. For most of the other vineyards, key data or history was not available which would have allowed validation. Where the Calculator has predicted no change or very long time periods, the vineyard acidification is balanced by alkalinising processes. One soil has an extremely high pH buffering capacity which manifests as 'no change' in soil pH. Several vineyards were very young, but it was felt that the calculator did a reasonable job of calculating the time to the observed pH change. Among the reasons for 'Insufficient data' were:

- Missing information on irrigation water volumes used. This is needed to calculate the average volume of soil I which pH change could be expected.
- An increase was observed in pH but no information given on the amount of lime used. It is often applied at vineyard establishment.

[1] The Langelier or saturation index (Evangelou 1998) is used to predict precipitation of $CaCO_3$ from alkaline water.

- When establishing new vineyards, soil may be hilled along the vine row. This makes the use of vine row and mid row soil data inappropriate.
- Two vineyards were fertilised with animal manures. Since no information was available on their acid neutralising capacity, it is not possible to model their effect.
- Some fertilisers used were special 'formulations' and their composition were not known.
- Average values from the literature were used for nitrogen transformations which cause changes in soil acidity. It is probable that the average values may not be appropriate for some of the sites where ammoniacal or nitrate fertilisers are used.

It was not possible to obtain full fertiliser and management histories of all of the vineyards over the entire life of the vineyard. For this reason, along with those in the dot points above, the Calculator was not expected to perform perfectly, but it seems that the results obtained are encouraging. Reasonable validating predictions were obtained for seven of the vineyards. For eight of the vineyards, a validation was possible (compare the age of vineyard column with the calculator-estimated age in Table 3; the more comparable the estimated age to the actual age, the better the Calculator has performed) and the Calculator gave reasonable prediction of the observed progression of acidification or otherwise over the life of the vineyards.

Predicting years to critical soil acidity

As indicated in Table 3, the calculator was used to investigate the path of acidification or alkalinisation in those vineyards where sufficient management information was available. Prediction of time in years to critical pH_{ca} values of 5.5 or 4.8 are provided for 12 of the vineyards using current management practices. No matter what the outcome of the prediction, vineyard managers are advised to consider them as indicative and monitor their soil pH at appropriate intervals. The calculator does indicate which of the management factors are most likely to be affecting soil pH.

6.2.4 The Calculator of Soil pH Change as a vineyard management and "learning tool"

Whilst the Calculator of Soil pH Change is not absolutely accurate in predicting soil pH changes, it should prove to be a powerful and valuable learning and vineyard management tool. Growers can utilise the Calculator to assess the likely effects of changes in vineyard management practices on soil pH. Used in conjunction with regular soil tests, the Calculator should enable growers to effectively manage soils with various pH values, textures and pH buffering capacities.

6.2.5 Managing high SAR irrigation water

The previous version of the Calculator of Soil pH Change 'flagged' the potential problem of development of soil sodicity if the Sodium Absorption Ratio (SAR) of the irrigation water was greater than 3. High sodicity (ESP) in clayey soils results in increased potential for clay dispersion when low salinity water (eg, rainwater) is applied. The mobile clay particles can clog pores and lead to decreased permeability, perching of water and waterlogging, especially in clayey subsoils (Clark *et al*. 2002). High sodicity also usually results in high soil pH (> 8.4) with the increased presence of sodium bicarbonate and carbonate in the soil profile, though this may be flushed from the upper soil layers in irrigated situations. The upgraded version of the Calculator of Soil pH Change includes a module for water SAR, which may be utilised if the concentration of sodium, calcium and magnesium in the water is known. The module also includes a calculation for the amount of gypsum required (per ML of irrigation water) to offset the sodium applied in the irrigation water.

Like soil pH and lime requirements, the use of gypsum in vineyard management should be checked periodically with measurements of soil exchangeable sodium percentage (ESP).

Table 3 – Validation of Calculator of Soil pH Change and prediction of time to critical soil pH values

Region	Vineyard	Original pH_{Ca} [a]	Current pH_{Ca} [b]	Age (years)	Calculator estimated age [c] (years)	Estimated time to pH_{Ca} 5.5 [d] (years)	Estimated time to pH_{Ca} 4.8 [e] (years)	Water quality comment [f]	Other comments
Hunter Valley New South Wales	A	6.7	7.2	2				182 mgL^{-1}	Vineyard only 2 years old.
	B	6.6	6.8	9	Insufficient data			88 mgL^{-1}	Insufficient management data; possible effect of irrigation water on soil Na and Mg
	C	5.7	6.6	6	Insufficient data			450 mgL^{-1}	Water alkalinity ignored because of relatively small pH increase.
Central Ranges New South Wales	A	5.9	7.4	24	Insufficient data	40	54	Dam/bore	Probably limed, not recorded.
	B	5.3	5.3	7	Predicts no change	Already acid	Very long period	Rain/bore	Soil has a very high pH buffering capacity. Changes in pH very slow.
	C	5.6	7.0	9	Insufficient data				Unusual soil chemistry. Soil treatment in vine row uncertain.
	D	5.4	6.3	7	7	6	12	39 mgL^{-1}	
MIA New South Wales	A	6.4	6.8	9	Insufficient data			48 mgL^{-1}	Organic manures used, alkalinity not known.
	B	5.8	6.0	8	Insufficient data			48 mgL^{-1}	Organic manures used, alkalinity not known.
	C	6.3 (8.3)[g]	6.6	20	65 (29)[h]	108	135	48 mgL^{-1}	Stated irrigation rate very high.
Eastern Victoria	A	5.9 (7.4)[g]	6.0	9	10	2	4	11 mgL^{-1}	Exchangeable Ca increase reflects liming.
	B	4.6	5.2	6	Insufficient data	Already acid	3	11 mgL^{-1}	
	C	6.2	7.0	24	Insufficient data				

Region	Vineyard	Original pH_{Ca} [a]	Current pH_{Ca} [b]	Age (years)	Calculator estimated age [c] (years)	Estimated time to pH_{Ca} 5.5 [d] (years)	Estimated time to pH_{Ca} 4.8 [e] (years)	Water quality comment [f]	Other comments
Western Victoria	A	6.7	6.1	37	52	Predicts alkalisation	Predicts alkalisation	Dam	
	B	6.7	5.7	25	20	23	37	220 mgL^{-1}	Recycled wastewater. Water alkalinity ignored for predictions.
	C	7.3	6.3	5	10	19	26	25 mgL^{-1}	
	D	5.5	6.5	16	Insufficient data	57	97	Dam, low alkalinity	Probably limed, but not recorded.
Margaret River Western Australia	A	6.5	6.5	23	Insufficient data			Very low	Form of nitrogen fertiliser unknown.
	B	6.0	5.9	29	Insufficient data			Very low	Organic products used; application rates and alkalinity unknown.
	C	5.5	6.2	8	7	13	22	Very low	CAN applications assumed to have no effect on pH.

Notes:

a The pH in calcium chloride of the 0 – 15 cm of soil sampled from the mid row.
b The pH in calcium chloride of the 0 – 15 cm of soil sampled from the vine row.
c Age of vineyard predicted using Calculator of Soil pH Change. This number should be compared with the actual age in the previous column. The closeness of these numbers is an indication of the validity of the Calculator.
d Calculator used to predict years to reach pH_{Ca} value of 5.5.
e Calculator used to predict years to reach pH_{Ca} value of 4.8.
f Average alkalinity of irrigation water, if known.
g pH_{Ca} in parenthesis is calculated from known application rate of lime and was used as the original pH in the Calculator.
h For this vineyard, the stated irrigation delivery per dripper is unreasonably high. It was assumed the value given was a value for each vine, which decreased the number of years to 29.

7 OUTCOME/CONCLUSION

The Calculator of Soil pH Change is a valuable tool available to grape growers and viticulturists across Australia. Although not absolutely accurate, it can be used to provide a reasonable estimate of the rate of soil pH change as a result of a set of particular vineyard management practices. In fact, it can and should be regarded more as a 'learning tool' as it enables growers/viticulturists to alter management strategies to limit soil pH change. It should be remembered that the Calculator was designed to be used in conjunction with but not instead of regular soil testing which remains the most reliable method of assessing soil pH.

Despite considerable effort, it was not possible to achieve a regular effect of water alkalinity on soil pH. Clearly, the effect of water quality (alkalinity) on soil pH requires further attention.

Apart from being used to validate the Calculator of Soil pH Change, analyses conducted on soil samples collected from vineyards in several main viticultural regions of Australia highlighted the following key issues:

- In many regions, the pH values of the vine row and mid row topsoil and subsoil samples are higher than the external reference site. This suggests that most growers in acid soil areas are well aware of the risk of soil acidity and have applied lime.
- In Western Victoria, the pH of the topsoil sample from the vine row in 3 of the sites was lower than the topsoil sample from the mid row. This suggests that acidification of the vine row soil has occurred.
- Topsoil samples from several sites in Western and Eastern Victoria are considered sodic. Taking soil pH, cation exchange capacity and salinity into consideration, there is probably some risk of dispersion in these soils.
- In many vineyards, topsoil samples from the vine row had lower concentrations of exchangeable potassium compared to the mid row or external reference point. This reflects the significant amount of potassium removed in grapes each harvest.

8 RECOMMENDATIONS

In its current form, the Calculator of Soil pH Change is a valuable tool available to grape growers and viticulturists across Australia either as a management or learning tool. However, this project has highlighted the following areas that require further attention.

- **Water alkalinity**. Considerable effort was made to try to incorporate water alkalinity into the Calculator of Soil pH Change. However, the effect of water alkalinity on soil pH was highly variable which, as discussed, was probably related to the form of alkalinity present in the water. Assessment of the effect of water alkalinity on soil pH and the mechanisms involved is required.
- **Leaching.** Bicarbonate alkalinity may be lost from surface soil layers via leaching. Where sodium bicarbonate is applied in irrigation water and subsequently leached, there may be no change in soil pH. It was initially planned to include a leaching component in the Calculator of Soil pH Change, however, the Calculator predicted soil pH changes more accurately when a leaching component was not included.
- Clearly, more information is needed to determine the possible role of leaching in soil pH change in drip irrigated vineyards.
- **Ongoing monitoring of soil pH change**. One of the key limitations when developing and validating the Calculator of Soil pH Change was the sometimes sketchy management information available. By using the soil analysis results obtained for this project as a baseline, reassessing soil pH in several years and keeping thorough management records, the Calculator of Soil pH Change could be refined and developed even further.

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9 APPENDIX 1 – COMMUNICATION

The results of the soil analyses and the Calculator of Soil pH Change were presented at grower group meetings in each major viticultural region from which soil samples were collected as follows:

Friday, 1st June 2007 – Hamilton, Victoria (Western Victoria)

Presentation of Western Victoria results at the DPI Grapecheque information seminar for the Henty Region Wine Grape Growers entitled "Frost, Pruning, Grapevine Nutrition and Biosecurity".

Monday, 4th June 2007 – Healesville, Victoria (Eastern Victoria)

Presentation of Eastern Victoria results at the DPI Grapecheque and the Yarra Valley Technical Subcommittee seminar entitled "Pruning after Frosts, Grapevine Nutrition and Soil Management, Frost Boss Wind Machines, Bird Control, Alternative Red Varieties".

Tuesday, 5th June 2007 – Dalwood, New South Wales (Hunter Valley)

Presentation of Hunter Valley results Hunter Valley Vineyard Association Seminar

Thursday, 7th June 2007 – Orange, New South Wales (Central Ranges)

Presentation of Central Ranges results at a Drought Vineyards and Phylloxera Workshop

Friday, 15th June 2007 – Cowaramup, Western Australia (Margaret River)

Presentation of Margaret River results at the Agricultural Research WA, Landmark 2007 Seminar Series – Technical Sessions

Thursday, 21st June 2007 – Magill, South Australia (Fosters Group)

Presentation of Foster's Group results at the Foster's Group regional viticulturists meeting

Wednesday, 27th June 2007 – Griffith, New South Wales (Murrumbidgee Irrigation Area)

Presentation of Murrumbidgee Irrigation Area results at the Riverina Wine Grapes Marketing Board Annual General Meeting.

It was initially planned to disseminate information from the project in industry publications during the project. This will now be conducted following acceptance of this report by GWRDC and several industry publications have requested articles.

10 APPENDIX 2 – INTELLECTUAL PROPERTY

As foreseen in the Final Project Application, no intellectual property was generated by this project. Whilst the Calculator of Soil pH Change is a unique product, it is for use by all growers and their advisers. In any case, the Calculator is of a nature that would be difficult to protect and the delays that this might well entail would be against the basic intent of the project to provide a grower service and management tool.

11 APPENDIX 3 – REFERENCES

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12 APPENDIX 4 – STAFF

Project Supervisor / Chief Investigator:	Ben Thomas (Scholefield Robinson)
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Technical Support:	Amanda Schapel (Scholefield Robinson)
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13 APPENDIX 5 – REFINED CALCULATOR OF SOIL pH CHANGE





Vineyard Soil Acidity and Water Sodicity Calculator 2-1

Developed by Richard Merry, Ben Thomas, Ben Robinson and Doug Reuter for Land and Water Australia and GWRDC
Version 2-1 developed by Richard Merry and Ben Thomas with support from GWRDC, which is gratefully acknowledged.

Worksheet 1	Menu	This sheet
Worksheet 2	Notes	Explains background for Calculators
Worksheet 3	Acid Soil and Liming Calculator	Calculates lime rates for acidic soils
Worksheet 4	Vineyard Annual Acidification Calculator Water Sodicity Calculator	Uses detailed input information to calculate acidification or alkalisation, and some water sodicity characteristics
Worksheet 5	Documentation	Explanation of formulas used in the calculators
Worksheet 6	References	Literature references for data and formulas

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Notes for Users of the Vineyard Soil Acidity Calculator

This calculator uses simple models and functions that are intended to predict from known or estimated vineyard management conditions:
a) the amount of lime needed to treat an acidified soil. Calculator 1
b) the amount of lime needed to treat the acidified soil wetted by drippers. Calculator 1
c) the probable soil pH status over time of the soil volume wetted by dripper irrigation. Calculator 2
d) the amount of gypsum needed to off-set the SAR of irrigation water to a desirable level. Calculator 2
In c) the "wetted volume" is the soil volume that receives the applied nitrogen fertiliser and water.
This is regarded as the "affected" area relative to the remaining area of the vineyard where acidity and alkalinity responses are expected to be less marked and more easy to manage.

Macros should be enabled.

Acidities and alkalinities are expressed as negative and positive amounts of $CaCO_3$, respectively, as this is generally more easily understood than scientific units (cmol H^+) and is more readily connected to remediation of acidity by liming.

Note on soil variability: studies on spatial variability of soil properties, for example from precision agriculture, indicate that the spatial distribution of soil properties used in this calculator cannot be expected to be uniform. Coefficients of variation are available for some soil properties within vineyards or farmed paddocks (see below).

A "reasonable", constant value for some properties, based on what is known of common practice, has been chosen to calculate some inputs and outputs. These values and other assumptions made are shown on the worksheets as text below the calculators or, commonly, as cell notes indicated by a red triangle in the top right corner of the cell. **Users are advised to read the cell notes as they become familiar with the calculator.**

What the calculator aims to tell you:

A) Lime application estimated to be required to raise soil pH to a target level for the area wetted by the dripper and amount of lime needed to be used per hectare.

B) Estimates the soil pH buffering capacity, if it is not already known.

C) Whether the soil is likely to be becoming more acidic, alkaline or sodic, and can estrimate the gypsum needed to off-set sodium added in irrigation water.

D) The time in years that it is expected to take to reach a pH_{ca} of 5.5, at which point root and plant growth begins to decrease.
The critical pH of 5.5 where vine root growth begins to decrease is based on Robinson (199x).

E) The time in years that it is expected to take to reach a pH_{ca} of 4.8, at about which point root and plant growth is expected to be minimal.
The critical pH of 4.5 where vine root growth effectively ceases is based on Robinson (199x). Aluminium release in soils becomes significant at pHca values less than 4.8.

With increased familiarity with the calculators, it is easy to manipulate inputs to see the effects of different management actions.

Missing data/information

The ash alkalinity of all grapes varieties are not known.
The use of mulching materials and manures is increasing in some districts. This is not addressed in the calculator because of absence of information on rates applied, the ash alkalinity of the mulching materials used and the forms of nitrogen in the manures.

General Assumptions

Vineyard Management

All leaves and prunings are recycled and there is no net movement of alkalinity away from the row.
100 % of exported alkalinity in grapes harvested comes from the dripper wetted zone.
All ash alkalinity from the harvested grape derives from the dripper wetted zone. This is thought to be an assumption that is likely to result in only minor errors, especially in low yielding vineyards.

Soil Chemistry

The effects of nitrate formation and uptake are uniform. In fact, leaching is likely to occur under winter rainfall conditions and salt distributions will not be uniform within the wetted area. This may result in increased acidification rates in the upper soil layers and increased alkalinity in the subsoil where nitrate may be taken up by the plant.
The starting condition of the soil is the current condition as indicated by appropriate soil testing, or by using data obtained from the Australian National Land and Water Audit database.

Water Distribution and Chemistry

These calculators make no assumptions about the shape of the volume of soil wetted by dripper irrigation. A simple calculation of an expected wetted volume is used, based on the "average" expected water holding capacity of the soil of a selected texture.
Values for average water properties (see Table in the calculators) are based on the average clay contents of soil texture classes in McDonald *et al*. (1992) and an earlier, simpler version of the "Soil Water Characteristic" calculator of Dr K E Saxton (see references).
The values for volume % of available water are close to values currently used in the wine industry.
Future modifications could be based on the more advanced soil water characteristic calculator now shown on Dr Saxton's web site, but should be modified for texture classes used in Australia and would add considerably to complexity.
Compared to other possible errors and assumptions, these assumptions are thought not to be too serious.
Water alkalinity is ignored in this version. Validation work suggests that even where there is high sodium bicarbonate alkalinity, it appears to leach and not affect the calculations. However, where the irrigation water has a Langelier (or saturation) index that suggest precipitation of calcium carbonate, it is likely that the precipitated lime will contibute acid neutralising to the soil. Accounting for this requires complexities that we do not, at this stage, want to add to the claculator.
Rainfall and surface waters that are neutral to slightly acidic are assumed to have negligible effect (approach a natural condition) compared with those waters that have alkalinity. This may result in a small underestimate of acidification rates which is proportional to the amount of annual rainfall received.

Acid Soil and Liming Calculator

Work your way from the top down - the sheet extends below the page in view.

Yellow boxes require you to place values in them.

Blue boxes are values calculated for lime applications.

Red triangles have comments to help you fill the box.

Clear boxes are constants or calculated values

If the soil properties vary with depth, you can use depth weighted values for soil properties.

a) For soil that is uniformly acidified, that is, an area that is about to be planted and uniform treatment of acidified soil is required:

Input Data: move the scroll bars to the value you want

Soil pH: 4.9

Target pH: 6

Field texture: Ave Clay %: 25 %

Organic Carbon %: 4.7

Calculated pH buffer capacity in *tonnes $CaCO_3$/ha.pH unit 10 cm*: 2.44

Calculated soil bulk density: 1.51 *g/cc*

Tonnes of lime per hectare 15 cm **required to raise acidified soil to target pH**
(lime requirement x 1.3 for expected inefficiency): **7.9** *t/ha 10 cm*

If other than 15 cm, soil layer depth in cm: 30 cm → **15.8** *t/ha layer*

Field texture	Ave Clay %	Available Water AW vol %
Sand	2	6.1
Loamy sand	5	6.8
Clayey sand	7.5	7.1
Sandy loam	15	7.9
Loam	20	8.7
Silt loam	20	11.9
Sandy clay loam	25	8.2
Clay loam	28	10.2
Silty clay loam (& silty clay)	32	13.5
Sandy clay	32	8.3
Light clay	40	9.9
Medium clay	50	10.7
Heavy clay	55	11.1

b) For soils where the area wetted by drippers has acidified:

Drippers per hectare	3175	Dripper delivery rate	2 *litres/h*
AW vol%	9.9	Average duration	5 *hours/irrigation*

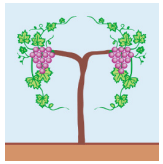
Estimated soil volume wetted per dripper 101 litres

Kg of lime per dripper **0.53** *kg*
(assumes lime neutralises volume of soil used above)

Total lime needed per hectare **1.69** *tonnes*

Assumptions: ***Soil properties change with depth***; carbon contents decrease and clay contents often increase. This means that pHBC also changes. If this is thought to be a problem, separate lime requirements should be calculated for each soil layer or depth weighted values for these properties should be used to approximate the situation.
This worksheet assumes that the irrigation water supplies no alkalinity.

Notes: ***Most soils show variablity*** (often as much as 30%; 10% for pH) in texture, pH, carbon content and bulk density.
Lime moves very slowly into soils; overliming should be avoided by mixing to a suitable depth or adding lime over several years.
1 ha 10 cm equals 1000000 litres



Calculator of Soil pH Change for Drip Irrigated Vineyards

Values calculated are indicative only.

This calculator is a simple acidity/alkalinity balance that aims to help predict the effects of vineyard management on soil pH changes. It requires simple annual inputs that should help managers make decisions about whether or not a vineyard is acidifying or becoming alkanine.
Read the cell comments - indicated by the small red triangle in the top right corner.
Always use soil testing to check actual soil condition.

Work downwards through the worksheet

Yellow boxes data require values

Green boxes calculate an alkaline input

Orange boxes calculate an acidic input

Blue boxes calculate answers/predictions

Clear boxes are constants or calculated values

These boxes relate to values calculated for sodic irrigation water.

If soil tests show that the soil is layered, you can use depth weighted averages, otherwise assume the soil is uniform.

Column N contains hidden cells used in calculations

Soil Module

Fill in data from soil tests or table to the right

pH_{ca}	Organic C %	Ave Clay %	AW *vol%*	Soil $CaCO_3$ %	pHBC	Bulk Density
5.8	2.5	15	7.9	0	1.25	1.55
or use pH_w - 0.9					*t $CaCO_3$/ha 10*	*g/cc*

Water Module

Water alkalinity *mg/L* as $CaCO_3$	Sodium Adsorption Ratio *SAR*	Total Volume *ML/ha/year*	Water delivered *Litres/dripper*	No of irrigations per year	Water alkalinity per dripper	
25.7	1.38	2	513.2	15	**0.0132**	*kg $CaCO_3$*

Fertigation Module

Type	Amount applied to vines/drippers *kg N/ha*	Equivalent soil acidity or alkalinity *kg $CaCO_3$*	Fertiliser acidity/alkalinity per dripper	
Urea or am nitrate - N	20	-36	**-0.0092**	*kg $CaCO_3$*
DAP - N	0	0	**0.0000**	*kg $CaCO_3$*
MAP - N	0	0	**0.0000**	*kg $CaCO_3$*
Calcium nitrate - N	0	0	**0.0000**	*kg $CaCO_3$*
Lime (***kg/ha $CaCO_3$***)	0	0	**0.0000**	*kg $CaCO_3$*

Vineyard Module

Grape Yield *kg/ha* (at harvest)	Ash alkalinity of grapes *kg $CaCO_3$/kg*	Dry wt factor (see table)	Vines per ha *no.*	Drippers per vine *no.*	Acidity through grape export per dripper	
15000	0.014	0.3	1821	2.14	**-0.0162**	*kg $CaCO_3$*

Assumes that most alkalinity exported as grapes comes from the area wetted by dripper.

Water Sodicity Module

(see cell P58)

Water Sodium Adsorption Ratio *SAR*	Irrigaton water analysis - units are *mg/L*				
1.38	Na	17.7	**Ca required to decrease SAR to <3**	-0.29	*meq/L*
	Ca	4.1		**-0.17**	*t/ML*
	Mg	5.1		**corrected for water Ca**	
	Calculated SAR	1.38			

Field texture	Average Clay % **Ave Clay %**	Available Water **AW vol %**
Sand	2	6.1
Loamy sand	5	6.8
Clayey sands	7.5	7.1
Sandy loam	15	7.9
Loam	20	8.7
Silt loam	20	11.9
Sandy clay loam	25	8.2
Clay loam	28	10.2
Silty clay loam (& silty clay)	32	13.5
Sandy clay	32	8.3
Light clay	40	9.9
Medium clay	50	10.7
Heavy clay	55	11.1

Grape Ash Alkalinity Variety	*kg $CaCO_3$/kg* **Ash alkalinity**	**Dry wt factor**
Table grapes	0.010	0.13
Shiraz	0.014	0.30
Cabernet sauvgnon	0.014	0.30
Merlot (single sample)	0.010	0.30
Riesling	0.011	0.25
Semillon	0.012	0.25
General wine arieties		
Red	0.014	0.30
White	0.011	0.25

Calculator results

The soil wetted by the dripper is becoming more:

acidic	**Yes**	
alkaline	**No**	
sodic	**No**	**-0.17** Estimated t gypsum /ML irrigation water applied: negative values require no gypsum

Acidity calculator

Net *acidification* (-ve) or *alkalisation* (+ve) rate	**-0.0254**	*kg $CaCO_3$/dripper/year*
based on annual inputs and exports	-99	*or kg $CaCO_3$/ha/yr*

Estimated time to pH_{ca} 5.5 **9.9** *years*

A negative number means the soil is becoming alkaline and the estimated time should be ignored.

Estimated time to pH_{ca} 4.8 **33.0** *years*

A negative number means the soil is becoming alkaline and the estimated time should be ignored.

If the soil has free lime ($CaCO_3$), that is, there is a value in cell E24 above, and the soil is acidifying:

It will take about **0** **years to neutralise it and decrease the soil pH**

Add this number to the times in years given above.

"Not acidifying" means that the soil is becoming more alkaline and the calcium carbonate in the soil should not decompose.

Notes on water chemistry

Water chemistry may be critical if soil pH is found to be increasing, especially its sodium and calcium content (or SAR).
Validation of the calculator indicates that high $NaHCO_3$ in water does not seem to affect prediction of soil pH and is ignored here. However, water with a Langelier (or saturation) index that indicates $CaCO_3$ precipitation, as frequently found in the SE of South Australia, is likely to be a factor which adds alkalinity to the soil.

High sodium values will cause the soil to become sodic (high exchangeable sodium) and the pHca may increase beyond about 7.5 (pH_w = 8.4). Sodium salts are very soluble and may leach in winter, lowering pH.
A critical value for SAR of 3 is used here, following Rengasamy and Olssen (1993).

Assumptions and sources of error

Values for soil and water tests are taken as given. Water alkalinities and SAR values vary with time, and soil properties vary spatially so that data used depends on adequate sampling and laboratory analysis.

Difficulties arise through changes in soil properties with depth, especially pH buffer capacity, which depends on carbon and clay contents, and free carbonates, if present. These changes in properties are ignored as treatment will greatly complicate the data needed and calculations required - the calculator concentrates on the top surface to 30 cm soil layer which is usually analysed in soil tests.

It is assumed that alkaline and acidic processes operate uniformly through the dripper wetted zone.

The calculator simply estimates a volume of soil at the inputted field texture value without considering the shape that the wetted volume might be.

It is assumed that water and fertiliser is applied or moves from the surface downwards and outwards. The predictions made by the calculator should therefore be more realistic for the near-surface layers.
This is supported by validations using actual vineyard management information.

Note that the decomposition of mulches used in vineyards will usually produce some alkalinity. The amount of alkalinity will depend on the rate of application and its ash alkalinity. However the effect has not been investigated and may only affect the top few cm of soil. It is not considered here, but could be added to future calculators.

Water Qua *mg/L* Nov-Mar averages

Location	**Alkalinity**	**Na**	**Ca**	**Mg**
Victoria				
Goulburn,	25.7	17.7	4.1	5.1
Lil Yarra, Y	10.9	9.3	2.3	1.1
Yarra, @W	19.6	na	na	na
Gt Western	298.0	304.0	13.9	24.0
NSW				
Wollombi	78.8	90.3	11.6	17.0
Hunter R, I	183.1	39.6	33.9	22.9
Muggyrang	335.0	139.6	61.9	51.1
M'mbidgee	32.4	5.6	5.9	3.1
M'mbidgee	34.1	10.7	7.1	4.0
Griffith Sew	287.1	225.7	25.8	24.2
Jondaryan	0.8	na	na	na
Lachlan, H	121.8	44.2	27.9	21.9
Maules, Av	113.0	26.3	27.9	11.0
B'mans Sw	151.5	54.7	22.9	12.9

Calculator 1

C22 Uses the relationship from Merry (1997) to calculate pHBC.
t CaCO3/ha 10cm = 0.200 + 0.364 %C + 0.0213 FT-Clay (n = 158; R^2 = 76.2%)

G22 Uses a regression equation derived by JO Skjemstad (CSIRO) based on % clay content and using bulk density data from Forrest et al. and Geeves et al. for SE Australian soils. Although a "noisy" relationship, it was felt that the BD data produced was reasonable.

G26 Calculates amount of lime needed to raise the soil pH of a top 15 cm soil layer to the target pH using the calculated pHBC and bulk density. If a subsoil layer, or layer of different texture, is required simply use this calculator with appropriate texture and depth data.

G28 Multiplies G19 by a given layer depth when not equal to 15 cm as used in G19.

Lookup table for "Ave clay %" and "Available Water %"

This table has been generated using the soil hydraulic properties calculator developed by Dr KE Saxton of Washington State University. The calculator can be seen and used at the following web site:

http://wilkes.edu/~boram/grphtext.htm?91,185

A more advanced calculator can be found at http://www.bsyse.wsu.edu/saxton/

For Australian purposes, the clay and sand % values used were not those indicated on the web site texture triangle, but were "median" values taken from the texture triangle published by Marshall (1947) where the field texture class placements of Australian pedologists were indicated. American soil texture triangles do not use the International limits for the silt to clay size classes (ie 20 microns is used internationally and 50 microns is used in the USA). This calculator also provides a values for soil bulk density. The facility was not used here (G24) as it was felt that some extreme BD values were provided and the equation is based on the different texture classes (cf Australia) mentioned above. Although some error has been introduced by using American texture data, these errors are small compared to other assumptions used and the available water data generated are not very different from values used widely in Australian vineyards for estimating water holding capacities from field texture.

E38 This function calculates the soil volume wetted by the volume of water applied by each dripper. It is simply the dripper delivery rate (L/h) multiplied by the time of delivery equivalent to that proportion of a hectare 10 cm layer (volume 10^6 litres) of soil that would be wet at the appropriate AW%.

F41 To neutralise the volume of soil calculated in E38, this calculates the amount of lime (in kg per dripper) by the proportion of the dripper-wetted volume (in litres) to the t/ha 10 cm value (C22) needed to neuralise a ha 10 cm (1,000,000 litres) layer.

F44 This simply multiples F41 by the number of drippers per hectare and converts to tonnes.

Calculator 2

Starting soil pH should be above 4.8

If there is soil texture contrast in the dripper wetted zone, depth weighted average values for % clay and AW% may give a more accurate result.

There are 1,000,000 litres in a ha/10cm. pHBC is multiplied by 1000 to convert tonnes to kg/ha/pH unit.10cm

F24, G24 These values are as for C22 and G22 in Calculator 1.

B31 The critical value of SAR = 3% is based on Rengasamy and Olsen (1993) who showed that SAR > 3% resulted in ESP values > 6 in soils with clay. If the soils are not cultivated, the critical value may be a little higher.

G31 This is the value "Litres per dripper" (D31) multiplied by the irrigation water alkalinity (in mg/L; A31) converted to kg $CaCO_3$.

C37 - C41 For each nitrogen fertiliser, this value is the average acidification (-ve) or alkalisation (+ve) per kg N expressed in kg $CaCO_3$.

G37 - G41 These use C37 to C41 to calculate the acidification effect per dripper.

B47 The values for ash akalinity of grapes our data and a single value for table grapes is taken from Moody and Aitken (1997). The data provided for wine grapes are for berries samples from SA vineyards. Values for the different varieties shown are likely to vary with season and may not apply to varieties not specifically included in the table.

G47 Calculates the exported alkalinity (resulting in net soil acidification) from the grape crop, expressed as acidification per dripper wetted zone. This calculation assumes that all alkalinity associated with the grape is exported from the dripper wetted volume as the majority of roots should be active in this volume during the irrigation season.

F58 This simply sums the acidification (-ve or +ve alkaline processes) calculated in Column G

F62 This calculates the estimated time taken for the soil in the dripper wetted volume to reach a critical pHca of 5.5 (Robinson, 1993) See the worksheet for the formula. This formula calculates as follows:

(current pH - 5.5 or 4.8)x(water delivered per dripper/irrigations per year)x(100/Available water %)x(1000 [kg]pHbc/1000000[litre volume of soil])x bulk density/(-acidification rate)

the acidification term is made negative to output a positive value for years until critical pH or negative value if already acidified.
"If " statements are used to indicate that the soil has already moved beyond the critical soil pH value.

F65 As for F62, but using 4.8 as the critical pH value.

D70 If the soil is acidifying, uses E24 to calculate approximate time to neutralise soil $CaCO_3$.

Selected References

For acidifying affects of fertilisers:
Adams, F (1984) Crop responses to lime in the southern United States. In, Fred Adams (ed): Soil Acidity and Liming, Second Edition. Pp211-266. (American Society of Agr

For discussion of soil acidification:
Helyar, KR, and Porter, WM (1989) Soil acidification, its measurementand the processes involved. In 'Soil Acidity and Plant Growth' (Ed. A.D. Robson). Pp. 61 - 102. (Aca

For function used to calculate soil pH buffer capacity:
Merry RH (1997) Estimation of Simple Lime Requirement Based on pH Buffer Capacity Measurement and Other Soil Factors. Unpublished report, CSIRO Land and Water. 4 pp.

Ash alkalinity of grapes:
Moody, PW, and Aitken, RL (1997) Soil acidification under some tropical agricultural systems. 1. Rates of acidification and contributing factors. Aust J Soil Res 35, 163 - 17

For SAR values and irrigation water effects:
Rengasamy, P, and Olssen, KA (1993) Irrigation and sodicity. Aust. J. Soil Res. 31, 821-837.

Critical acid pH values for growing wine grapes:
Robinson, JB (1993) Managing soil acidification. p 45 - 48. In: C.S. Stockley, R.S. Johnstone, P.A. Leske and T.H. Lee (ed.). Proceedings of the 8th Australian wine industry technical conference; 25- 29 October, 1992; Melbourne, Victoria. Winetitles.

For soil-water characteristics and soil texture:
Saxton, KE, Rawls, WJ, Romberger, JS and Papendick, RI (1986) Estimating generalised soil-water characteristics from texture. Soil Sci. Soc. Am. J. 50, 1031-1036.
Also see the related web site at www.bsyse.wsu.edu/saxton/

14 APPENDIX 6 – OTHER RELEVANT INFORMATION

Appendix 6.1 – Soil sampling protocol

Appendix 6.2 – Vineyard Management Questionnaire

Appendix 6.3 – Soil analysis data for each major viticultural region

15 APPENDIX 6.1 – SOIL SAMPLING PROTOCOL

Scholefield Robinson
HORTICULTURAL SERVICES

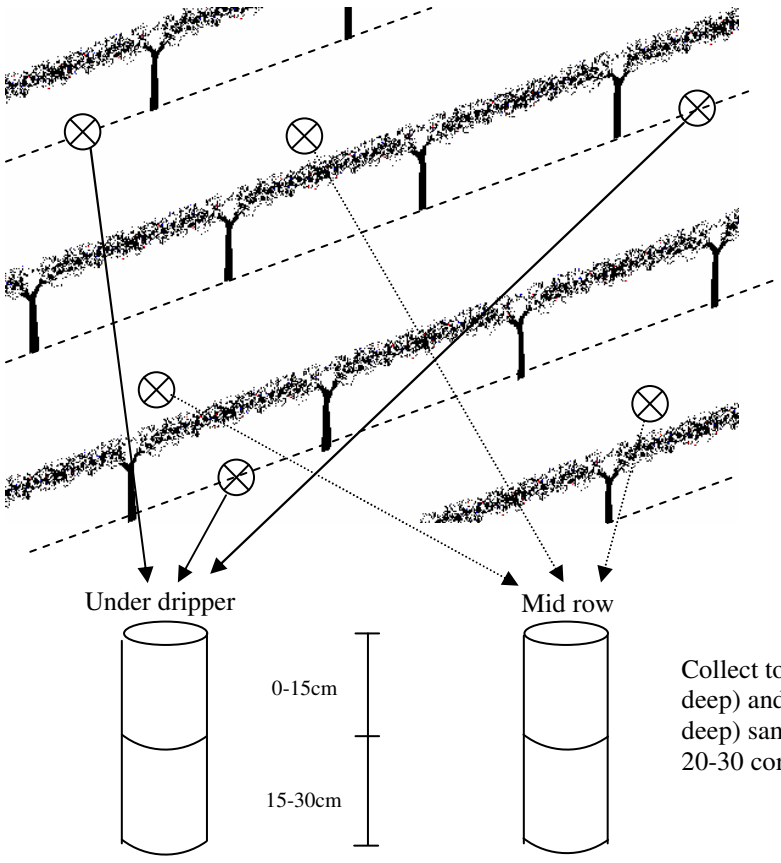
GWRDC SOIL pH PROJECT - SOIL SAMPLING INSTRUCTIONS

You will need:

- A soil core sampler (often referred to as a soil spear or digstick)
- clean plastic buckets to collect the samples in
- clean labelled plastic bags in which to send the samples to the laboratory. These will be provided along with Express Post bags by Scholefield Robinson Horticultural Services.

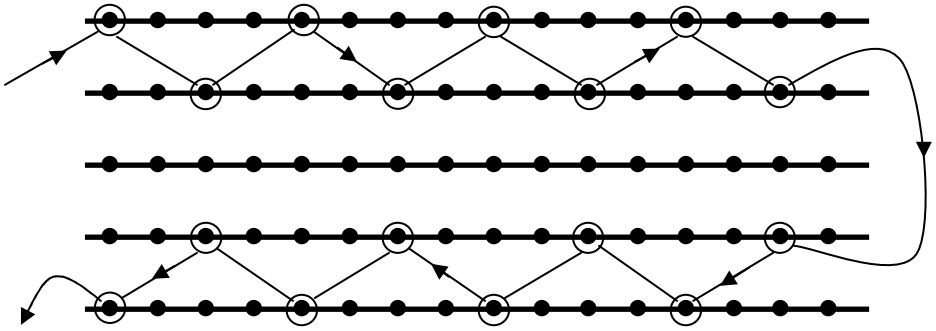
The soil samples that we send to the laboratory are composites of a number of individual cores collected across the area of interest. The idea of this is to minimise the effect of the variability which exists in the soil. To collect the sample(s):

- After selecting a suitable block for sampling (drip irrigated with lighter textured soils and a history of nitrogen fertiliser use), review the area to be sampled to ensure that the cores are taken from an area which has a uniform soil type.
- For this project, separate composite samples consisting of 20-30 cores need to be collected from the topsoil (0-15cm deep) and subsoil (15-30cm deep) from three positions (see diagram below):
  - Directly under the drippers
  - In the mid row space
  - At a nearby external reference site with a similar soil type that has not received any fertilisers, irrigation etc. (e.g. a scrub block or fenceline).



Collect topsoil (0-15cm deep) and subsoil (15-30cm deep) samples - composite of 20-30 cores.

- Moving up and down at least two pairs of rows in the block in a zigzag pattern (see diagram below), stop and sample as often as needed to collect 20-30 cores. The more cores that make up a composite sample the better the data will be. In the present case, it is usually easier to collect the under dripper cores first and then retrace your steps to collect the mid row samples. Obviously, you collect the external reference sample separately.



- At each stop, use a shovel to remove any grass or thatch from the surface of the soil.
- Using a soil spear/digstick, collect a soil core to 30cm deep. This core is then split into 0-15cm and 15-30cm depths. Place each depth interval into a separate appropriately labelled clean bucket and move on to the next spot.
- Once 20-30 cores have been collected, break up any clods, pick out any major pebbles etc. and mix the composite thoroughly. The composite sample that is sent to the laboratory should be about 750g of this mixed soil.
- Place each composite sample into the appropriately labelled plastic sample bag provided. Clearly label each bag with your vineyard and block name. At the end of sampling, you should have 6 composite soil samples as follows:
  - Directly under drippers – 0-15cm deep.
  - Directly under drippers – 15-30cm deep.
  - Mid row – 0-15cm deep.
  - Mid row – 15-30cm deep.
  - External reference site – 0-15cm deep.
  - External reference site – 15-30cm deep.
- Place the samples into the addressed Express Post bags supplied and send the soil samples to our contracted laboratory (CSBP in Perth). Fill out the Sample to Laboratory form provided and place a copy into each Express Post Bag. You will need to send your samples directly to the laboratory due to quarantine restrictions in South Australia. Please send another copy of the Sample to Laboratory form to SRHS so we can keep track of the samples.

If at any stage you have any queries regarding the soil sampling procedure, please do not hesitate to contact Ben Thomas on (08) 8373 2488 or 0438 732 488.

16 APPENDIX 6.2 – SOIL SAMPLING QUESTIONNAIRE

Scholefield Robinson
HORTICULTURAL SERVICES

GWRDC SOIL pH PROJECT - SOIL SAMPLING QUESTIONNAIRE

Participant details

Company name: ……...

Contact name: ……...

Address: ……..Postcode: …….....

Phone: ……..Fax: ……Mobile: ……...

Block details:

Block name:

Block area (ha): Variety:

Vine age: Rootstock:

Vine spacing in row: Row width:

Dripper spacing: No. vines per hectare:

Soil type: Previous history of land:

Has organic matter been applied? (Y/N) If yes, what application strategy is used?

Is the vineyard mulched? (Y/N) If yes, what with?

Irrigation history:

Water source: Alkalinity: Salinity:

Years on drip irrigation: Is a full water analysis available (Y/N):

Irrigation rate (ML/ha/year): Irrigation frequency: per week

Normal irrigation: mm or L per vine per irrigation.

Normal fertigation strategy:

Harvest (tonnes/ha) for this block in last 5 years:

Year	Harvest (tonnes/ha)
2005/6	
2004/5	
2003/4	
2002/3	
2001/2	

Nitrogen fertiliser, manure and lime applications in last 5 years (attach separate sheet if necessary):

Year	Product	%N, %P, %K	Vine row or Mid row	Broadcast or Fertigation	Rate/ha

Any other comments:

17 APPENDIX 6.3 – SOIL ANALYSIS DATA FOR EACH MAJOR VITICULTURAL REGION

SOIL ANALYSIS DATA - HUNTER VALLEY, NEW SOUTH WALES

Element or Test	Soil Depth	Hunter Valley A			Hunter Valley B			Hunter Valley C		
		Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External
EC based on 1:5 extract (dS/m)	0-15	0.14	0.16	0.14	0.08	0.07	0.13	0.10	0.06	0.07
	15-30	0.20	0.19	0.18	0.07	0.04	0.04	0.13	0.06	0.06
pH (calcium chloride) - Preferred value	0-15	7.2	6.7	6.6	6.8	6.6	5.1	6.6	5.7	4.4
	15-30	7.2	6.8	6.8	6.5	5.9	4.9	6.3	6.0	4.8
pH (water)	0-15	7.9	7.3	7.2	7.5	7.1	5.7	7.4	6.7	5.5
	15-30	7.9	7.6	7.6	7.2	6.5	5.7	7.1	6.9	6.0
Exchangeable Calcium (Ca) - (meq/100 g)	0-15	21.13	24.33	21.53	6.05	7.56	7.11	21.78	29.87	13.20
	15-30	22.50	26.26	21.73	3.77	3.33	3.58	32.55	34.21	19.52
Exchangeable Magnesium (Mg) - (meq/100 g)	0-15	19.02	17.21	19.75	2.25	0.58	0.91	9.62	3.78	2.85
	15-30	20.18	20.14	21.24	1.70	0.32	0.64	4.26	3.77	5.46
Exchangeable Sodium (Na) - (meq/100 g)	0-15	0.93	1.00	0.84	0.23	0.07	0.05	1.29	0.20	0.15
	15-30	1.54	2.11	1.33	0.38	0.07	0.04	2.13	0.23	0.16
Exchangeable Potassium (K) - (meq/100g)	0-15	1.16	2.09	1.31	0.55	0.69	0.71	0.62	0.83	1.61
	15-30	1.05	1.61	1.05	0.29	0.34	0.49	0.43	0.77	1.44
Exchangeable Aluminium (Al) - (mg/kg)	0-15	0	0	0	0	0	0.02	0	0	0.06
	15-30	0	0	0	0	0	0.02	0	0	0.10
Cation exchange capacity	0-15	42.24	44.63	43.43	9.08	8.90	8.80	33.31	34.68	17.81
	15-30	45.27	50.12	45.35	6.14	4.06	4.77	39.37	38.98	26.58
Exchangeable sodium percentage	0-15	2.20	2.24	1.93	2.53	0.79	0.57	3.87	0.58	0.84
	15-30	3.40	4.21	2.93	6.19	1.72	0.84	5.41	0.59	0.60
Organic carbon - (%)	0-15	2.17	2.75	2.71	0.94	1.27	2.68	2.54	2.31	2.52
	15-30	1.98	2.63	2.17	0.56	0.44	0.92	1.70	1.87	1.87
Extractable Aluminium* - (mg/kg)	0-15	0	0	0	0	0	1.3	0	0	2.9
	15-30	0	0	0	0	0	0.7	0	0	0.8
Extractable Calcium Carbonate** - (mg/kg)	0-15	0.28	0	0	0	0	0	0	0	0
	15-30	0.3	0	0	0	0	0	0	0	0

Notes:

* - Only soils with pHCa values below 5.5 were analysed for extractable aluminium. It was assumed that soils with pHCa values greater than 5.5 contained no extractable aluminium

** - Only soils with pHCa values above 7.0 were analysed for calcium carbonate. It was assumed that soils with pHCa values less than 7.0 contained no calcium carbonate.

SOIL ANALYSIS DATA - CENTRAL RANGES, NEW SOUTH WALES

Element or Test	Soil Depth	Central Ranges A			Central Ranges B			Central Ranges C			Central Ranges D		
		Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External
EC based on 1:5 extract (dS/m)	0-15	0.087	0.038	0.045	0.07	0.09	0.07	0.08	0.07	0.05	0.07	0.06	0.18
	15-30	0.074	0.04	0.014	0.05	0.06	0.05	0.08	0.06	0.04	0.11	0.06	0.12
pH (calcium chloride) - Preferred value	0-15	7.4	5.9	4.5	5.3	5.3	4.4	7.0	5.6	5.3	6.3	5.4	5.6
	15-30	7.4	5.6	4.8	4.6	4.4	4.3	7.0	5.7	5.8	6.8	6.1	6.1
pH (water)	0-15	8.4	6.9	5.4	6.0	5.9	5.2	7.8	6.5	6.2	7.0	6.4	6.2
	15-30	8.6	6.5	6	5.4	5.2	5.1	7.9	6.6	6.8	7.2	6.7	6.6
Exchangeable Calcium (Ca) - (meq/100 g)	0-15	8.05	8.14	1.36	14.94	16.51	6.53	8.85	9.15	8.63	6.13	5.13	9.12
	15-30	4.2	3.34	0.75	5.31	2.53	2.17	9.94	7.57	10.63	7.44	4.56	7.93
Exchangeable Magnesium (Mg) - (meq/100 g)	0-15	6.77	1.79	1.45	1.38	0.95	1.41	7.53	2.32	4.33	1.22	1.18	1.61
	15-30	4.57	1.38	1.84	0.49	0.27	0.67	9.64	5.54	7.43	1.68	1.37	1.68
Exchangeable Sodium (Na) - (meq/100 g)	0-15	0.41	0.1	0.08	0.19	0.16	0.28	0.24	0.17	0.16	0.13	0.05	0.13
	15-30	0.38	0.17	0.08	0.17	0.16	0.39	0.55	0.26	0.23	0.22	0.09	0.16
Exchangeable Potassium (K) - (meq/100g)	0-15	0.3	0.48	0.24	0.37	0.30	0.36	0.32	0.30	0.42	0.59	0.98	2.29
	15-30	0.14	0.25	0.25	0.19	0.14	0.27	0.22	0.22	0.32	0.38	0.62	1.91
Exchangeable Aluminium (Al) - (mg/kg)	0-15	0	0	0.12	0.03	0.22	2.67	0	0	0.03	0	0.02	0
	15-30	0	0	0.05	0.90	2.74	3.75	0	0	0	0	0	0
Cation exchange capacity	0-15	15.53	10.51	3.25	16.88	17.92	8.58	16.94	11.94	13.54	8.07	7.34	13.15
	15-30	9.29	5.14	2.97	6.16	3.10	3.50	20.35	13.59	18.61	9.72	6.64	11.68
Exchangeable sodium percentage	0-15	2.64	0.95	2.46	1.13	0.89	3.26	1.42	1.42	1.18	1.61	0.68	0.99
	15-30	4.09	3.31	2.69	2.76	5.16	11.14	2.70	1.91	1.24	2.26	1.36	1.37
Organic carbon - (%)	0-15	1.558	2.111	1.507	5.15	5.20	5.30	1.29	1.63	1.83	1.09	1.73	2.62
	15-30	0.746	0.719	0.691	4.11	3.48	3.66	0.90	0.68	1.08	0.61	0.71	1.33
Extractable Aluminium* - (mg/kg)	0-15	0	0	4.2	0.36	1.13	1.98	0	0	1.45	0	0.48	0
	15-30	0	0	0.8	0.45	6.41	13.99	0	0	0	0	0	0
Extractable Calcium Carbonate** - (mg/kg)	0-15	0.32	0	0	0	0	0	0	0	0	0	0	0
	15-30	0.26	0	0	0	0	0	0	0	0	0	0	0

Notes:

* - Only soils with pHCa values below 5.5 were analysed for extractable aluminium. It was assumed that soils with pHCa values greater than 5.5 contained no extractable aluminium

** - Only soils with pHCa values above 7.0 were analysed for calcium carbonate. It was assumed that soils with pHCa values less than 7.0 contained no calcium carbonate.

SOIL ANALYSIS DATA - MURRUMBIDGEE IRRIGATION AREA (MIA), NEW SOUTH WALES

Element or Test	Soil Depth	MIA A			MIA B			MIA C		
		Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External
EC based on 1:5 extract (dS/m)	0-15	0.05	0.05	0.10	0.11	0.08	0.04	0.08	0.08	0.58
	15-30	0.07	0.10	0.11	0.06	0.08	0.07	0.05	0.18	2.04
pH (calcium chloride) - Preferred value	0-15	6.0	5.8	5.0	6.8	6.4	5.4	6.6	6.3	7.8
	15-30	6.6	5.7	5.3	6.2	6.5	5.3	6.1	6.8	7.9
pH (water)	0-15	7.0	6.6	5.9	7.7	7.3	6.6	7.0	7.0	8.3
	15-30	7.4	6.7	6.1	6.8	7.4	6.4	6.9	7.4	7.9
Exchangeable Calcium (Ca) - (meq/100 g)	0-15	6.10	5.80	4.55	8.00	9.25	6.74	15.39	11.22	18.51
	15-30	5.90	4.98	6.38	7.37	8.36	5.84	12.08	12.01	12.93
Exchangeable Magnesium (Mg) - (meq/100 g)	0-15	2.01	1.45	1.33	3.71	3.20	2.12	7.13	8.38	9.41
	15-30	3.24	4.50	2.38	2.60	3.61	2.44	8.60	11.85	10.41
Exchangeable Sodium (Na) - (meq/100 g)	0-15	0.23	0.10	0.12	0.24	0.18	0.19	0.26	0.42	2.67
	15-30	0.59	0.74	0.32	0.40	0.56	0.45	0.47	1.82	8.85
Exchangeable Potassium (K) - (meq/100g)	0-15	0.32	1.18	1.42	0.66	1.81	1.14	1.04	1.65	2.66
	15-30	0.48	0.84	1.04	0.69	1.40	0.91	0.95	1.45	1.64
Exchangeable Aluminium (Al) - (mg/kg)	0-15	0	0	0.04	0	0	0.04	0	0	0
	15-30	0	0	0.04	0	0	0.06	0	0	0
Cation exchange capacity	0-15	8.66	8.53	7.42	12.61	14.44	10.19	23.82	21.67	33.25
	15-30	10.21	11.06	10.12	11.06	13.93	9.64	22.10	27.13	33.83
Exchangeable sodium percentage	0-15	2.66	1.17	1.62	1.90	1.25	1.86	1.09	1.94	8.03
	15-30	5.78	6.69	3.16	3.62	4.02	4.67	2.13	6.71	26.16
Organic carbon - (%)	0-15	0.84	1.00	1.17	0.93	1.17	1.11	1.50	1.33	1.82
	15-30	0.54	0.55	0.80	0.69	0.72	0.78	1.03	0.99	1.02
Extractable Aluminium* - (mg/kg)	0-15	0	0	0.77	0	0	6.01	0	0	0
	15-30	0	0	0.54	0	0	3.61	0	0	0
Extractable Calcium Carbonate** - (mg/kg)	0-15	0	0	0	0	0	0	0	0	4.4
	15-30	0	0	0	0	0	0	0	0	1.62

Notes:

* - Only soils with pHCa values below 5.5 were analysed for extractable aluminium. It was assumed that soils with pHCa values greater than 5.5 contained no extractable aluminium

** - Only soils with pHCa values above 7.0 were analysed for calcium carbonate. It was assumed that soils with pHCa values less than 7.0 contained no calcium carbonate.

SOIL ANALYSIS DATA - EASTERN VICTORIA

Element or Test	Soil Depth	Eastern Victoria A			Eastern Victoria B		Eastern Victoria C		
		Vine Row	Mid Row	External	Vine Row	Mid Row	Vine Row	Mid Row	External
EC based on 1:5 extract (dS/m)	0-15	0.126	0.067	0.073	0.16	0.13	0.11	0.06	0.06
	15-30	0.116	0.038	0.091	0.06	0.10	0.08	0.05	0.04
pH (calcium chloride) - Preferred value	0-15	6	5.9	4.3	5.2	4.6	7.0	6.2	4.5
	15-30	5.5	4.9	4.2	4.9	4.2	7.0	6.2	4.7
pH (water)	0-15	6.6	6.6	5.3	5.9	5.5	8.2	7.1	5.7
	15-30	6.1	5.8	5.1	5.9	5.2	8.4	7.2	6.2
Exchangeable Calcium (Ca) - (meq/100 g)	0-15	15.25	9.71	5.07	7.56	3.26	5.79	5.96	2.38
	15-30	11.25	3.3	4.18	4.51	2.16	3.26	3.74	2.47
Exchangeable Magnesium (Mg) - (meq/100 g)	0-15	2.48	3.19	5.09	3.62	1.77	1.56	0.90	1.36
	15-30	2.25	1.98	4.29	2.18	2.95	0.97	0.70	1.93
Exchangeable Sodium (Na) - (meq/100 g)	0-15	0.34	0.13	0.32	0.63	0.60	1.19	0.29	0.21
	15-30	0.35	0.13	0.39	0.24	0.50	1.42	0.29	0.51
Exchangeable Potassium (K) - (meq/100g)	0-15	0.23	0.25	0.39	0.32	0.18	0.30	0.32	0.85
	15-30	0.15	0.15	0.32	0.30	0.27	0.13	0.17	0.52
Exchangeable Aluminium (Al) - (mg/kg)	0-15	0	0	0.37	0.09	0.34	0	0	0.14
	15-30	0	0.08	0.36	0.15	1.53	0	0	0.18
Cation exchange capacity	0-15	18.30	13.28	11.24	12.13	5.81	8.84	7.47	4.80
	15-30	14.00	5.64	9.54	7.23	5.88	5.78	4.90	5.43
Exchangeable sodium percentage	0-15	1.86	0.98	2.85	5.19	10.33	13.46	3.88	4.38
	15-30	2.50	2.30	4.09	3.32	8.50	24.57	5.92	9.39
Organic carbon - (%)	0-15	3.324	2.289	3.532	3.44	1.69	0.97	1.31	1.30
	15-30	2.696	1.23	2.354	2.41	1.14	0.41	0.55	0.83
Extractable Aluminium - (mg/kg)*	0-15	0	0	2.9	**	**	0	0	0.30
	15-30	0	1.6	4	**	**	0	0	0.24

Notes:

* - Only soils with pHCa values below 5.5 were analysed for extractable aluminium. It was assumed that soils with pHCa values greater than 5.5 contained no extractable aluminium

** - Extractable aluminium not determined in Eastern Victoria B samples due to lack of sample.

SOIL ANALYSIS DATA - WESTERN VICTORIA

Element or Test	Soil Depth	Western Victoria A			Western Victoria B			Western Victoria C			Western Victoria D		
		Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External
EC based on 1:5 extract (dS/m)	0-15	0.13	0.13	0.05	0.15	0.07	0.06	0.10	0.24	0.14	0.08	0.06	0.06
	15-30	0.09	0.03	0.04	0.17	0.05	0.06	0.16	0.25	0.09	0.08	0.06	0.06
pH (calcium chloride) - Preferred value	0-15	6.1	6.7	4.3	5.7	6.7	6.0	6.3	7.3	5.9	6.5	5.5	5.3
	15-30	5.3	5.8	4.5	6.0	6.3	5.8	6.7	7.4	6.6	5.7	5.3	5.1
pH (water)	0-15	6.6	7.3	5.2	6.8	7.6	6.9	6.9	7.7	7.1	6.9	6.5	6.2
	15-30	6.1	6.7	5.3	7.1	7.3	6.8	7.1	7.8	7.4	6.7	6.4	6.2
Exchangeable Calcium (Ca) - (meq/100 g)	0-15	6.35	9.27	1.53	4.48	9.55	5.48	21.62	33.66	13.71	18.89	9.68	9.96
	15-30	3.22	3.19	1.01	3.88	3.74	6.01	24.37	34.45	11.11	10.90	4.76	5.04
Exchangeable Magnesium (Mg) - (meq/100 g)	0-15	1.60	0.88	0.63	1.14	0.64	1.60	5.74	7.43	6.81	3.63	3.78	2.87
	15-30	1.07	0.72	0.52	1.18	0.82	1.44	5.90	6.73	6.13	4.18	3.27	3.77
Exchangeable Sodium (Na) - (meq/100 g)	0-15	0.64	0.48	0.37	1.12	0.09	0.32	0.27	0.38	0.50	0.56	0.21	0.25
	15-30	0.52	0.21	0.14	1.22	0.20	0.25	0.20	0.26	0.41	0.56	0.34	0.38
Exchangeable Potassium (K) - (meq/100g)	0-15	0.17	0.13	0.22	1.24	0.46	0.36	0.90	0.72	1.05	0.37	0.56	0.71
	15-30	0.10	0.09	0.16	0.75	0.23	0.46	1.19	0.84	0.38	0.18	0.22	0.31
Exchangeable Aluminium (Al) - (mg/kg)	0-15	0	0	0.26	0	0	0	0	0	0	0	0	0.06
	15-30	0.12	0	0.44	0	0	0	0	0	0	0	0.08	0.07
Cation exchange capacity	0-15	8.76	10.76	2.75	7.98	10.74	7.76	28.53	42.19	22.07	23.45	14.23	13.79
	15-30	4.91	4.21	1.83	7.03	4.99	8.16	31.66	42.28	18.03	15.82	8.59	9.50
Exchangeable sodium percentage	0-15	7.31	4.46	13.45	14.04	0.84	4.12	0.95	0.90	2.27	2.39	1.48	1.81
	15-30	10.59	4.99	7.65	17.35	4.01	3.06	0.63	0.61	2.27	3.54	3.96	4.00
Organic carbon - (%)	0-15	1.57	1.95	1.66	1.09	1.34	1.16	1.81	1.68	1.91	3.52	3.41	3.69
	15-30	1.18	0.54	0.96	0.83	0.63	1.23	2.17	1.66	0.78	2.72	1.20	1.59
Extractable Aluminium* - (mg/kg)	0-15	0	0	4.80	0	0	0	0	0	0	0	0	0.31
	15-30	6.66	0	0.94	0	0	0	0	0	0	0	0.53	0.31

Notes:

* - Only soils with pHCa values below 5.5 were analysed for extractable aluminium. It was assumed that soils with pHCa values greater than 5.5 contained no extractable aluminium

SOIL ANALYSIS DATA - MARGARET RIVER, WESTERN AUSTRALIA

Element or Test	Soil Depth	Margaret River A			Margaret River B			Margaret River C		
		Vine Row	Mid Row	External	Vine Row	Mid Row	External	Vine Row	Mid Row	External
EC based on 1:5 extract (dS/m)	0-15	0.11	0.03	0.07	0.11	0.07	0.06	0.07	0.03	0.03
	15-30	0.06	0.07	0.05	0.07	0.05	0.03	0.05	0.03	0.03
pH (calcium chloride) - Preferred value	0-15	5.9	5.8	6.0	5.9	6.0	5.9	6.2	5.5	5.1
	15-30	5.9	6.0	6.0	6.0	6.0	5.8	5.7	5.3	5.5
pH (water)	0-15	6.9	6.6	6.6	6.9	6.6	6.6	6.6	6.2	5.8
	15-30	6.6	6.6	6.5	6.6	6.5	6.6	6.4	6.0	6.2
Exchangeable Calcium (Ca) - (meq/100 g)	0-15	8.44	2.53	3.59	8.44	7.25	5.13	2.55	2.27	0.96
	15-30	5.13	7.25	2.40	3.59	2.40	2.53	2.33	0.92	0.78
Exchangeable Magnesium (Mg) - (meq/100 g)	0-15	2.68	0.58	1.28	2.68	1.18	1.01	0.92	0.30	0.12
	15-30	1.01	1.18	0.45	1.28	0.45	0.58	0.86	0.12	0.18
Exchangeable Sodium (Na) - (meq/100 g)	0-15	0.27	0.10	0.20	0.27	0.16	0.17	0.08	0.06	0.05
	15-30	0.17	0.16	0.08	0.20	0.08	0.10	0.09	0.03	0.06
Exchangeable Potassium (K) - (meq/100g)	0-15	0.73	0.06	0.31	0.73	0.33	0.15	0.19	0.06	0.04
	15-30	0.15	0.33	0.13	0.31	0.13	0.06	0.12	0.06	0.07
Exchangeable Aluminium (Al) - (mg/kg)	0-15	0.04	0.04	0.04	0.04	0.04	0.04	0	0	0.11
	15-30	0.04	0.04	0.03	0.04	0.03	0.04	0	0.14	0
Cation exchange capacity	0-15	12.12	3.27	5.38	12.12	8.92	6.46	3.74	2.69	1.17
	15-30	6.46	8.92	3.06	5.38	3.06	3.27	3.40	1.13	1.09
Exchangeable sodium percentage	0-15	2.23	3.06	3.72	2.23	1.79	2.63	2.14	2.23	4.27
	15-30	2.63	1.79	2.61	3.72	2.61	3.06	2.65	2.65	5.50
Organic carbon - (%)	0-15	3.57	1.84	1.45	3.57	2.96	2.37	1.09	0.97	0.67
	15-30	2.37	2.96	1.22	1.45	1.22	1.84	1.28	0.52	0.38
Extractable Aluminium* - (mg/kg)	0-15	0	0	0	0	0	0	0	0	0.39
	15-30	0	0	0	0	0	0	0	0.25	0

Notes:

* - Only soils with pHCa values below 5.5 were analysed for extractable aluminium. It was assumed that soils with pHCa values greater than 5.5 contained no extractable aluminium

18 APPENDIX 7 – BUDGET RECONCILIATION