Assessing the pH and pH buffering capacity of Australian viticultural soils.

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Abstract
This work assesses soil pH status and pH buffering capacity (pHBC) of surface soils from Australian viticulture, through interrogation of data from the National Land and Water Resources Audit's (NLWRA) Australian Soil Test Inventory.
Soil pH_{ca} data was available for 4877 surface soils from five states, NSW, Queensland, SA, Tasmania and Victoria. pHBC estimates were made using a simple pedotransfer function based on soil organic carbon content and field texture. It was not known whether the samples came from existing or proposed vineyards and mostly locations were not known much closer than the nearest town. However, sample sites could mostly be allocated to accepted wine regions of Australia and these groupings formed the basis for statistical analysis of the data. The soil pH data were classified using histograms with fixed class intervals and simplified to extremely acidic ($pH_{ca} \leq 4.8$), extremely to moderately acidic ($pH_{ca} \leq 5.5$) and highly alkaline ($pH_{ca} \geq 7.7$), as it is in these classes that problems could be expected. Soil pHBC was classified into four groupings. Basic statistics are presented for range, means, median and skewness. Although there was often considerable variation within a region in each state, a large proportion (38-76%) of soils for all Eastern states are already considered moderately acidic whilst 18-26% are considered extremely acidic. In the Riverland and Sunraysia regions, a high proportion of surface soils were strongly alkaline, a condition that also requires careful management.
Soils from all states had low to very low pHBC, except Tasmania, where the soils generally had higher organic carbon contents.
Soil acidity and alkalinity status, and the processes of soil acidification or alkalinisation, require further investigation in viticultural soils of Australia to confirm whether or not the indications of possibly widespread soil constraints given in this assessment are limiting productivity.

Introduction
The Australian National Land and Water Resources Audit project entitled "Nutrient balance in regional farming systems and soil nutrient status" (http://audit.ea.gov.au/ANRA/atlas_home.cfm) estimated that annual losses caused by soil acidification in viticultural and horticultural regions in Australia may be as high as $818 million for orchards and $118 million for grapes. In fact, if this was the case, it could be the equivalent to 20,000 ha of vineyards in areas with acid soils or soils prone to acidification as a result of vineyard management. The predicted losses equate to 70,000 to 80,000 tonnes of grapes, or 4 tonnes per ha, which is considered by the industry to be too high. It is probable that soil acidity results in lower yields of grapes and therefore, at moderate acidities, its effect is difficult to distinguish among the variations that occur seasonally.

Grapes are known to be moderately sensitive to acidity. 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 where they become more susceptible to zinc, iron, manganese and copper deficiency, and soil physical condition can be adversely affected by sodicity. In some soils iron deficiency is difficult to treat.

Extreme soil pH is recognised as an issue by viticultural Research and Development managers. However, extreme soil pH is generally considered a low priority because there are few sites where low pH is an intractable problem (untreatable by lime application) and generally micronutrients can be efficiently applied to vines in foliar nutrient sprays in high pH soils. Previous work has indicated a tendency toward acidification in the Riverland of South Australia, while some other districts have tended toward alkalinisation, presumedly due to the composition of irrigation water (Robinson 1993). Other work (Seeliger and French 1971) has shown acidification occurs under mature vineyards after long use of high

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rates of nitrogen fertiliser. Clark *et al*. (2002) have also shown alkalinisation occurs following use of saline irrigation water with a high Sodium Adsorption Ratio (SAR).

However, the Audit suggested much higher viticultural production losses due to acidification than the industry currently accepts. This project was designed to provide an assessment of pH status and pH buffering capacity (pHBC) of surface soils from Australian viticultural areas (eastern states and South Australia) through interrogation of data from the National Land and Water Resources Audit's (NLWRA) Australian Soil Test Inventory.

Methods

Viticultural soils database

The NLWRA assembled a soil test database (with 640,000 entries on surface soil properties for the years 1990 to 1999) and has shown that value can be generated from soil data base information, input/output type models and industry and regional case studies. This project has built upon that foundation. The Australian Soil Testing Inventory was considered to be the most useful source of accessible information on the extent of acid soils in vineyards. Soil testing data from twelve private and public soil testing services were merged for the years 1990 to 1999 to compile the NLWRA Australian Soil Test Inventory. It is important to emphasise that data in the Inventory were neither randomly nor strategically surveyed. The Inventory is simply a very large body of data, providing a decade of analyses submitted by growers to commercial soil testing services. During this decade, significant areas of vineyards were established in all States.

Regional interpolated maps of surface soil fertility status, covering a range of soil properties, were subsequently published (NLWRA 2001). No information was available on where the samples were taken within vineyards (*e.g.* under drippers or from inter-row areas).

Viticultural soil data (all soil depths to 15 cm) from the above Inventory were assembled and sorted by State. These records were then grouped into viticultural regions, essentially similar to the "Wine Regions of Australia", as defined by the Australian Wine and Brandy Corporation in 2003 (see http://www.awbc.com.au/GIMapList.aspx?p=31). Some regions had sparse data sets and were either omitted from further analysis or merged with adjacent viticultural regions. The regionally disconnected nature, relatively small numbers and poor geographic data meant that the soil data for vineyards were not amenable to interpolated mapping. Unfortunately, the very large data set for southern Western Australia could not be accessed. By prior arrangements with the two data suppliers, data for WA had been assembled as mean values for 20 x 20 km land grids with no land use descriptions attached to individual grid records. Nevertheless, large areas of southern WA were shown to have moderately acidic soils (pH_{ca} < 5.5) with low pHBC.

NLWRA soil acidity specialists ranked grape vines as being moderately sensitive to soil acidity (see http://audit.ea.gov.au/ANRA/land/land_frame.cfm?region_type=AUS&region_code=AUS&info=soil_acid). In field experiments conducted in South Australia, root growth became depressed at pH_{Ca} < 5.5 and essentially ceased at pH_{Ca} 4.5 (Robinson 1993). As soil pH_{Ca} values decrease below 4.8, soil aluminium (and manganese) usually becomes more soluble in most soils, entering the soil solution and inhibiting root growth and function.

Soil data for pH, organic carbon and soil field texture information was available for 4877 surface soils from viticulture in five states – Queensland, New South Wales, Victoria, Tasmania and South Australia.

Soil pH status

Within the Inventory, soil pH was usually measured as pH in water (pH_w) or in 0.01M $CaCl_2$ (pH_{Ca}). Where pH_w soil tests only were reported (mainly in Queensland), pH_{Ca} data were derived for this study using the third order polynomial calibrated by Ahern *et al*. (1995) for 7894 Queensland soils. Within each viticultural region, soil pH_{ca} data were grouped into the following class intervals: ≤ 4.3; 4.31 – 4.8; 4.81 – 5.5; 5.51 – 6.0; 6.01 – 6.5; 6.51 – 7.0; 7.01 – 8.0; 8.01 – 8.5; and ≥ 8.51 and frequency distribution of records within each class were plotted. The first 3 classes were adopted by NLWRA to classify the degree of soil acidity: extremely acidic; strongly acidic; and, moderately acidic, respectively.

Subsequently, the following soil pH_{ca} class intervals were used to assess the relative risks of soil acidity and alkalinity status within each viticultural region: ≤ 4.8 (extremely and strongly acidic soils), ≤ 5.5 (extremely to moderately acidic soils) and ≥ 7.7 (highly alkaline soils). Relative risk was expressed as the number of records in each class as a percentage of the total number of records for the region. Note that the ≤ 5.5 class interval includes the records for soils with pH_{ca} ≤ 4.8. Other statistical analyses (range; mean; standard deviation; median; and skewness) were determined using Minitab™ Release 13 software. Skewness in regional data classes referred to in this report are defined as follows: "Normal" – normally distributed data; "Positive" skewness – data are concentrated at low values and skewed towards higher values (long tail); "Negative" – the reverse of "Positive". Some regional data sets were multi-modal, usually indicating some variation in soil type.

pH buffering capacity (pHBC)

This soil property measures the capacity of soils to resist changes in pH and is essential for determining lime requirements. Strictly speaking, it usually applies to soils with pH_{ca} values between about 4.5 and 6.5 where the rate of pH change following additions of acid or alkali is approximately linear. Lime requirement is essentially the product of the soil pH change required (desired pH – measured pH) and pHBC. Soils with low pHBC values acidify more rapidly than soils with higher pHBC values and soil pH responses to lime applications are correspondingly greater in low pHBC soils.

pHBC is a soil chemical test, but is not specifically undertaken by Australian commercial soil testing services. NLWRA commissioned Dr Andrew Noble (formerly CSIRO Land and Water) to prepare a review of pedotransfer functions for estimating soil pHBC for Australian soils (see Dolling *et al.* 2001). The review indicated that pHBC can be estimated from pedotransfer functions using soil organic matter, clay content and effective cation exchange capacity (ECEC), and a number of recommendations were made for its estimation in both surface soils and subsoils, depending on soil properties that were measured by commercial soil testing services. The pedotransfer function used in this study (see below) was among those assessed by Noble.

Because of the availability of soil field texture (as distinct from clay content) information for these viticultural soils, pH buffer capacity was calculated from a function developed by Merry (1997, CSIRO unpublished report) for 170 surface soils (A1 and A2 horizons) from South Australia and Victoria, which incorporated measurements of % total soil carbon (% TC) and % clay content ($100R^2 = 76.2$). For this study, the pHBC was expressed as lime requirement equivalents in t/ha.10cm.pH unit (converted from mmol H^+/ha) as lime equivalents are usually better understood. For each unit increase in soil pH, the quantity of lime required is given by:

Lime requirement (t/ha.10cm.pH unit) = 0.2 + 0.364 %TC + 0.0213 FT-Clay %

where: %TC is total soil organic carbon (if the Walkley and Black method was used, %TC was derived by multiplying % soil organic carbon by 1.3); FT-Clay % (Field Texture Clay %) was derived from the relationship of "class average" soil clay % with soil field texture indicated in McDonald *et al.* (1990).

For each viticultural region, pHBC classes were defined as follows: ≤ 0.75 t lime /ha.10 cm.pH unit (very low); 0.751 – 1.5 t lime /ha.10 cm.pH unit (low); 1.51 – 2.5 t lime /ha.10 cm.pH unit (moderate); and ≥ 2.5 t lime /ha.10 cm.pH unit (high to very high). These classes were not based on critical soil values, as used for soil pH, however they do provide a convenient representation of the known continuum of values from experience with agricultural soils. The proportions of records for pHBC within each viticultural region were then calculated as percentages. Statistical analyses of the data were performed using Minitab™ Release 13 software.

Results and discussion

pH status of viticultural surface soils

NLWRA soil acidity specialists ranked grape vines as being moderately sensitive to soil acidity (see http://audit.ea.gov.au/ANRA/land/land_frame.cfm?region_type=AUS&region_code=AUS&info=soil_acid). In field experiments conducted in South Australia, root growth became depressed at pH_{Ca} < 5.5 and essentially ceased at pH_{Ca} 4.5 (Robinson 1993). As soil pH_{ca} values decrease below 4.8, soil aluminium (and manganese) usually becomes more soluble in most soils, entering the soil solution and inhibiting root growth and function. In very alkaline soils (pH_{ca} values greater than 7.7), grapevines often exhibit symptoms of trace metal deficiency or the soil physical conditions are adversely affected by sodicity. These "critical" values are used here to guide assessment of risk in Tables 1 and 2.

Table 1: Estimates of soil pH_{Ca} risks in viticultural surface soils for the States of eastern and southern Australia (derived from the NLWRA Australian Soil Test Inventory).

State	Number samples	Relative soil pH risk (% of total samples)		
		$pH_{ca} \leq 4.8$	$pH_{ca} \leq 5.5$	$pH_{ca} \geq 7.7$
NSW	841	21.3	49.0	1.4
Queensland	195	18.5	49.7	1.0
SA	2161	7.0	23.9	17.2
Tasmania	68	26.4	76.5	1.4
Victoria	1612	24.1	38.3	36.5
Soil pH classes represent extremely and strongly acidic ($pH_{ca} \leq 4.8$); Extremely to moderately acidic ($pH_{ca} \leq 5.5$) and highly alkaline ($pH_{ca} \geq 7.7$). Note that the ≤ 5.5 class interval includes the records for soils with $pH_{ca} \leq 4.8$.				

Table 2: Statistics for surface soil pH_{Ca} data recorded in viticultural regions of eastern and southern Australia between 1990 and 1999.

Region	Number samples	Soil pH_{ca} Range	Mean (SD)	Median	Skewness	Relative soil pH risk (% samples)		
						$pH_{ca} \leq 4.8$	$pH_{ca} \leq 5.5$	$pH_{ca} \geq 7.7$
NSW								
Cowra	68	4.2 – 7.6	5.98 (0.84)	6.3	Multi modal	7.4	27.9	0
Hunter River	82	4.2 – 6.9	5.29 (0.7)	5.1	Multi modal	**34.1**	**64.6**	0
Canberra	26	4.2 – 6.7	5.29 (0.71)	5.1		**30.8**	**65.3**	0
Mudgee	117	4.3 – 7.8	5.42 (0.74)	5.2	Positive	17.9	**70.9**	0.9
Orange	73	4.3 – 6.9	5.09 (0.72)	5.0	Positive	**37.0**	**84.9**	0
Gundagai	23	4.2 – 7.0	5.37 (0.77)	5.3	Positive	**34.3**	**71.4**	0
Hilltops	54	4.0 – 7.4	4.94 (0.64)	4.8	Positive	**59.3**	**88.9**	0
Shoalhaven Coast	15	4.4 – 5.8	4.89 (0.44)	4.7		**60**	**93.3**	0
Sthn Highlands	20	4.2 – 7.0	5.08 (0.82)	4.7		**55**	**75**	0
Tumbarumba	18	3.9 – 6.1	4.82 (0.59)	4.9	Multi modal	**50**	**88.9**	0
Riverina	338	4.0 – 8.1	6.21 (0.79)	6.3	Normal	5.3	20.1	3.2
Queensland								
Northern	108	4.0 – 7.8	5.63 (0.85)	5.5	Sl. Positive	16.7	**52.8**	0
South East	74	4.3 – 7.3	5.54 (0.73)	5.5	Positive	24.3	**54.1**	0.9
South Australia								
Adelaide Hills	251	4.1 – 7.7	5.64 (0.86)	5.4	Positive	16.7	**57.4**	0.8
Barossa	339	4.2 – 8.2	6.38 (0.85)	6.4	Sl. Negative	4.1	19.2	5.3
Clare	186	4.2 – 8.1	6.53 (1.07)	6.8	Negative	9.1	22.0	16.1
Coonawarra	192	4.0 – 8.2	6.37 (0.99)	6.6	Negative	10.4	23.4	5.7
Fleurieu Penin.	57	4.2 – 7.7	5.34 (0.84)	5.1	Positive	**36.8**	**70.2**	1.8
Padthaway	112	4.3 – 8.0	7.21 (0.79)	7.5	Negative	1.8	6.3	**39.2**
Langhorne Creek	151	4.1 – 8.2	6.06 (0.91)	6.1	Normal	9.3	**35.8**	3.3
Limestone Coast	157	4.5 – 7.9	6.64 (0.89)	6.9	Negative	2.5	17.2	7.6
McLaren Vale	300	4.4 – 7.9	6.13 (0.84)	6.1	Normal	4.7	29.7	3.3
Riverland	416	4.2 – 9.1	7.56 (0.62)	7.7	Negative	0.7	1.2	**57.2**
Tasmania								
North East	30	3.5 – 8.1	5.48 (1.02)	5.2	Positive	20	**66.7**	3.3
South East	33	3.9 – 6.1	5.04 (0.46)	4.9	Normal	**33.3**	**81.8**	0.9
Victoria								
Central North	40	4.0 – 7.8	5.41 (0.84)	5.3	Positive	22.5	**65.0**	2.5
North East	106	3.5 – 7.9	4.87 (0.72)	4.7	Positive	**56.6**	**85.8**	0.9
Pt Phillip Bay	148	3.5 – 7.7	5.07 (0.79)	4.9	Positive	**48.6**	**82.4**	0.7
Pyrenees	318	3.8 – 7.7	4.96 (0.72)	4.8	Positive	**54.1**	**80.0**	0.3
South West	35	4.2 – 7.0	5.37 (0.77)	5.3	Multi modal	**34.3**	**71.4**	0
Sunraysia	858	4.4 – 9.0	7.68 (0.55)	7.8	Negative	0.3	1	**68.2**
Yarra Valley	107	4.0 – 6.8	4.93 (0.6)	4.8	Positive	**56.1**	**85**	0
Data Source: NLWRA Australian Soil Testing Inventory. Soil pH risks as defined in Table 1.								

The number of records for soil pH varied markedly among States and viticultural regions within States (Tables 1 and 2). It is probable that the three south-eastern mainland states, which make up the largest proportion of the total number of samples, also have the highest number of samples from vineyards in long established regions and are therefore more likely to have soil pH values affected by vineyard management practices such as the application of irrigation waters or acidifying ammoniacal fertilisers. All States had a high proportion of acidic surface soils (Table 1), but the risk of extreme pH, especially for SA and Victoria, partly reflected variations in the number of samples from individual viticultural regions. For example, in these two States, a relatively large number of samples were derived from the Riverland and Sunraysia regions, which had mainly alkaline soils containing carbonate minerals.

Within-regions (Table 2), variations in surface soil pH were often skewed either negatively (seven regions, mainly in SA), positively (21 regions) or were multi modal (five regions). Six regions had normally distributed values. Such variations mainly reflect known variations in soil types within a region, but may also be associated with past vineyard management practices, which were not specifically known.

In NSW, low soil pH values dominated most regional data sets. Acidity in the Cowra and Riverina regions was less pronounced than in other regions, but still comprised over 20 % of samples ≤ pH_{ca} 5.5. Few soils had high pH values. Although the numbers of soil samples were relatively small, over 50 % of viticultural surface soils from Queensland had values ≤ pH_{ca} 5.5, but the soils were less extremely acidic than in NSW. In SA, high proportions of acidic surface soils existed in the Adelaide Hills, Fleurieu Peninsula, and to a lesser extent in the Langhorne Creek and McLaren Vale viticultural regions. The Riverland, Padthaway and Clare regions had a high incidence of strongly alkaline soils. The high alkalinity may be due to either the natural condition of the soil or to the use of alkaline irrigation water. High proportions of acidic soil existed in all Victorian viticultural regions (pH_{ca} ≤ 4.8 and 5.5), with the exception of the Sunraysia region where nearly 70 % of samples had pH values ≥ 7.7, again reflecting the known distribution of alkaline soil types in this region. A high proportion of the small data sets for two regions in Tasmania were also strongly and moderately acidic, reflecting the normal acidic nature of many Tasmanian soils.

pHBC status of viticultural surface soils

A major proportion of viticultural surface soils in the Australian Soil Test Inventory were classed as having low or moderate pHBC values (Tables 3 and 4). Soils with very low pHBC values existed mainly in the Riverland and Sunraysia viticultural regions. Tasmanian soils were predominately in the moderate to high classes.

Table 3: Estimates of soil pHBC (expressed as t lime /ha.10cm.pH unit) in viticultural surface soils for the States of SE Australia (derived from the NLWRA Australian Soil Testing Inventory)

State	Number samples	Soil pHBC class (% samples)			
		Very low	Low	Moderate	High
NSW	787	2.2	52.2	44.1	1.4
Queensland	195	3.1	60.5	35.9	0.5
SA	2076	**15.0**	54.1	29.0	1.9
Tasmania	61	0	13.1	**70.5**	**16.4**
Victoria	1609	**14.2**	50.3	31.1	4.5
pHBC classes: Very low: <0.75 t lime/ha.10 cm.pH unit; Low 0.75 – 1.5 t lime/ha.10 cm.pH unit; Moderate 1.5 – 2.5 t lime/ha.10 cm.pH unit; High > 2.5 t lime/ha.10 cm.pH unit					

Within-region variation (Table 4) in estimated pHBC range varied several fold and the values were often skewed (15 positively; 1 negatively; 5 multi-modal). Values for 9 regions were normally distributed. These variations in pHBC are associated with changes in soil type and their properties (organic matter, ECEC or clay status). Soils with very low pHBC have low clay and organic matter contents, both of which are difficult or expensive to modify. An additional, important factor affecting pHBC in alkaline soils that was not assessed in this project is the presence of carbonate minerals. The relatively insoluble calcium and magnesium carbonate minerals buffer soils against acidification, such as that which results from the use of ammoniacal fertilisers, while the soluble sodium carbonate and bicarbonates present in alkaline sodic soils is less effective because of their presence at much lower concentration (usually) and their capacity to be leached with irrigation.

More than 96 % of NSW viticultural soils had low to moderate pHBC values. High proportions of low values existed in Cowra, Mudgee, Gundagai and Hilltops regions, while moderate values were more common in the Hunter River, Canberra, Orange, southern Highlands and Tumbarumba regions. Some high values existed in the small data set for Shoalhaven Coast. The Northern region of Queensland had mainly low to moderate pHBC values, whereas the South East region was dominated by low pHBC values.

In SA, significant percentages of very low pHBC values were estimated in the Padthaway, Langhorne Creek and Riverland regions. Most other regions had the majority of values in the low to moderate ranges. Around 10 % of samples from the Fleurieu Peninsula had high pHBC values. By contrast, moderate to high pHBC values dominated the small regional data sets from Tasmania. These soils generally had much higher organic carbon contents than the soils from the other states. Over 80 % of pHBC values in viticultural surface soils of Victoria were in the low to moderate ranges. A significant number of very low pHBC values existed in the Sunraysia region (similar to the South Australian Riverland) and high values were observed more commonly in the South West, Yarra Valley and Port Phillip Bay regions.

Table 4: Statistics for surface soil pHBC data recorded in viticultural regions of eastern and southern Australia between 1990 and 1999.

Region	Number samples	Range	Mean (SD)	Median	Skewness	Soil pHBC class (% samples)			
						V.Low	Low	Moderate	High
NSW									
Cowra	66	0.86 – 2.02	1.41 (0.27)	1.36	Normal	0	63.6	36.4	0
Hunter River	71	0.51 – 5.71	1.68 (0.8)	1.59	Positive	4.2	33.8	57.7	4.2
Canberra	26	0.8 – 2.63	1.77 (0.47)	1.81	Multi-modal	0	34.6	57.7	7.7
Mudgee	107	0.62 – 2.19	1.39 (0.25)	1.39	Normal	0.9	72.9	26.2	0
Orange	70	0.99 – 3.53	1.81 (0.53)	1.71	Positive	0	32.9	67.1	0
Gundagai	23	0.76 – 1.98	1.33 (0.07)	1.35	Multi modal	4.3	87	8.7	0
Hilltops	53	0.75 – 1.67	1.21 (0.18)	1.24	Normal	0	98.1	1.9	0
Shoalhaven Ct	15	1.08 – 3.01	1.81 (0.58)	1.45		0	46.7	40.0	13.3
S Highlands	18	1.14 – 2.54	1.68 (0.38)	1.61		0	38.9	55.6	5.6
Tumbarumba	15	1.49 – 2.69	1.8 (0.31)	1.73	Positive	0	6.7	86.7	6.7
Riverina	317	0.35 – 2.78	1.46 (0.32)	1.52	Normal	4.1	46.1	49.5	0.3
Queensland									
Northern	108	0.61 – 2.77	1.45 (0.41)	1.51	Positive	4.6	46.3	48.1	0.9
South East	74	0.71 – 2.35	1.27 (0.34)	1.23	Multi modal	1.3	75.7	23.0	0
South Australia									
Adelaide Hills	250	0.55 – 3.11	1.67 (0.5)	1.69	Normal	5.6	31.6	59.2	3.6
Barossa	310	0.43 – 2.65	1.17 (0.39)	1.14	Positive	10.6	73.5	15.5	0.3
Clare	175	0.42 – 2.62	1.53 (0.32)	1.50	Normal	0.6	50.2	48.0	1.1
Coonawarra	173	0.57 – 3.9	1.54 (0.61)	1.52	Positive	5.8	42.8	45.1	6.4
Fleurieu Penin.	56	0.44 – 3.71	1.47 (0.74)	1.22	Positive	14.2	44.6	30.4	10.7
Padthaway	92	0.36 – 1.9	1.10 (0.38)	1.18	Bi modal	22.8	67.4	9.8	0.0
Langhorne Creek	151	0.34 – 3.06	0.97 (0.48)	0.83	Positive	34.4	52.9	11.9	0.7
Limestone Coast	157	0.47 – 3.53	1.29 (0.47)	1.18	Positive	5.7	69.4	22.9	1.9
McLaren Vale	296	0.43 – 2.86	1.40 (0.47)	1.47	Positive	11.1	43.6	42.9	2.4
Riverland	416	0.4 – 2.35	0.98 (0.34)	0.86	Positive	31.3	59.9	8.9	0.0
Tasmania									
North East	25	1.36 – 3.64	2.09 (0.47)	2.11	Positive	0	12	80	8
South East	33	0.92 – 3.25	2.14 (0.63)	1.49	Normal	0	15.2	60.6	24.2
Victoria									
Central North	40	0.73 – 2.57	1.68 (0.47)	1.78	Negative	2.5	47.5	47.5	2.5
North East	106	0.59 – 3.03	1.56 (0.47)	1.49	Sl. Positive	1.9	50	45.3	2.8
Pt Phillip Bay	148	0.7 – 4.19	1.96 (0.63)	1.89	Positive	0.7	23	61.5	14.9
Pyrenees	316	0.77 – 6.41	1.66 (0.55)	1.56	Positive	0	44	51.9	4.1
South West	35	0.64 – 5.37	2.13 (1.08)	1.89	Multi modal	2.9	28.6	31.4	37.1
Sunraysia	857	0.4 – 12.0	1.07 (0.55)	1.05	Normal	26	64.2	9.7	0.1
Yarra Valley	107	1.39 – 2.89	2.14 (0.36)	2.12	Normal	0	3.7	78.5	17.8

Data source: NLWRA Australian Soil Testing Inventory. Soil pHBC classes (t lime /ha.10 cm.pH unit) as defined in Table 3.

Conclusions

The soil pH values recorded are a broad indication of the status of existing vineyards, or of land at the time of vineyard establishment. Clearly, a large number of these soils are already significantly acidified or alkaline-sodic. Future changes in soil pH depend on vineyard management, such as the use of acidifying fertilisers or alkaline irrigation waters. To maintain long-term soil health, there is a strong need to consider remediation of the many soils that have already acidified. There is also a need to predict the behaviour of soils that are yet to acidify or become alkaline-sodic (pH_{ca} > 7.7) as a result of management practices, and manage those soils that are already alkaline-sodic. However, this needs to be approached in a way that will not conflict with desired vineyard management for plant vigour and grape yield and quality.

The evidence from a review of the available databases shows that the soil characteristics conducive to development of soil acidity (low pH buffering capacity) are present in many Australian viticultural soils, and that a large number of soils are already acidic. As the exact nature of these samples is not known, (i.e. whether they were taken prior to vineyard development and the application of ameliorative treatments, or from mature vineyards, where amelioration has already taken place) we conclude that the processes of soil acidification require further investigation in viticultural soils of Australia and their pH condition should continue to be monitored.

Estimates of pHBC determined from a pedotransfer function were also found to vary widely within and among viticultural regions. This soil property assesses the capacity of soil to resist changes in soil pH and guide ameliorative lime application. Across the five States, pHBC values were predominately in the low to moderate range, but some regions had relatively high proportions in the very low and high ranges. Low pHBC values indicate that soil acidity (pH decrease) is likely to change relatively quickly when the soil has acid inputs, but the reverse is also generally true in that smaller amounts of lime are needed to gain a significant pH increase.

The above preliminary evidence indicates that soil acidity and alkalinity, and the processes of soil acidification or alkalinisation, require further investigation, including an assessment of resulting yield loss and its economic consequences. Continued monitoring of the pH of Australian viticultural soils is essential. In relation to the concerns of the viticultural industry regarding possible losses caused by acidification or alkalinisation, no estimate of actual areas of vineyards with acid or alkaline soil could be drawn from the audit data.

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